

ENGINEERING, OPERATION and MAINTENANCE



**Prepared by
BUREAU OF NAVAL PERSONNEL**

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PREFACE

This text has been prepared primarily as an aid for general line officers and engineering officers who desire to increase their knowledge of ship-board engineering through self-study. The text is also intended to assist officers in qualifying as engineering watch officers.

Engineering, Operation and Maintenance is based on the assumption that the reader is familiar with the duties and responsibilities of a general line officer or an engineering officer, and has acquired a general knowledge of naval machinery and equipment. This text is intended as a training aid, not as an official reference. If the information contained herein is in conflict with any official directive or doctrine publication, such directive or publication must apply. Current official directives and technical sources of information should always be consulted for the latest information related to the operation and maintenance of naval machinery and equipment.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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CHAPTER 1

BOILERS

Reliability is of primary importance in the operation of the machinery installation on a naval ship. The military value of a naval ship depends in a large measure upon the ship's cruising radius, which, in turn, depends upon the efficiency with which a given installation is operated. Therefore, it is important that the engineer officer not only maintain his plant in reliable operating condition, but also operate the plant at maximum efficiency. A thorough knowledge of the principles of combustion as applied to a boiler furnace is a prime requisite for engineering efficiency in a naval ship. It is in the fireroom that more savings in fuel can be made, with a resulting increase in steaming radius, than in all the rest of the engineering department combined. The net result from an otherwise efficient department will be poor when fireroom efficiency is not the best obtainable.

Although experience gained through actual practice in operating a fireroom is unquestionably important, best results are obtained when this experience is supplemented by an understanding of the principles of combustion. This is true especially in operating modern naval boilers, which have been developed to a high degree of efficiency.

The complex design of modern naval boilers necessitates a high degree of technical knowledge and skill on the part of fireroom personnel and the officers responsible for boiler operations. Therefore, all engineering officers should have some knowledge of the principles of combustion, the manner in which combustion occurs in a boiler, and the combustion requirements for operating a boiler in the most efficient possible manner.

PRINCIPLES OF COMBUSTION

Fuels combine with oxygen to produce heat and energy. Utilizing fuels to produce heat and

energy almost always involves a reaction with air. The combustible components of fuels are mainly carbon and hydrogen, usually in the form of hydrocarbons. Sulphur is present in small quantities. The incombustible components are mainly nitrogen, moisture, and ash. Oxygen in the air entering the furnace is the only element which supports combustion. Therefore, in order to understand what is happening in the boiler furnace, the operator must know how the oxygen in the air combines with the elements in the fuel.

In almost all burning processes, the principal reaction is the combination of the carbon and the hydrogen of the fuel with the oxygen of the air to form carbon dioxide and steam. To a lesser extent, sulphur dioxide is also formed from the burning of the sulphur in the fuel. Combustion, therefore, is purely a chemical reaction.

In the combustion of fuel oil, the following chemical reactions must be considered:

Combustible substance	Reaction	Product of the combustion
Carbon	$2C + O_2 \rightarrow 2CO$	Carbon monoxide.
Carbon	$2C + 2O_2 \rightarrow 2CO_2$	Carbon dioxide.
Carbon monoxide	$2CO + O_2 \rightarrow 2CO_2$	Carbon dioxide.
Hydrogen	$2H_2 + O_2 \rightarrow 2H_2O$	Water vapor.
Sulphur	$S + O_2 \rightarrow SO_2$	Sulphur dioxide.

In the equations shown in the "Reaction" column, the elements are designated by symbols, and compounds by a combination of symbols of the elements forming the compound. For example, the equation of $2C + O_2 \rightarrow 2CO$ indicates that two molecules of carbon combine with one of oxygen to form two molecules of carbon

monoxide. The combination of oxygen with the combustible substances is always the same as shown.

It must be remembered that the source of oxygen for the combustion reaction in a marine boiler is atmospheric air. Air is a mechanical mixture of oxygen, nitrogen, and very slight amounts of other elements and compounds. For shipboard purposes, air can be considered as being composed of approximately 23 percent oxygen and 77 percent nitrogen, by weight. It is apparent, therefore, that to supply one pound of oxygen for combustion it will be necessary to supply approximately four pounds of air. The nitrogen serves no useful purpose in combustion but produces a cooling effect in that it absorbs heat while passing through the furnace and carries off a portion of this absorbed heat upon leaving the heating surfaces of the boiler. It is necessary, therefore, to reduce the air supply of a boiler to a minimum consistent with complete combustion.

In practice, the amount of air necessary for complete combustion is slightly in excess of that theoretically required. The effect of excess air on boiler performance is illustrated in figure 1-1. From this figure, it can be seen that increasing the excess air from 10 percent to 90 percent reduces the over-all and fireroom efficiencies by approximately 10 percent. Percentages of excess air as high as 200 are a common occurrence. This is the most common and most serious cause of low operating economy. Another common combustion loss is that due to the incomplete combustion of the carbon in the fuel. This loss can be prevented by the admission of sufficient air in a manner that will make complete combustion possible.

Close and thoughtful attention to fireroom operation, particularly to the reduction of excess air to a minimum consistent with complete combustion, is mandatory. The economy accrued by such operation will result in a very appreciable reduction in fuel consumption, with a resultant increase in steaming radius.

BOILER TERMINOLOGY

Before studying the types of boilers used in propulsion plants aboard Navy ships, it is important to know the boiler terms and definitions used most frequently by shipboard personnel.

The total quantity of steam required to develop contract shaft horsepower of the ship, divided by the number of boilers installed in the ship, gives **BOILER FULL-POWER CAPACITY**. Boiler full-power capacity is expressed as the number of pounds of steam generated per hour at a specified pressure and temperature. Boiler full-power capacity can be found by looking in the manufacturer's technical manual for the specific installation, in the design data section; it may be listed as capacity at full power or as designed rate of actual evaporation per boiler at full power.

BOILER OVERLOAD CAPACITY is usually 120 percent of boiler full-power capacity. Boiler overload capacity is usually given with boiler full-power capacity in the design data section of the manufacturer's technical manual; it may be listed as boiler overload capacity or as full power plus 20 percent.

SUPERHEAT OUTLET PRESSURE is the actual steam pressure at the superheater outlet.

STEAM DRUM PRESSURE is the pressure actually carried in the boiler steam drum.

OPERATING PRESSURE is the **CONSTANT** pressure at which the boiler is operated in service. Depending upon various factors (chiefly design features of the boiler) the constant pressure may be carried at the steam drum or at the superheater outlet. Operating pressure is specified in the design of the boiler, and is given in the manufacturer's technical manual.

DESIGN PRESSURE is the pressure specified by the boiler manufacturer as a criterion for boiler design. It is often about 103 percent of steam drum pressure. The term is mentioned here because it is given in the manufacturer's technical manual and there is a good deal of confusion between design pressure and operating pressure; the two terms do **NOT** mean the same thing.

DESIGN TEMPERATURE is the intended maximum operating temperature at the superheater outlet, at some specified rate of operation. Normally, for combatant ships, the specified rate is full-power capacity.

OPERATING TEMPERATURE is the actual temperature at the superheater outlet. As a rule, operating temperature is the same as design temperature only when the boiler is operating at the rate specified in the definition of design temperature.

BOILER EFFICIENCY, expressed as a percentage, is the ratio of the Btu per pound of fuel absorbed by the water and steam to the Btu

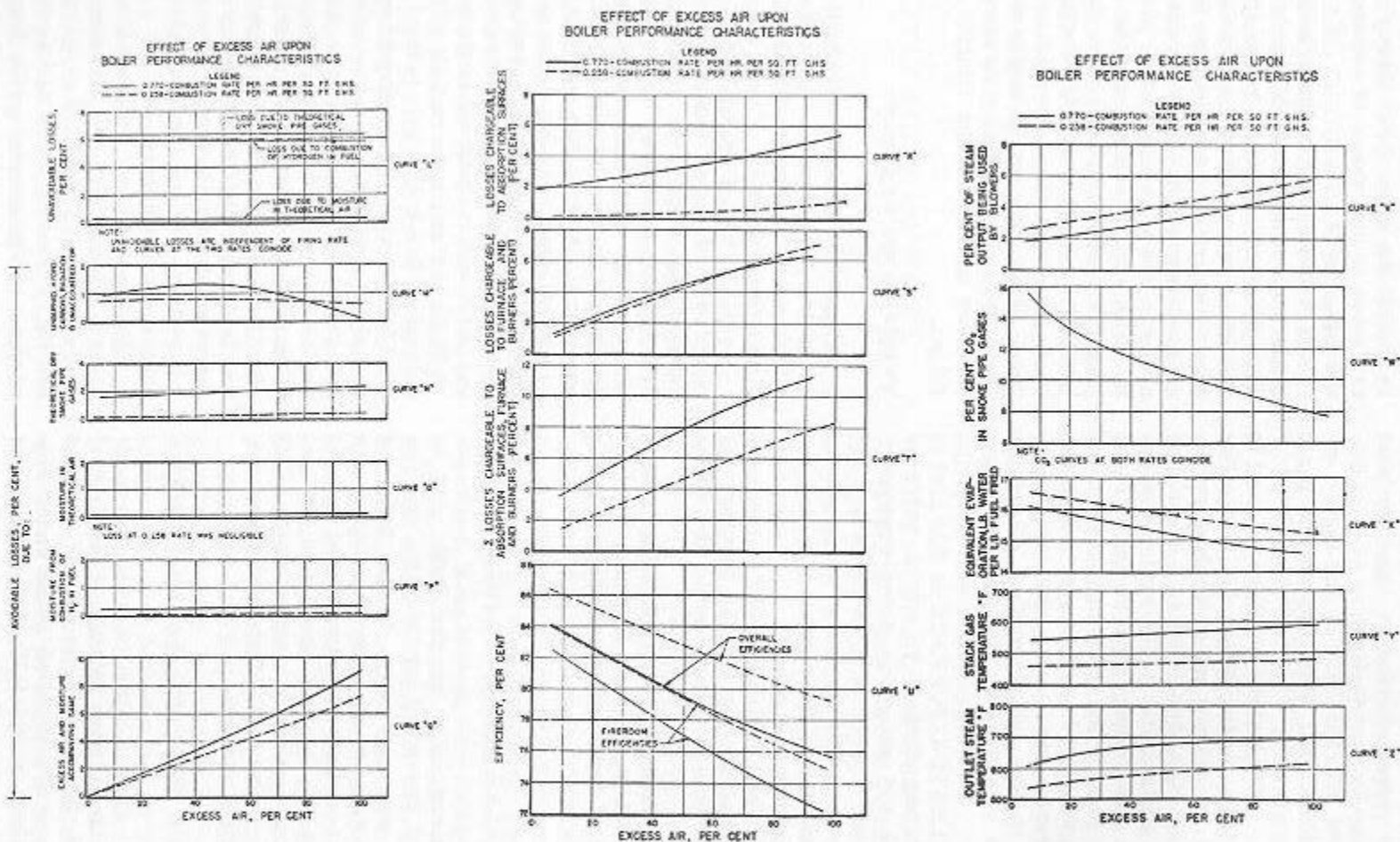


Figure 1-1. —Effect of excess air upon boiler performance characteristics.

per pound of fuel fired. In other words, boiler efficiency is output divided by input, or heat utilized divided by heat available.

FIREROOM EFFICIENCY is the boiler efficiency CORRECTED FOR blower and pump steam consumption.

The term "STEAMING HOURS" is used to include all time during which the boiler has fires lighted for raising and generating steam.

The **TOTAL HEATING SURFACE** of a boiler includes all parts of the boiler which are exposed on one side to the gases of combustion and on the other side to the water and steam being heated. Thus the total heating surface equals the sum of the generating surface, the superheater surface, and the economizer surface. All heating surfaces are measured on the combustion gas side.

The **GENERATING SURFACE** is that part of the total heating surface in which water is being heated and steam is being generated. The generating surface includes the generating tubes, the water wall tubes, the water screen tubes, and any water floor tubes that are not covered by refractory material.

The **SUPERHEATER SURFACE** is that portion of the total heating surface in which the steam is superheated after leaving the boiler steam drum.

The **ECONOMIZER SURFACE** is that portion of the total heating surface in which the feed water is heated before it enters the generating system.

BOILER CLASSIFICATION

Most boilers used in the Navy can be classified and described on the basis of a few features or characteristics. In the following sections the classification of naval boilers is considered according to (1) location of fire and water spaces; (2) type of circulation; (3) arrangement of steam and water spaces; (4) furnace arrangement; (5) control of superheat; and (6) operating pressure.

LOCATION OF FIRE AND WATER SPACES

The basic classification of boilers is made according to the relative location of the fire and water spaces. Thus, all boilers may be divided into two groups: fire-tube boilers and water-tube boilers. In **FIRE-TUBE BOILERS** the gases of combustion flow through the tubes and thereby

heat the surrounding water. In **WATER-TUBE BOILERS** the water flows through the tubes and is heated by the gases of combustion that fill the furnace.

All boilers used in the propulsion plants of modern naval ships are of the water-tube type. Fire-tube boilers (such as the "Scotch marine boiler") were once used in shipboard propulsion plants and are still used in some older merchant ships. However, fire-tube boilers are not suitable for use in modern naval ships because of their excessive weight and size, the excessive length of time required to raise steam, and their inability to meet demands for rapid changes in load. The only fire-tube boilers now used on naval ships are small auxiliary boilers that supply steam or hot water for various auxiliary services on some ships (chiefly diesel-driven ships).

TYPE OF CIRCULATION

Water-tube boilers are further classified according to the cause of water circulation as either natural circulation boilers or controlled circulation boilers.

In **NATURAL CIRCULATION BOILERS** the circulation of water depends on the difference between the density of an ascending mixture of hot water and steam and a descending body of relatively cool and steam-free water. The difference in density occurs because the water expands as it is heated and thus becomes less dense. Another way to describe this type of circulation is to say that it is caused by convection currents which result from the uneven heating of the water contained in the boiler.

Natural circulation may be either free or accelerated. In a boiler with natural circulation of the **FREE** type, the generating tubes are installed at a slight angle of inclination so that the lighter hot water and steam can rise while the cooler and heavier water descends. When the generating tubes are installed at a greater angle of inclination, the rate of water circulation is definitely increased. Therefore, boilers in which the tubes slope quite steeply from steam drum to water drum are said to have **ACCELERATED** natural circulation.

Most modern naval boilers have accelerated natural circulation. A sufficient number of downcomers are installed so that all small tubes can be generating tubes and all downward flow of water can be carried by the downcomers. The size and number of downcomers installed varies

from one type of boiler to another, but some are installed on all natural circulation boilers now used by the Navy.

CONTROLLED CIRCULATION BOILERS depend upon pumps rather than upon natural differences in density for the circulation of water within the boiler. Because controlled circulation boilers are not limited by the requirement that hot water and steam must be allowed to flow upward while cooler water flows downward, a great variety of arrangements are possible in controlled circulation boilers. Some controlled circulation boilers look very much like natural circulation boilers; others look very different.

Controlled circulation boilers have been used in some naval ships in the past. In general, however, they are still considered experimental for Navy use.

ARRANGEMENT OF STEAM AND WATER SPACES

Natural circulation boilers are classified as drum-type boilers or as header-type boilers, depending upon the arrangement of the steam and water spaces. **DRUM-TYPE BOILERS** have one or more water drums (and generally one or more water headers as well). **HEADER-TYPE BOILERS** have no water drum; instead, the tubes enter a great many water headers which serve the same purpose as water drums.

What is a header, and what is the difference between a header and a drum? The term **HEADER** is commonly used in engineering to describe any tube, chamber, drum, or similar piece to which a series of tubes or pipes are connected in such a way as to permit the flow of fluid from one tube (or group of tubes) to another. Essentially, a header is a type of manifold. As far as boilers are concerned, the only distinction between a drum and a header is the distinction of size. Drums are larger than headers, but both serve basically the same purpose.

Drum-type boilers may be further classified according to the overall shape formed by the steam and water spaces. For example, the **M-type** boiler gets its name from the fact that the arrangement of tubes is roughly M-shaped. **D-type** boilers are so called because the tubes form a rough letter D. An interesting variation in names occurred when **D-type** boilers became standard for destroyer escorts and thus became known as **DE-type** boilers. However, this term is somewhat misleading because **D-type** boilers are now installed on many other types of ships

as well as on destroyer escorts. The term "**DE-type boiler**" is not, therefore, a term that will be used in this training course.

FURNACE ARRANGEMENT

All boilers that are now commonly used in the propulsion plants of naval ships may be classified according to furnace arrangement as either **SINGLE-FURNACE BOILERS** or **DOUBLE-FURNACE BOILERS**. Double-furnace boilers may also be called **DIVIDED-FURNACE BOILERS**. The **M-type** boiler is a double-furnace or divided-furnace boiler. The **D-type** boiler is a single-furnace boiler.

CONTROL OF SUPERHEAT

Until recently, the term **SUPERHEAT CONTROL BOILER** was used to identify a double-furnace boiler and the term **UNCONTROLLED SUPERHEAT BOILER** was used to identify a single-furnace boiler. These terms probably are still used in this way, since most double-furnace boilers now in use do, in fact, have controlled superheat and most single-furnace boilers do not have controlled superheat.

However, recent developments in boiler design make superheat control independent of furnace arrangements. Single-furnace boilers **WITH** controlled superheat have been developed, and double-furnace boilers **WITHOUT** controlled superheat are a possibility. The time has come, therefore, to stop confusing the number of furnaces with the control (or lack of control) of superheat. Keep the following definitions in mind:

SINGLE-FURNACE BOILER: A boiler that has one furnace. It may or may not have controlled superheat. Most single-furnace boilers now in use do **NOT** have controlled superheat.

DOUBLE-FURNACE BOILER: A boiler that has two furnaces. It may or may not have controlled superheat. Most double-furnace boilers now in use **DO** have controlled superheat.

BOILER WITH UNCONTROLLED SUPERHEAT: A boiler in which the amount of heat supplied to the superheater is closely related to the amount of heat supplied to the generating tubes. It may be a single-furnace boiler or a double-furnace boiler.

BOILER WITH CONTROLLED SUPERHEAT: A boiler in which the amount of heat supplied to the superheater is pretty much independent of the amount of heat supplied to the generating

tubes. It may be a single-furnace boiler or a double-furnace boiler.

OPERATING PRESSURE

For some purposes it is convenient to classify boilers according to operating pressure. Most classifications of this type are approximate rather than exact. Header-type boilers and some older drum-type boilers are often called "400psi boilers" even though the operating pressures may range from 300 psi (Or even lower) to about 450 psi. The term "600-psi boiler" is often applied to various double-furnace and single-furnace boilers with operating pressures ranging from about 435 psi to about 615 psi.

The term "high pressure boiler" is at present used rather loosely to identify any boiler that operates at substantially higher pressure than the so called "600—psi boilers." A good many boilers recently installed on naval ships operate at approximately 1200 psi: for some purposes these boilers are grouped together and referred to as "1200—psi boilers." Classifying boilers by operating pressure is not very *precise*, since actual operating pressures may vary widely within any one group. Also, any classification based on operating pressure may easily become obsolete. What is called a high pressure boiler today may well be called a low pressure boiler tomorrow.

PROPULSION BOILERS

Most water-tube boilers now used by the Navy have essentially the same components: steam and water drums, generating and circulating tubes superheaters, economizers, furnaces, casings, supports, and a number of accessories and fittings required for operating and control. Detailed information concerning the basic components of a boiler can be obtained either from the manufacturer's technical manual for the specific installation or chapter 9510(51) of Bureau of Ships Technical Manual.

The sections which follow show how the components are arranged to form the types of boilers that are used in propulsion plants of naval ships.

HEADER-TYPE BOILERS

Sectional header boilers, commonly called

header-type hollers, are installed in many auxiliary Ships. The basic design of this type of boiler is shown in figures 1-2 and 1-4. A front view of a header-type boiler is shown in figure 1-4.

Sectional header boilers normally operate at 450 to 465 psig, and are designed for maximum superheater outlet temperature of 740°F to 750°F. In capacity, they range from about 25,000 to about 40,000 pounds of steam per hour.

Sectional header boilers are sometimes referred to as CROSS-DRUM boilers because many of them were designed to be installed with the steam drum athwartships rather than fore and aft. However, some header-type boilers are not of the cross-drum type.

Sectional header boilers may also be referred to as SIDE-FIRED boilers. This term is used to indicate the location of the burners with respect to the position of the steam drum. However, the term "side-fired" tends to be misleading. Since the surface of a boiler alone which the burners are installed is generally considered to be the FRONT of the boiler. In the following discussion, the front of the boiler will be taken as the surface along which the burners are installed. From this point of view, then, the steam drum is installed lengthwise along the top of the boiler front.

The sectional header boiler gets its name from the header sections which are connected by the generating tubes. There may be 12, 14, or 16 of these sections, depending on the size of the boiler. Half of the header sections are installed under the steam drum, at the front of the boiler. The other half are installed at the rear of the boiler, at a somewhat higher level. The header sections are installed at a slight angle from the vertical leaning somewhat toward the front of the boiler. The angle of inclination of the headers allows the straight generating tubes (which enter the headers normal to the header surfaces) to slope slightly upward from the front of the boiler toward the rear, thus allowing free natural circulation within the boiler.

The header sections installed under the steam drum at the front of the boiler are known as downtake headers. Each downtake header is connected to the steam drum by a short down-take nipple. The lower end of each downtake header is connected to the junction header (sometimes called the MUD DRUM) by a short nipple. The downtake headers, downtake nipples, and junction header can be seen in the mock-up of a header-type boiler shown in figure 1-4.

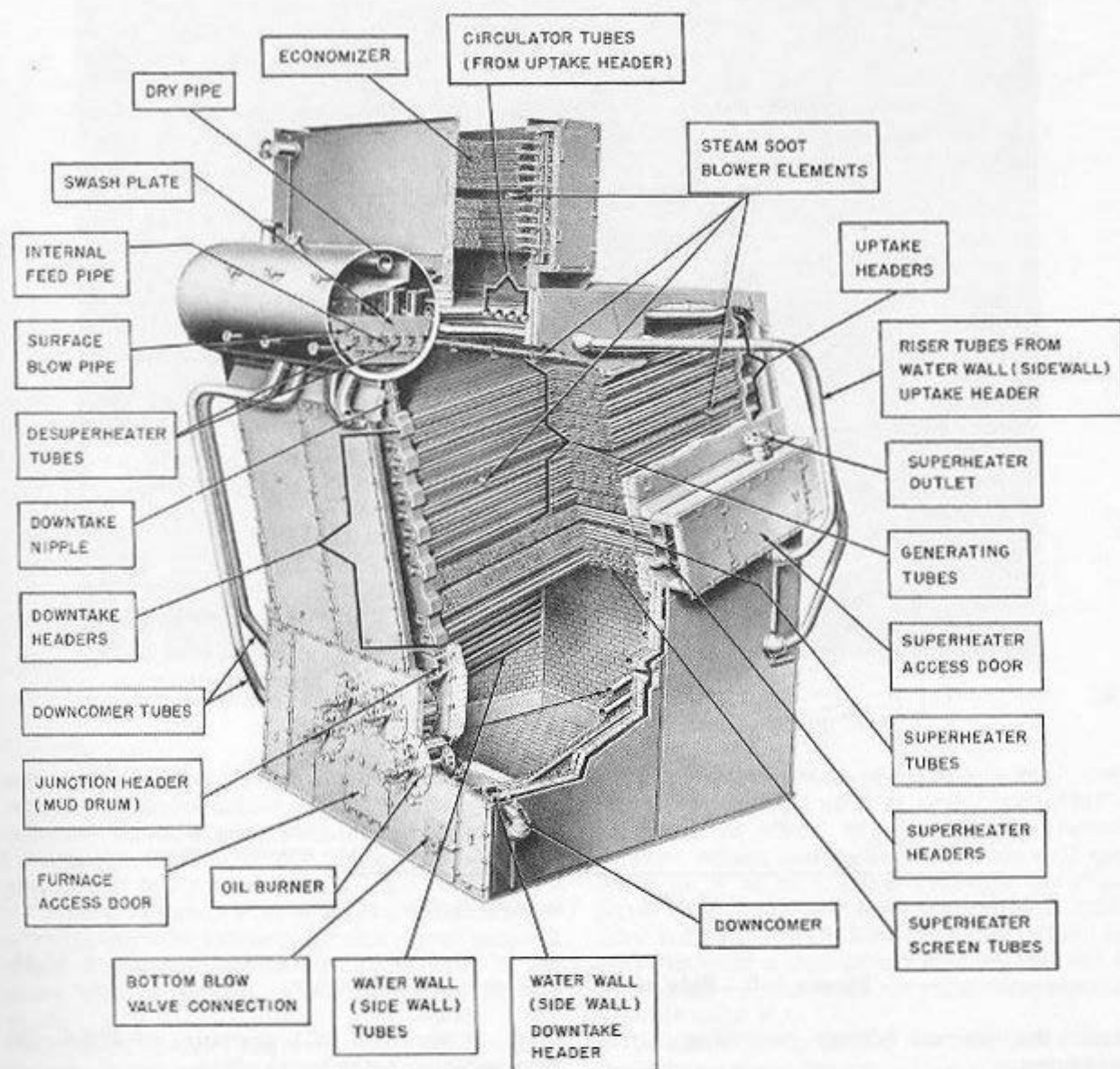


Figure 1-2,—Cutaway view of sectional header boiler.

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The uptake headers are installed at the rear of the boiler. Each uptake header is connected to the steam drum by a large circulator tube which enters the steam drum slightly above the normal water level.

As shown in figures 1-2 and 1-3, the generating tubes in this type of boiler are straight rather than curved. They connect the downtake headers at the front of the boiler with the uptake headers at the rear of the boiler.

The superheater consists of U-bend tubes, an upper superheater header, and a lower superheater header. The superheater tubes are installed at right angles to the generating tubes, between the main bank of generating tubes and the water screen tubes.

The steam drum is similar to that used on a drum-type boiler, except that the sectional header boiler steam drum usually has a manhole at each end of the drum. The steam drum

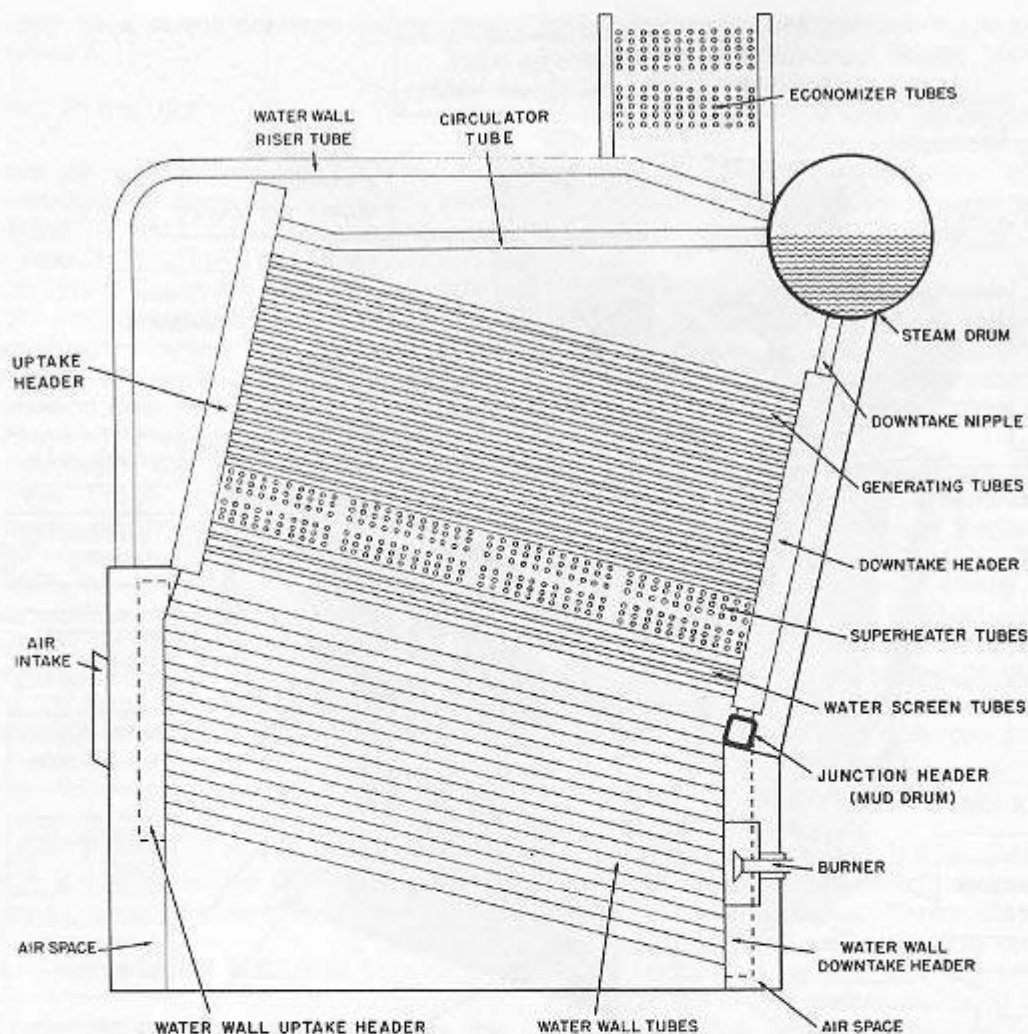


Figure 1-3.—Side view of sectional header boiler.

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contains the internal fittings, including a de-superheater.

How would you classify this boiler? On the basis of the classification methods given earlier in this chapter, the sectional header boiler has the following characteristics:

1. It is a water-tube boiler.
2. It has natural circulation of the free type (not accelerated).
3. It is a header-type boiler rather than a drum-type boiler.
4. It has only one furnace. However, this boiler is never referred to as a single-furnace boiler; that term seems to apply only to drum-type boilers.
5. It does not have controlled superheat.

6. It operates at a pressure of 450 to 465 psig on some older naval ships. However, you may hear header-type boilers called "400-psi boilers."

DOUBLE-FURNACE BOILERS

Double-furnace boilers (also called M-type boilers) are installed on most older destroyers and on many other combatant ships. These boilers are designed to carry a steam drum pressure of approximately 615 psig and to generate saturated steam at approximately 490°F. The saturated steam for auxiliaries goes directly from the steam drum to the auxiliary steam line. All other steam goes through the

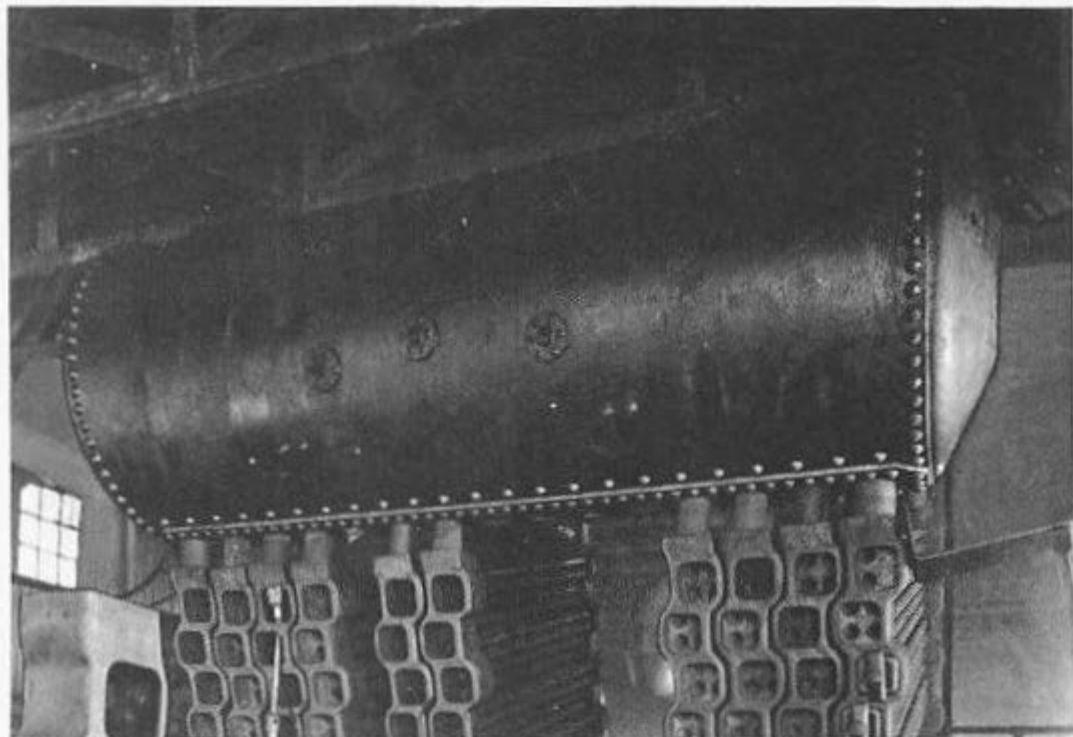


Figure 1-4.—View of a sectional header boiler.

38.35

superheater. Double-furnace boilers are designed in various sizes and capacities to suit different installations. They range in capacity from about 100,000 to 250,000 pounds of steam per hour at full power.

Figure 1-5 shows the general arrangement of a double-furnace boiler commonly used in naval ships. Figure 1-6 shows a sectional view of the same boiler, and figure 1-7 shows a cutaway view.

Since a modern boiler is likely to contain between 1,000 and 2,000 tubes, some system of tube identification is essential. Generating and circulating tubes (generating, water wall, water screen tubes, and downcomers) are identified by **LETTERING** the rows of tubes and **NUMBERING** the individual tubes in each row. A tube row runs from the front of the boiler to the rear of the boiler. The row of tubes next to the furnace is row A, the next is row B, the next is row C, and so forth. If there are more than 26 rows in a tube bank, the rows after Z are lettered AA, BB, CC, DD, and so forth. Each tube in a row is then designated by a number, beginning with 1 at the front of the boiler and numbering back toward the rear.

The letter which identifies a tube row is often preceded by an R or an L, particularly in the case of water screen tubes, superheater support tubes, and furnace division wall tubes. When an R or an L is used **AFTER** the regular letter and number identification of a tube, it may indicate either that the tube is bent for a right-hand or a left-hand boiler or that the tube is studded or finned on the right-hand side or on the left-hand side.

Because each of the two furnaces can be fired separately, thus allowing control of superheated steam temperature over a wide range of operating conditions, the double-furnace boiler has long been called a "superheat control boiler." As noted earlier in this chapter, however, the control of superheat is not necessarily related to the number of furnaces in a boiler. Therefore, this boiler will be referred to as a **DOUBLE-FURNACE BOILER**; this particular boiler which is illustrated here does have controlled superheat—remember, however, that it is possible to have a double-furnace boiler in which superheat is not separately controlled.

How is superheat controlled in the double-furnace boiler? By proportioning the amount of

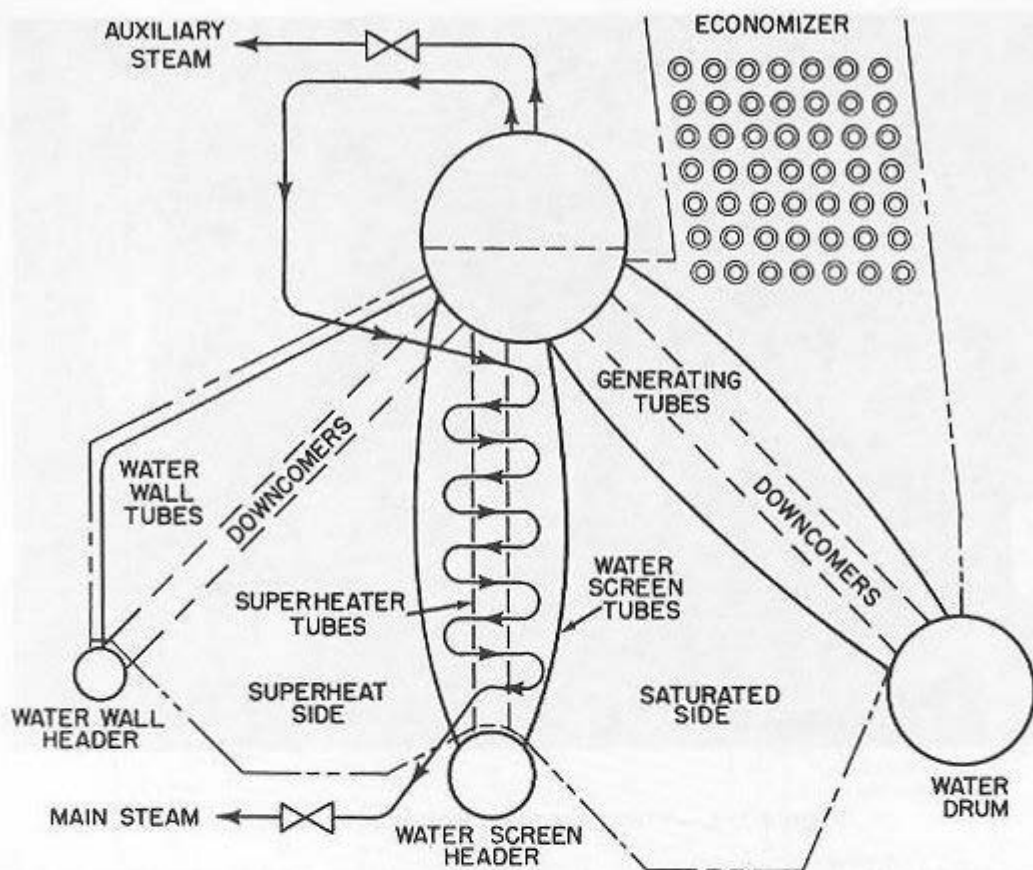


Figure 1-5.—General arrangement of double-furnace boiler.

38.63

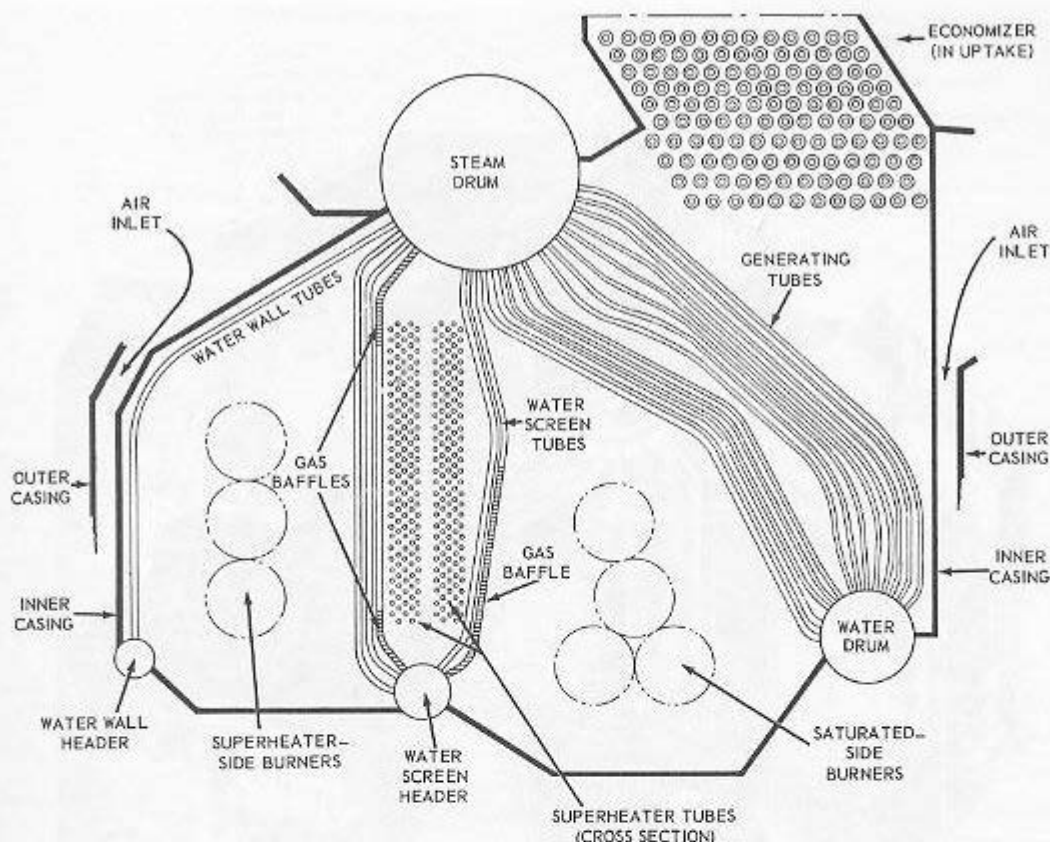
oil burned in the superheater-side furnace to the amount of oil burned in the saturated-side furnace. When burners are lighted only on the saturated side, saturated steam is generated. When burners are lighted on the superheater side as well as on the saturated side, the saturated steam flowing through the superheater becomes superheated.

The rate of steam flow through the superheater also affects the degree of superheat obtained. However, the rate of steam flow through the superheater is basically dependent upon the firing rate on the saturated side. Therefore, the degree of superheat depends primarily upon the ratio of the amount of oil being burned in the superheater side to the amount being burned in the saturated side.

The flow of combustion gases in the double-furnace boiler is partly controlled by gas baffles (fig. 1-6) at the upper and lower ends of the LC row tubes and at the lower ends of the division wall tubes next to the saturated-side

furnace. Originally, the gas baffles were made by using partially studded tubes, packed with plastic chrome ore. However, a newer type of LC row tube has been designed and is being installed whenever the plastic chrome ore on the old stud tubes is so worn that replacement would be required. The new type of LC row tube is finned, rather than studded, and requires no packing with plastic chrome ore.

What is the purpose of the gas baffles? The baffles on the LC row tubes direct the combustion gases toward the superheater tubes and also deflect the combustion gases away from the steam drum and the water screen header. The baffles on the tubes by the saturated-side furnace keep combustion gases from flowing toward the superheater tubes, thus protecting the superheater when the superheater-side is not lighted off. In addition, the baffles on the saturated side deflect combustion gases from the superheater side up toward the top of the saturated side, thus allowing them to pass



38.37

Figure 1-6.—Double-furnace boiler (sectional view, looking toward rear wall).

toward the uptake without disturbing the fires in the saturated-side furnace.

How would you classify this double-furnace boiler that has just been described? On the basis of the classification methods given earlier in this chapter, this double-furnace boiler has the following characteristics:

1. It is a water-tube boiler.
2. It has natural circulation of the accelerated type. (Note that the generating tubes slope much more steeply in this boiler than in the sectional header boiler previously described.)
3. It is a drum-type boiler in which the tubes are arranged in the shape of a letter M.
4. It has two furnaces—one for the saturated side and one for the superheater side—and is thus called a double-furnace boiler.
5. It has controlled superheat.
6. It operates at a pressure of about 615 psig, and is often called a "600-psi boiler."

SINGLE-FURNACE BOILERS

The older single-furnace boilers that were installed on many World War II destroyer escorts differ in some important respects from the newer single-furnace boilers that have been installed on ships built since World War II. Therefore the older and the newer types will be considered separately in this discussion.

Older Single-Furnace Boilers

A single-furnace boiler of the older type is shown schematically in figure 1-8 and in cut-away view in figure 1-9. This boiler produces about 60,000 pounds of steam per hour at full power. At full power the steam drum pressure is about 460 psig, the superheater outlet pressure is about 435 psig, and the superheater outlet temperature is about 750°F.

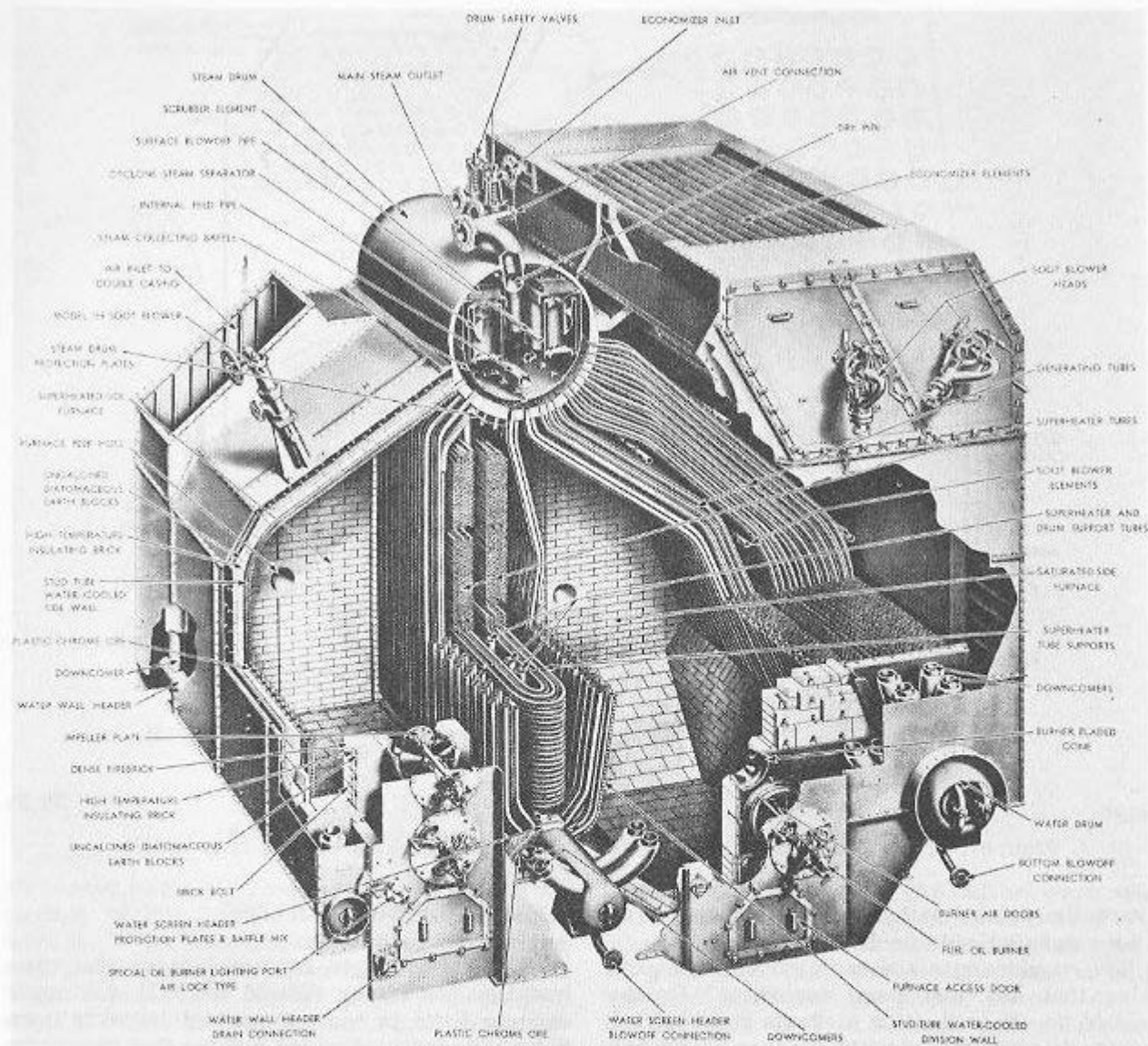


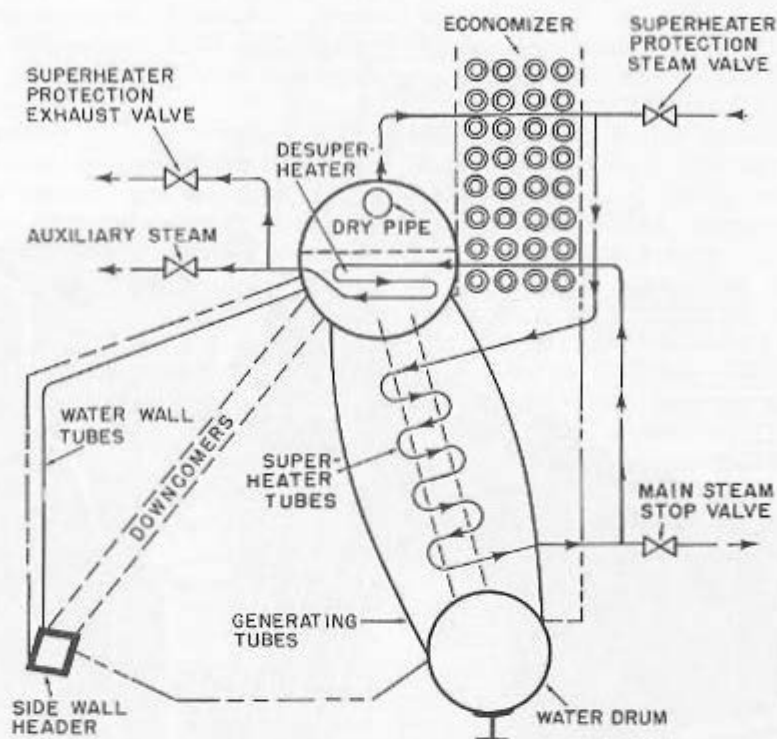
Figure 1-7.—Double-furnace boiler (cutaway view).

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This boiler does not have controlled superheat. When the boiler is lighted off, both the generating tubes and the superheater tubes are heated. In order to protect the superheater tubes from overheating, all steam generated in the boiler must be led through the superheater. The saturated steam goes from the dry pipe in the steam drum to the superheater inlet. It goes through the superheater tubes, out the superheater outlet, and into the main steam line.

Auxiliary steam must also go through the superheater in order to protect the superheater

tubes. Since most auxiliaries are designed to operate on saturated steam, some of the superheated steam must be desuperheated so that it can be used to operate the auxiliaries. Desuperheating is accomplished by passing some of the superheated steam through a desuperheater, which is basically a coil of piping submerged in the water in the steam drum. Heat transfer takes place from the steam in the desuperheater to the water in the steam drum. The desuperheated steam which passes out of the desuperheater and into the auxiliary steam line is once



38.39

Figure 1-8.—General arrangement of older type of single-furnace boiler.

again at (or very close to) saturation temperature.

Thus far consideration has been given to the flow of steam as it occurs after the boiler has been cut in on the steam line. But what happens when a cold boiler is lighted off? How can the superheater tubes be protected from the heat of the furnace after fires are lighted but before sufficient steam has been generated to ensure a safe flow through the superheater?

Various methods are used to protect the superheater during this critical period immediately after lighting off. Very low firing rates are used, and the boiler is warmed up slowly until an adequate flow of steam has been established. Many single-furnace boilers have connections through which protective steam can be supplied from another boiler on the same ship or from some outside source such as a naval shipyard or a tender. As shown in figure 1-8, this steam comes in (under pressure) through the superheater protection steam valve. It enters the superheater inlet, passes through the superheater tubes, goes out the superheater outlet, passes through the desuperheater, and then

goes into the auxiliary exhaust line by way of the superheater protection exhaust valve.

On single-furnace boilers which do not have a protective steam system for use during the lighting off period, even greater care must be taken to establish a steam flow through the superheater. In general, the steam flow is established by venting the superheater drains to the bilges while warming up the boiler very slowly.

How would you classify this boiler? On the basis of the classification methods given earlier in this chapter, this single-furnace boiler has the following characteristics:

1. It is a water-tube boiler.
2. It has natural circulation of the accelerated type. (Note the slope of the tubes.)
3. It is a drum-type boiler, with the tubes arranged in the shape of a letter D. Because of its general arrangement, this boiler is often called a D-type boiler.
4. It has only one furnace.
5. It does not have controlled superheat.
6. It is often classified as a "600-psi boiler." However, it actually operates at about 435 psig.

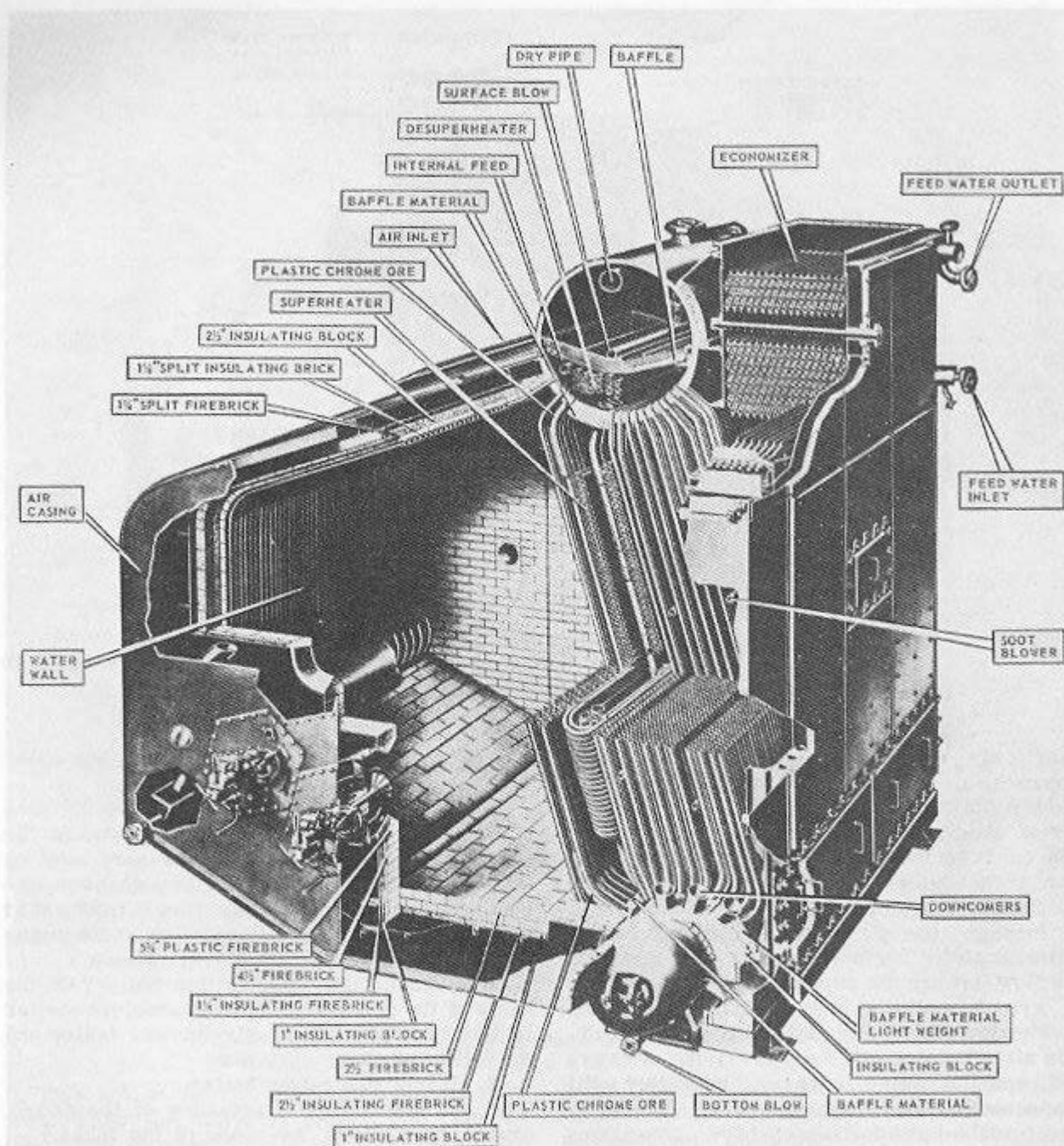


Figure 1-9.—Older type of single-furnace boiler (cutaway view).

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Newer Single-Furnace Boilers

The basic design of the single-furnace boiler is being used increasingly. Except for a few boilers that have been installed more or less

experimentally, all natural circulation boilers installed in combatant ships since World War II are of the single-furnace type.

The basic difference between the newer and the older single-furnace boilers is that the

newer ones are designed for higher operating pressures and temperatures. Operating pressures range from 600 psig to 1200 psig. Operating temperature (superheater outlet temperature) is quite commonly 950°F.

Some of the newer single-furnace boilers look quite like the older ones. Others look very different. Specific details on the design and construction of any particular boiler should be obtained from the manufacturer's technical manual. Some of the changes on the newer boilers are discussed in the following paragraphs.

Perhaps the most important change to be noted in the new single-furnace boilers is the change in furnace design. Higher heat release rates are possible in these boilers than in earlier single-furnace boilers. The use of higher air pressures causes an increase in the velocity of the combustion gases, and the increased velocity results in a higher rate of heat transfer to the generating tubes. Water-cooled rear walls, as well as the more familiar water-cooled side walls, are required in many of these boilers because of the higher heat release rates in the furnace. The rear water wall tubes enter one header at the bottom of the boiler and another header at the top. The lower rear water wall header is supplied with water through several downcomers from the steam drum. The upper rear water wall header discharges its mixture of steam and water to the steam drum through riser tubes.

A destroyer boiler of recent design is shown in figure 1-10. Note the water-cooled rear wall.

Another difference between the newer and the older single-furnace boilers is in the design of the superheater. The walk-in or cavity-type superheater is commonly used in the newer single-furnace boilers. As noted before, some of the newer superheaters have the familiar U-shaped tubes but others have W-shaped tubes.

Many of the newer single-furnace boilers have somewhat different fittings and instruments than those used on older boilers.

NEW TYPES OF BOILERS

The tendency in modern boiler design is toward the use of higher operating pressures and temperatures. So far, higher pressures and temperatures have been achieved mostly by making the necessary modifications in conventional single-furnace boiler designs. In the future, however, different kinds of boilers may

be installed in the propulsion plants of naval ships. Some of the possibilities for future boiler type are mentioned here.

CONTROLLED CIRCULATION BOILERS have been installed on a few naval ships. Although the particular boiler designs that were used did not prove entirely satisfactory for the special requirements of naval service, more satisfactory controlled circulation boilers may be developed in the future.

In theory, controlled circulation has some very definite advantages. In natural circulation boilers, circulation occurs because the ascending mixture of water and steam is lighter (less dense) than the descending body of relatively cool and steam-free water. As boiler pressure increases, however, there is less difference between the density of steam and the density of water. At pressures of over 1000 psi, the density of steam differs so little from the density of water that natural circulation is harder to achieve. At high pressures, controlled circulation boilers may have a distinct advantage because their circulation is controlled by pumps and does not depend on differences in density. Because controlled circulation boilers can be designed without regard to the differences in density, they can be arranged in practically any way that is required for a particular type of installation. In theory, therefore, controlled circulation boilers should take up less space and weigh less than natural circulation boilers of the same capacity.

PRESSURIZED-FURNACE BOILERS, also called **SUPERCHARGED BOILERS**, or **Pressure-Fired Steam Generator**, are an interesting new development in boiler design. Boilers of this type have recently been installed on some naval ships. The pressure-tight furnace is more or less cylindrical in shape, with the long axis of the cylinder running vertically. The boiler drum is mounted horizontally, some distance above the pressurized furnace; the drum is connected to the steam and water elements in the furnace by downcomers and risers, all of which are external to the casing. Some boilers of this type are side-fired. Others are top-fired—that is, the burners are at the top of the boiler firing downward into the pressurized furnace.

Forced draft blowers for conventional boiler installations furnish air pressures ranging from 0 to 10 psig. In a pressurized-furnace boiler installation, an air compressor supplies combustion air at pressures of between 30 and 100

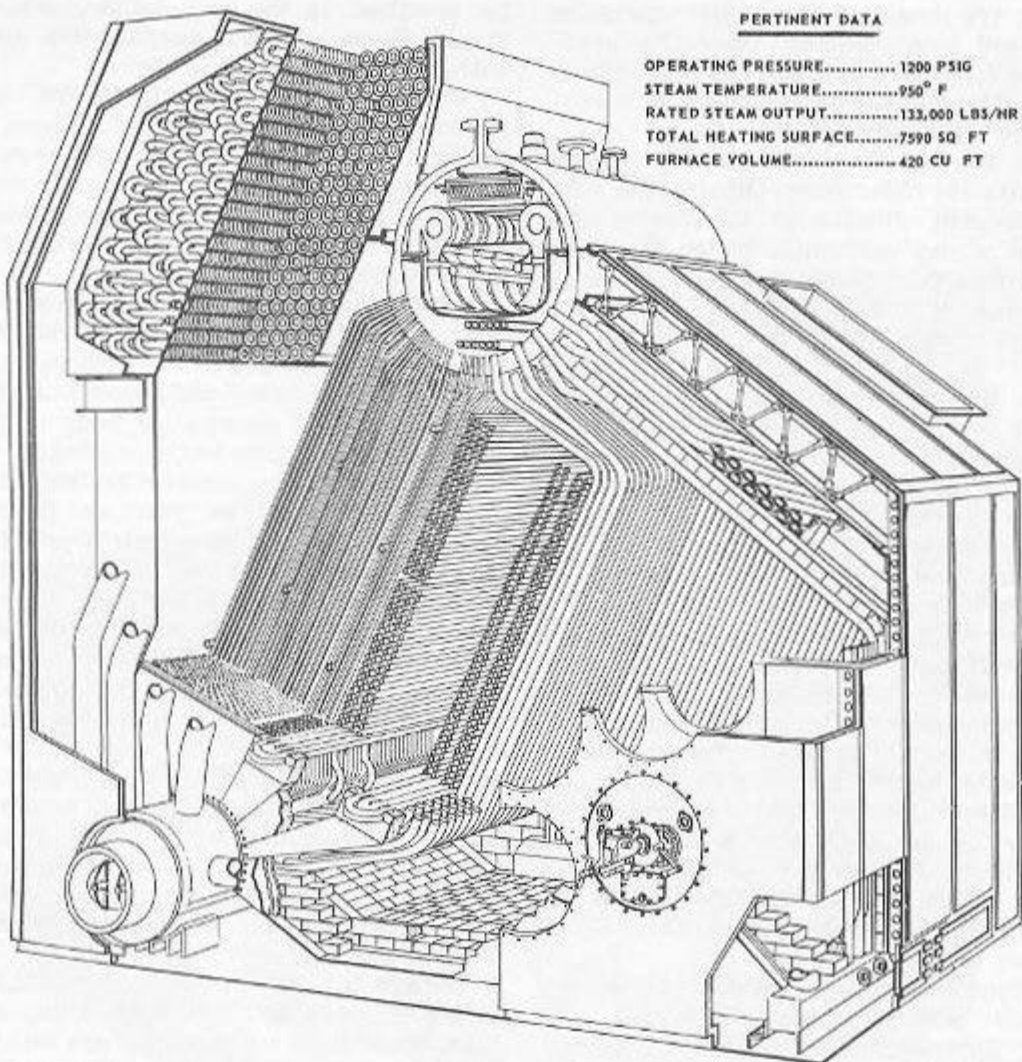


Figure 1-10.—1200-psi single-furnace boiler for post World War II destroyer.

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psig. What is the advantage of pressurizing the furnace? Increasing the pressure on the combustion gas side increases the rate of heat transfer to the water in the boiler. Therefore a pressurized-furnace boiler can be smaller and lighter than a conventional boiler of the same capacity.

The air compressor which supplies the combustion air under pressure is driven by a gas turbine. The air compressor and the gas turbine together are often called a SUPERCHARGER. Part of the energy needed for driving the gas turbine is obtained from the combustion gases leaving the boiler furnace. The combustion gases expand through the gas turbine,

where some of the heat is converted into work. This is the same kind of energy transformation that occurs in a steam turbine; the difference is that hot combustion gases, rather than steam, carry the energy to the gas turbine. After the combustion gases leave the gas turbine, some of their remaining heat is used to heat feed water as it flows through an economizer.

LIGHTING OFF BOILERS

When it has been established that a boiler is to be lighted off, the engineer officer will

obtain the necessary permission from the commanding officer, through the officer of the watch and the OOD. Lighting off instructions for each boiler are specified by the Naval Ship Systems Command, the engineer officer, and the manufacturer of the equipment. The following basic instructions are generally applicable to most modern naval boilers. Special procedures required for lighting off some types of boilers are given after the general instructions.

GENERAL INSTRUCTIONS FOR LIGHTING OFF

A lighting off sheet must be filled out for each boiler as it is being lighted off. The sheet indicates the step-by-step procedures required for lighting off. As each step is completed, the petty officer in charge of the watch checks off the step on the lighting off sheet. The lighting off sheet serves as a record that each step has been completed in the proper sequence.

The general procedures for lighting off a boiler are:

1. Remove the smokepipe cover.
2. Inspect the bilges to be sure they are free of oil. If necessary, wash and pump the bilges.
3. Inspect the bottoms and inner fronts of air casings to be sure they are free of oil accumulations. Be sure that the register drip holes are not plugged.
4. Be sure that the torch pot is adequately secured to a structural part of the floorplates. Also, be sure that it is not so full of oil that the oil will spill when the lighting off torch is dipped into it.
5. Check the fuel oil strainers to be sure they are clean and in good condition.
6. Inspect all atomizer assemblies. Be sure that they are the correct size, clean, and properly made up. If the burner has been disassembled for cleaning or repair, check the setting of the distance piece to be sure that the face of the atomizer tip nut is the correct distance from the diffuser plate. This setting of the distance piece varies for different types of burners; consult the manufacturer's technical manual for the correct setting.
7. Move all air register doors to be sure that they operate freely.
8. Check individual atomizer valves and manifold valves. They should be CLOSED.
9. Wipe up all oil from the floorplates.

10. With the air register doors open, run a forced draft blower to ventilate the furnace and clear it of accumulated gases.

11. Examine all casing doors to be sure that they are closed and airtight.

12. Open the steam drum aircock and the superheater vents.

13. Check to see that the water gage cutout valves are open and that the drain valves are closed.

14. If the boiler has been laid up dry:

(a) close the manhole and handhole plate fittings, in accordance with Bureau of Ships Technical Manual, Chapter 9510(51) article 34;

(b) close the drain cocks;

(c) check the surface blow valve, the bottom blow valves, and all valves in the boiler blow piping to be sure they are CLOSED;

(d) open the feed stop and check valves, start the emergency feed pump, and bring the water level to about 1 inch above the bottom of the glass in the lowest water gage; this procedure fills the economizer with water, tests for possible obstructions in the feed lines and water gages, and tests the operation of the emergency feed pump.

15. If the boiler has been laid up full of water:

(a) run down or pump down the water in the boiler until it is just out of sight in the lowest water gage glass. To do this, it will be necessary to open the bottom blow valve on the water drum, the drain valves on the water headers, and the drain valves on the superheater. Then the water can either be run to the bilges or pumped directly overboard through the hose connection provided in the line to the bilges.

(b) Close the bottom blow valve and the drain valves to the bilges.

(c) Examine the surface blow piping and all valves in the boiler blow piping to be sure they are CLOSED.

(d) Using the emergency feed pump, bring the water level to about 1 inch above the bottom of the glass in the lowest water gage.

16. Using the main feed pump, raise the water level in the boiler about 1/2 inch. This tests the main feed pump and the feed lines.

17. Examine the hand gear for lifting safety valves, and operate this gear as far as can be done WITHOUT lifting safety valves.

18. Ease up on the main steam stops, the auxiliary steam stops, and the turbogenerator steam stops, WITHOUT lifting the valve disks off the seats. This procedure will keep the valves from sticking when they are heated.

19. Open the valves between the steam drum and the superheater inlet (if fitted).
20. Open the superheater gravity (open-funnel) drains.
21. Check to be sure that all cocks and valves in the line to the steam drum pressure gage are open.
22. Line up the fuel oil system. Open all necessary valves from the service tank to the service pump. Bypass the meter, and open all valves between the service pump and the burner manifold. Open the recirculating valves and start the service pump.
23. If the oil is very cold and viscous, so that the service pump has difficulty in taking suction, use the tank heating coils to warm the oil.
24. Cut in steam to the fuel oil heater.
25. Run a forced draft blower SLOWLY until the first burner is lighted.
26. If you are lighting off a single-furnace boiler that has superheater protective steam connections, open the protection steam exhaust valve and the protection steam inlet valve to establish a positive flow of steam through the superheater.
27. Bring the water in the boiler up to the lighting off level.
28. When the oil has reached atomizing temperature, partly close the recirculating valves to allow the fuel oil pressure to build up to at least 200 psi.
29. Light off the burner designated as the lighting off burner. Use a small size sprayer plate. Use a hand torch (fig. 1-11) for lighting off. Use diesel oil for lighting the hand torch. NEVER use gasoline, kerosene, naphtha, or any oil with a low flash point. When lighting off, stand clear to avoid injury from a flareback.
30. As soon as the first burner has been lighted, close the fuel oil recirculating valves and regulate the oil pressure with the micro-meter valve.
31. Open the fuel oil meter inlet and outlet valves and close the meter bypass valve.
32. Check the level in the water gages as the boiler begins to heat up, and check it frequently after steam has begun to form.

33. Close the steam drum aircock and the superheater vents, after steam has formed and has blown sufficiently to exclude all air from the boiler.

34. Check the steam drum pressure gage to see if it registers pressure, after the aircocks and vents have been closed.

35. As the boiler heats up, check all fittings and connections which may begin to leak as they heat up and expand. Some of the things to check for leakage are packing glands on boiler valves; water gages and remote water level indicators; gage lines; and all accessible manhole and handhole plates. Take whatever action is required to correct any leakage discovered.

36. Check the functioning of the water gage glasses by opening the drains and blowing through the gages.

37. See that the water in the boiler is kept at steaming level.

38. Before cutting the boiler in on the line, use the bypass valves or crack the boiler stop valves slightly to warm up the lines slowly and to allow gradual equalization of pressures between the boiler and the line. Be sure that the lines are properly drained during this warming-up period.

39. Cut in the boiler when the proper pressure has been reached. CAUTION: The boiler must first be cut in on the auxiliary steam line BEFORE being cut in on the main steam line.

40. Light off additional burners as required. When burners are lettered or numbered, they should always be lighted off in the indicated sequence. A HAND TORCH MUST BE USED TO LIGHT THE FIRST BURNER AND TO LIGHT ALL ADDITIONAL BURNERS UNTIL THE FURNACE BECOMES INTENSELY HOT!

Lighting Off Single-Furnace Boilers

The following additional instructions for lighting off single-furnace boilers must be followed in order to protect the superheater while steam is being raised in the boiler.

1. On or before lighting the first burner, establish a positive flow of steam through the

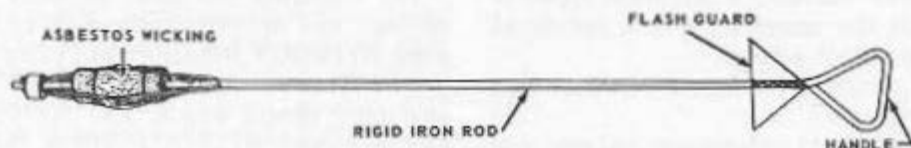


Figure 1-11.—Lighting off torch.

superheater. Many single-furnace boilers have protective steam systems for the superheater. Opening the superheater protection steam exhaust valve and the superheater protection steam inlet valve establishes a positive flow of steam through the superheater. If there is no protective steam system, the steam flow must be established by opening the superheater drains to the bilges and opening the superheater vent to the atmospheric escape pipe.

2. The superheater must be **THOROUGHLY DRAINED** at all times. Even on boilers that have superheater protective steam, the superheater gravity (open-funnel) drains must be opened when the boiler is being lighted off. The gravity drains should remain open until the boiler has built up enough pressure (about 50 psi) to allow the use of the high pressure drains.

3. If the boiler has a superheater protective steam system, close the protection steam **INLET** valve when the steam drum pressure reaches approximately 150 psi—or, in any case, by the time the steam drum pressure equals the pressure in the superheater protection steam supply line.

4. While steam is being raised, the allowable rate of combustion must not be exceeded. The superheater protective steam system is not designed to protect the superheater at high rates of combustion.

5. The superheater protection steam **EXHAUST** valve should be left open until the auxiliary steam stops are opened and the boiler is furnishing steam to the auxiliary steam line.

Lighting Off Double-Furnace Boilers

The following precautions must be observed in lighting off double-furnace boilers:

1. The superheater must be **THOROUGHLY DRAINED** at all times. When lighting off, open the low pressure drains and keep them open until the boiler has built up enough pressure (about 50 psi) to allow the use of the high pressure drains.

2. **NEVER** light burners on the superheater side until an adequate steam flow has been established through the superheater! **NEVER** light a burner on the superheater side unless one or more burners are in operation on the saturated side.

3. When only the saturated-side furnace is lighted off, keep the air registers tightly closed

on the superheater side. This precaution is necessary because air leakage through the superheater-side furnace would tend to cause condensation in the superheater.

4. When there is little or no flow through the superheater, great care must be taken to see that the saturated side is not overfired. Excessive heat from the saturated side can cause serious damage to superheater tubes.

5. Before lighting off the superheater side, check the superheater steam flow indicator to be sure that a safe minimum steam flow has been established.

Lighting Off With Automatic Combustion Controls

A boiler which is equipped with automatic combustion controls can usually be lighted off either with or without using the automatic control system. When compressed air is not available, the boiler must be lighted off on local manual control and operated on local manual until compressed air is available. When compressed air is available, the boiler may be lighted off either on local manual or on remote manual. It is normally transferred to automatic when operating steam pressure has been reached.

The following general rules for transferring from one method to another apply to most automatic combustion control systems now in naval use:

1. Transferring from local manual to remote manual may be done at any time when compressed air is available for the controls.

2. Transferring from remote manual to automatic may be done at any time after operating steam pressure has been reached and a sufficient steam flow has been established to permit continuous firing.

3. Transferring from local manual to automatic should be done by first transferring to remote manual and then from remote manual to automatic.

4. Transferring from automatic to remote manual may be done at any time.

5. Transferring from remote manual to local manual may be done at any time.

6. Transferring from automatic to local manual should be done by first transferring to remote manual and then transferring from remote manual to local manual.

PARALLELING BOILERS

The following procedure is used in cutting in additional boilers, when one or more boilers are already supplying steam to the line:

1. If the main and auxiliary steam lines to which the boiler is to be connected are cold, warm them thoroughly, by using the bypass valves; or by cracking the boiler main and auxiliary steam stop valves. Observe the steam lines during this process and set up on any leaky joints. Make sure that the slip joints or other expansion provisions in the steam line are free. Cut in the steam line drains and traps, and open the trap bypasses if the volume of water is too great for the traps to handle.

2. With a boiler, not fitted with a superheater, crack the boiler main steam stop valve (or its bypass valve, if one is fitted) from the fireroom, rather than from a station outside of the fireroom. This should be accomplished when the pressure reaches 5 to 10 psi above the line pressure. Allow the pressure to equalize; then slowly open the steam stop-valve until it is wide open. The boiler is cut in on the auxiliary steam line in a similar manner.

3. Under ordinary conditions, the saturated-steam load of a ship with superheat control boilers should be divided among all the boilers in use. Before any boiler is cut in on the main steam line, it should be cut in on the auxiliary steam line.

Any combination of boilers connected to a common main steam line must be connected to a common auxiliary steam line. Thus, if two boilers in the same fireroom are furnishing steam to the main steam line, the valve in the auxiliary steam line between those two boilers must be open. Similarly, if the cross-connection in the main steam line between the port and starboard engines and/or between the forward and aft engine rooms is open, the corresponding cross connection(s) in the auxiliary steam line must be open. Otherwise, an increase in the saturated-steam load on one boiler (or group of boilers, as the case may be), without a corresponding increase in the firing rate on the saturated side of the boiler(s), will cause a drop in drum pressure and may cause stagnation or reversal of flow through the superheaters of the boilers, with consequent overheating of the superheaters.

If a ship is to be operated with the cross-connections open, the cross-connection in the auxiliary steam line should be opened before the

cross-connection in the main steam line is opened.

4. With boilers which have integral, separately-fired superheaters, all steam lines from the incoming boiler or boilers to the superheated line should be thoroughly drained and warmed up before they are cut in. The incoming boiler or boilers should be cut in on the auxiliary steam lines in the manner outlined in previous paragraphs, following which they may be cut in on the superheated-steam lines. The steam line temperatures should be reduced to approximately 600°F before an additional boiler is cut in. This reduction in temperature should be made gradually, as time and circumstances permit, and preferably at a rate not exceeding 50°F every 5 minutes.

The maximum steam flow possible should be established through the superheater of the incoming boiler, by the use of drains to the bilges; leakoffs to the auxiliary exhaust line or to other locations; and steaming to a generator direct from the superheater outlet (if connections are provided to accomplish this operation). Thoroughly check the blow-down of the superheater drains to the bilge as a final moisture-elimination precaution; and open the bypass valves around the boiler and main line stop-valves to equalize pressure and establish additional flow. Open the main-line stop valve; and then crack, and slowly open, the main boiler stop-valve. It is preferable to have the fireroom force manipulate the valve connecting the boiler outlet to the line carrying superheated steam. As soon as the steam stop-valve is wide open and steam flow through the superheater is sufficient (as indicated by the superheater protection device), the superheater side of the incoming boiler should be lighted off; the superheater outlet temperature should be equalized with the line temperature; and the loads on the boilers should be equalized. The superheat should be raised again, evenly, on all boilers at the rate of 50°F every 5 minutes, as described previously.

When lighting off the superheater side of the incoming boiler, care should be taken that a minimum amount of air enters the furnace before the burner is actually lighted, in order to avoid the possibility of excessive condensation in the superheater with consequent carry-over into the main steam line. Where special instructions for cutting in have been issued by the Naval Ship Systems Command or are contained in the boiler technical manual for the ship concerned, such instructions shall apply.

5. With boilers equipped with integral superheaters which are not separately fired, open the superheater outlet valve. If open drains are fitted to the superheater or if an outlet connection to the auxiliary line is provided, follow the procedure previously outlined. When the superheater outlet valve has been opened wide, secure the discharge connection to the auxiliary exhaust line.

6. When battle conditions are such that additional boilers must be brought in on the line quickly and without dropping the superheat on the steaming boilers, or when battle drills are being conducted, the following procedure may be used to reduce the possibility of joint or gasket leaks in the main steam lines. Bring the boiler up to pressure, using saturated-side burners only, and cut the boiler in on the auxiliary steam line. Meanwhile, bleed the superheater of the boiler copiously to the bilge and to any other connection provided, such as the auxiliary exhaust line. Warm up the steam lines to the main line stop-valves, by means of the bypass valves or by cracking the boiler stops; and drain these lines copiously to the bilge. With the boiler pressure 5 to 10 pounds above the line pressure, establish flow from the incoming boiler to the main line carrying superheated steam, by opening the bypass valves. (Order of manipulation of the main boiler stops and main line stops or bypass valves will depend on the piping arrangements in the ship. In any case, it is preferable for the fireroom force to manipulate the valve connecting the boiler outlet to the line carrying superheated steam.)

If sufficient steam flow has been established (as shown by the superheater steam flow indicator) to protect the superheater, light off the superheater; and bring the steam temperature up gradually to equal that of the other boilers. If insufficient steam flow is obtained through the bypass, carefully crack the main stop to give adequate steam flow and proceed as described previously. The rate of firing of the superheater side will depend on the adequacy of the steam flow. Start with a small burner and watch the superheater-outlet thermometer. If it does not show a normal increase in temperature within 5 minutes, secure the superheater fires, establish more flow, and light off again. Open the boiler stops and equalize the pressures and temperatures.

7. Superheater fires should be secured when boilers with radiant superheaters are being cut in or out, under normal circumstances. When the

emergency procedure is being employed, greater precautions should be taken to ensure adequate circulation. In addition, when the boiler is steaming at low rates of flow, at sea or in port, the superheat temperature should be lowered and, if necessary, the superheater side secured entirely to protect the superheater.

8. The engineer officer should always be alert to anticipate additional boiler requirements so that boilers may be paralleled through the use of normal procedures.

9. The safe minimum steam flow through the superheater when superheat control boilers are operating at maximum steam temperatures varies from approximately 5000 to 9000 pounds of steam per hour, depending upon the type and the size of the boiler in question. The pressure drop on the superheat steam flow indicator is approximately two inches of water in the case of convection-type superheaters; and five inches of water in the case of radiant-type superheaters. The exact figure for each class of ship is specified in the boiler technical manual or in special instructions issued by the Naval Ship Systems Command. On boilers with radiant-type superheaters, all burners in the superheater side must be secured when the steam flow indicator is in the "red zone"; or when the warning signal is lighted. Convection-type superheat control boilers are less critical and may be operated at reduced superheat (approximately 700°F) with the pointer in the "red zone," provided the boiler is connected to its own turbogenerator on the ship's load and a positive steam flow is thereby ensured.

Boiler Control

In determining the combination of boilers and burners to be used, the engineer officer should select that combination which will give the greatest plant efficiency, with due regard to the necessity of providing for safety and military requisites. The curves of boiler-efficiency versus combustion-rate will show clearly that a boiler operating at its most efficient rate of combustion will have a large reserve to meet emergency demands for steam. The number of boilers to be used should be so selected that the rate of combustion and the number of auxiliaries used will result in the highest possible plant efficiency.

When the plant is steaming on a number of boilers that are not in the same fireroom, a carefully worked out system for controlling the rate of combustion of each boiler is essential.

The control station must be able to accomplish the following:

1. To know the pressure on the fuel-oil service line, and to indicate the oil pressure to be used.
2. To indicate to each fireroom, independently, the number of atomizers to be used on each individual boiler.
3. To warn the man controlling the blowers, when a change is made in the oil pressure.
4. To know the maximum and minimum steam pressures and temperatures in the main steam line and at the engine throttles.
5. To receive the change-in-speed signals from the bridge at the same time they are received in the engineroom.
6. To have telephone communication direct to each fireroom and to the engineroom-control platform.

When the control is from a central control station aboard a large ship, the burners are cut in or out in accordance with the signals of the visual indicator. The control operator is guided by the steam pressure and by the speed signals on the telegraph. He must try to keep the number of changes in the firerooms at a minimum, and to limit the number of firerooms affected by the changes.

With cross-connected superheat control boilers and a comparatively steady steaming condition, the engineer officer should direct that all boilers in use be operated with the same number of burners; the same size of sprayer plates; and the same oil pressure. One machinery space or fireroom should be designated to control each group of boilers and to take care of variations in load. Each boiler should make minor adjustments to the number of burners and the oil pressure to maintain the desired steam pressure and temperature. For large changes in load, all boilers should act individually, cutting burners in or out as necessary, to keep the pressure and the temperature from rising or dropping. If practicable, each fireroom should be informed prior to a large change in load, in order that an excessive rise or fall in pressure may be avoided.

On small ships, such as destroyers, the burnerman at the boiler must depend upon the boiler steam-pressure gage and the superheated-steam thermometer. As the steam requirements change, he rapidly cuts burners in or out so as to maintain, as steadily as possible, the desired boiler steam pressure and temperature. He should have no other duty while the ship is

maneuvering. If he observes a dirty atomizer, he notifies the boilerman in charge of the watch, instead of attending to it himself. Efficient operation of the boilers while large and frequent changes in rate of combustion are being accomplished requires careful training of the fireroom force. When more than one fireroom is in operation for steady steaming, it is advantageous to designate a control fireroom which will vary the number of burners in use in that fireroom to care for minor variations in pressure and temperature requirements.

UNDERWAY OPERATIONS

After boilers have been lighted off, the men on watch in the fireroom must pay constant attention to all details of boiler operation. In order to meet steam demands, the men on watch must keep close control over boiler water level, fuel oil pressures and temperatures, combustion air flow, and the operation of all auxiliary machinery serving the boilers.

Before the fireroom is reported ready to answer all bells, a number of checks and inspections must be made to see that everything is in order. The auxiliary machinery—pumps and forced draft blowers—must be operating properly. The fuel oil system must be lined up with the main fuel oil service pump in operation, a standby service pump lined up and ready to take suction from the standby fuel oil service tank, the fuel oil heater in operation with the appropriate number of units, and standby atomizer assemblies made up and stored in racks near the boiler. The feed water system must be lined up with the main feed pump in operation, a standby main feed pump warmed up, and the emergency feed pump operating slowly in a standby condition on cold suction. All gages, instruments, alarms, and annunciators must be checked to be sure that they are in good working condition. All safety precautions must be observed, and unsafe operating conditions must not be allowed to exist.

Most of the information given in the sections which follow on underway operations deals with manual, rather than automatic, operation of boilers. Most naval boilers are not at present equipped with automatic control systems; and, even on ships which do have automatic controls, fireroom personnel must still be completely familiar with all manual operating procedures. When an automatic control system is operating

correctly under steady steaming conditions, the fireroom force might almost seem to be unnecessary because the automatic controls take care of feed water, fuel oil, and combustion air demands. However, no automatic boiler control system yet invented has made the fireroom force obsolete. Automatic boiler controls installed in naval ships operate with a high degree of accuracy and reliability; but they are designed to AID operating personnel, not to replace them. Trained fireroom personnel must always be available to check on the operation of the automatic controls, to deal with large changes in steam demand, and to operate the boilers manually in the event of casualty to the automatic controls.

STEADY STEAMING

During in-port operation and under cruising conditions, the rate of combustion is fairly constant because changes in steam demand are, in general, very small. Every effort should be made to stabilize boiler operations—that is, to maintain constant conditions on as many as possible of the boilers in use. The following factors are important in maintaining steady boiler conditions:

1. The fuel oil should be kept at the specified temperature and pressure.
2. The blowers should be regulated to give the proper air pressure, and this air pressure should be kept steady as long as no change is made in the oil pressure, the number of burners in use, or the size of sprayer plates in use.
3. The water should be maintained at the proper level, without major fluctuations.
4. The air registers should be adjusted to the proper position for the steaming rate, and should be kept in the same position.
5. The atomizers should be clean and in proper adjustment.
6. The burners should be used according to the lighting-off sequence specified by the boiler manufacturer or by the Naval Ship Systems Command.
7. Feed water pressure and feed water temperature should be kept constant.
8. Superheater outlet pressure and temperature should remain steady. Wide or frequent fluctuations in the degree of superheat result in a considerable loss of efficiency in the engineering plant as a whole, and—if extreme enough—could cause extensive damage to machinery, piping, joints, valves, and casings.

9. When more than one boiler is in use, as many of them as possible should operate at the same rate of combustion; and the same number of burners should be used on each boiler.

10. The same size sprayer plates should be used in all burners of all boilers in use.

CONTROL OF FUEL OIL

The control of combustion involves heating the oil to atomizing temperature, forcing the oil into the furnace under pressure, supplying the proper amount of air for combustion, and supplying heat so that the oil will ignite and burn. Thus the control of fuel oil and the control of combustion air are the two basic requirements for efficient combustion in the boiler. Factors relating more or less directly to the control of fuel oil are discussed here; the control of combustion air is discussed later in this chapter.

Burner Sequence

The specified numerical or alphabetical sequence should be followed in lighting off and securing numbered or lettered burners and in changing the number of burners in use. If burners are neither numbered nor lettered, a low burner in the middle of the firing front should be lighted off first. As additional burners are lighted off, they should be symmetrical about the first one.

Changing the Firing Rate

The amount of steam that can be supplied by a boiler ranges from the amount obtainable with one burner fitted with the smallest size sprayer plate to the amount obtainable when all burners are in use and all are fitted with sprayer plates of the largest size allowed for that particular boiler. The two main ways of making large changes in firing rate are (1) by increasing or decreasing the number of burners in use, and (2) by changing the size of the sprayer plates in use. Smaller changes in firing rate may be taken care of by increasing or decreasing the fuel oil pressure.

Size of Sprayer Plates

The capacity of a sprayer plate depends upon its size—the larger the sprayer plate, the greater its capacity. In addition, sprayer plate

capacity is affected by the oil pressure. Increasing the fuel oil pressure increases the capacity of a sprayer plate of any given size.

The sprayer plates used in a boiler should normally all be of the same size. (NOTE: The numbering system used with sprayer plates is mentioned in chapter 3 of this publication.) Using mixed sizes of sprayer plates in the same boiler results in an incorrect relationship between the combustion air pressure and some of the sprayer plates. If the air pressure is correct for some of the plates, it is bound to be wrong for others. Under some circumstances—for example, when the ship is maneuvering at low firing rates—it may be necessary to keep a smaller sprayer plate in one burner temporarily in order to prevent loss of fires. Under some other circumstances, it might be necessary to use one larger sprayer plate for a short time. In all cases, however, sprayer plates of uniform size should be used as soon as possible.

Oversize sprayer plates—that is, plates larger than the largest size allowed for the ship—must NEVER be used.

Fuel Oil Pressure

On most ships, a fuel oil pressure of 200 to 300 psi gives the best atomization of the fuel oil. Somewhat lower pressures may be used when the smaller sizes of sprayer plates are in use; however, the lower pressures are generally used only to take care of temporary maneuvering conditions.

On ships having return-flow burners, the fuel oil supply pressure and the fuel oil return pressure are specified in the manufacturer's technical manual for the boilers. Fuel oil pressures about 1000 psi used for return-flow burners are much higher than those used for burners that are designed for the straight-through-flow type of atomizer.

Fuel Oil Temperature

Before fuel oil is burned in the boiler furnace, it must be heated to the temperature required for best atomization. The best atomization occurs when the oil is heated to a temperature that gives the oil a viscosity of 135 Seconds Saybolt Universal or 17.2 Seconds Saybolt Furol. Viscosity and the units in which it is measured are discussed in chapter 3 of this publication.

Since fuel oils differ in viscosity, the temperature required to provide the prescribed viscosity also differs for the various fuel oils. The best atomizing temperature for Navy Special fuel oil falls somewhere in the range of 115° to 145°F. After the best atomizing temperature has been determined for any particular shipment of fuel oil, the fuel oil heaters are used to maintain the oil at this temperature.

During underway operations, a close check must be kept on the fuel oil temperature. Large changes in firing rate require changes in the amount of steam going to the fuel oil heaters.

Operation of Fuel Oil Burners

Under normal steaming conditions, atomizer assemblies are made up, ready to be put in when needed. Standby atomizer assemblies are usually made up ahead of time, with different sizes of sprayer plates, and are stowed in racks near the burner front. When steam demands change, the spare atomizer assemblies are ready to be inserted as necessary to meet the changing conditions.

Suppose, for example, that the ship is steaming rapidly and steadily and that large size sprayer plates are in use in all burners. Suddenly a stop signal is given. The large size sprayer plates were just right for rapid steaming, but they have too great a capacity for the situation that now exists. In order to prevent a build up of pressure that would cause the safety valves to lift, the burnerman must quickly remove the atomizer assemblies that are fitted with large size sprayer plates and replace them with atomizer assemblies fitted with smaller size sprayer plates.

Before cutting in a burner, a check should be made to be sure that an atomizer assembly has been inserted into the burner. If an atomizer assembly has not been inserted when the burner root valve is open, hot oil under pressure will spray out into the fireroom. If the hot oil strikes an individual, it may cause serious burns. If it strikes a hot surface such as a pipe, it may flash into flame and cause a serious fire in the fireroom.

After the atomizer assembly has been inserted into the burner head and locked in place, the burner assembly should be pushed into the furnace until the distance piece indicates that the burner is in the proper position. The distance piece must be pushed in far enough to keep the oil from hitting the brickwork, but not

so far that it will allow air to enter the furnace without mixing with the oil. The correct position of the distance piece depends upon the number of burners in use and on the size of the sprayer plates in use. Slight adjustments in the position of the burner assembly may be made later, after the burner has been lighted off.

After positioning the burner assembly, the burner root valve, should be opened; this permits fuel oil to flow from the burner manifold to the burner. Before this valve is opened, the fuel oil pressure at the manifold should be at least 250 psi (or, for return-flow burners, the pressure specified by the manufacturer). At lower fuel oil pressures, other burners already lighted off may be extinguished as oil suddenly spurts from the manifold to the burner being lighted off. This sets up a perfect situation for a very dangerous flareback. Oil continues to spray out from the extinguished burners; when this oil hits the hot brickwork in the furnace, a flareback is likely to result.

After opening the burner root valve, the air register should be opened to the correct position. The atomizer valve, located on the burner head, should then be cracked open. This atomizer valve allows fuel oil to flow through the burner head, through the atomizer, and into the furnace. When opening the atomizer valve, it may be necessary to flip the air register shut for a moment to allow the flame from other burners to reach the burner being cut in.

After cutting in a burner, look through the peepholes at the boiler front and check the functioning of the burner. Check for correct atomization of the oil. Be sure the flame is near the diffuser. Be sure the cone of atomized oil is as near the burner opening as it can be without actually hitting the refractories.

As the burners are being operated, watch the steam pressure gage and make whatever adjustments or changes are required to keep the steam pressure constant. Small changes in steam demand can be met by adjusting the micrometer valve on the burner manifold and thus controlling the oil pressure to the burners. To meet larger changes in steam demand, it will be necessary to cut in or secure burners or change the size of the sprayer plates.

To cut out a burner, close the atomizer valve, close the air register, and retract the distance piece. NOTE: On some boilers, a very slight cracking of the air register is permitted when a burner is cut out. The instructions issued by the engineer officer, or given

in the manufacturer's technical manual for the boiler, should be followed.

When a burner has been cut out, close the burner root valve on the manifold and withdraw the atomizer assembly. If the burner is going to be used again almost immediately—as, for example, when the ship is maneuvering and there are rapid changes in steam demand—the burner root valve may be left open and the atomizer assembly may be left in place. But the normal procedure is to close the root valve and withdraw the atomizer.

Atomizers should be changed at least once each watch, and oftener if they appear to be dirty or clogged. As soon as an atomizer assembly is removed, all oil should be drained out of it and it should then be blown through with steam. Most firerooms have steam brackets or steam lines rigged for this purpose. Before blowing through the atomizer, remove the tip, the sprayer plate, and the nozzle. Put these parts to soak in a pan of kerosene or diesel oil. After the carbon has softened up, clean and polish the tip, the sprayer plate, and the nozzle. (Note: Abrasives or polishes should not be used on sprayer plates; only wood or soft copper tools should be used.)

At least once an hour, poke through the burner drain holes with a metal rod to make sure they are free of oil, carbon, and other material.

When operating burners on the superheater side of a double-furnace boiler, it may be necessary to raise or lower superheat for various operating conditions—maneuvering, astern operation, and so forth. The prescribed rate for raising or lowering superheat is about 50°F every 5 minutes.

If the superheater thermal alarm sounds, the superheater fires must be immediately decreased to bring the temperature down below the alarm temperature. Do NOT decrease the temperature any more than necessary. It is seldom necessary to secure all superheater burners in order to bring the temperature down to the prescribed point.

Automatic Control of Fuel Oil

When an automatic combustion control system is operating on automatic, the control system varies the fuel oil pressure and the fuel oil flow to meet changing steam demands. Under these conditions, the burnerman is only responsible for cutting burners in and out, for

changing and cleaning atomizers, and for controlling fuel oil temperatures. The automatic control system does the rest of the job of controlling fuel oil.

The automatic system may, of course, be shifted to remote manual and then to local manual at any time. When on remote manual, control of fuel oil is achieved by manipulation of knobs on the control console. On local manual, all operations are manually performed.

Most boilers that have automatic combustion control systems are equipped with return-flow burners. Some of the oil supplied to these burners is not burned; instead, it flows from the burner to a fuel oil return header and from there it eventually goes to the suction side of the fuel oil service pump. Cutting in or securing return-flow burners is somewhat more complicated than cutting in or securing straight-through-flow burners, mostly because there are more valves to be opened or closed. Follow the manufacturer's instructions for cutting in, operating, and securing return flow burners.

CONTROL OF COMBUSTION AIR

Forced draft blowers supply the air required for combustion of the fuel oil. The amount of air that enters the furnace is determined by the air pressure in the double casings. Although the air pressure is affected by the number of burners in use and by the amount that the air registers are open, it is primarily determined by the speed at which the forced draft blowers are operated. The speed of the forced draft blowers is controlled by manual adjustment of the blower throttle in all installations except those having automatic combustion control systems.

Forced Draft Blowers

The forced draft blowers should be operated in such a way as to furnish the required amount of air for the complete combustion of the fuel being burned. Approximately 14 pounds of air will furnish the oxygen theoretically required for the complete combustion of 1 pound of fuel oil. In actual practice, it is necessary to supply 110 to 115 percent of the amount of air theoretically required, in order to ensure the complete combustion of the fuel. Higher percentages of excess air are wasteful of fuel, since all air that does not actually enter into

a combustion reaction merely absorbs and carries off heat.

On the other hand, an insufficient quantity of air for combustion is also detrimental to boiler efficiency. If there is not enough air for complete combustion, there may be a loss of as much as 10,100 Btu per pound of carbon in the fuel. Or, if even less air is supplied, some of the carbon will not be burned at all but will pass out of the smokestack as black smoke. Insufficient air is also detrimental because it causes the boiler to pant and vibrate; this is one of the major causes of brick work failure.

Air Registers

Only the air registers of the burners in use should be open. All other registers should be kept closed to prevent excess air from entering the furnace. On air-encased single-furnace boilers, the air registers of all burners in use should be opened the same amount; on double-furnace boilers, the air registers of all burners in use on the same side of the boiler should be opened the same amount, but the size of the opening may be different on the two sides of the boiler.

In closed fireroom installations, it may be necessary to crack idle registers slightly in order to prevent overheating, warping, or burning of register parts. However, this is NOT necessary with burners of the type used on air-encased boilers; and on double-furnace boilers it is particularly important to keep idle registers closed on the superheater side when the superheater side is not lighted off.

Changing Air Pressure

The air pressure in the double casing must be increased BEFORE the rate of combustion is increased, and must be decreased AFTER the rate of combustion is decreased. There is usually little difficulty in teaching fireroom personnel to increase the air pressure before the rate of combustion is increased, since failure to do so results in panting and vibration of the boiler and in heavy smoke. It is more difficult, however, to teach the men to decrease the air pressure after the rate of combustion has been decreased. However, operating the blower at a faster speed than is required for the rate of combustion is definitely a poor

practice, since it introduces more excess air than is required for the combustion of the fuel.

Light Brown Haze

A trace of light brown smoke emitted in a uniform manner from the funnels is an indication that the amount of excess air entering the furnace is just about right—that is, approximately 10 to 15 percent excess air. On most ships the fireroom force should be instructed to operate the boilers with the amount of excess air that will produce this light brown haze. If a smoke screen is required, a command decision, based on an operational requirement, will be ordered by the commanding officer.

Smokeless Steaming

For a given rate of combustion, smokeless steaming requires a moderate increase in excess air. To make full speed while running smokeless requires careful attention to every detail of boiler operation. As you know, insufficient excess air is not the only cause of black smoke. Smoke can also be caused by poor atomization (due to faulty or dirty burners, low oil temperature, low oil pressure), by poor mixing of air and oil, by unconsumed oil striking the tubes or furnace walls, and by other conditions. Defects of this type must be eliminated before proper air and oil regulation can be achieved and before smokeless steaming can be performed.

CONTROL OF FEED WATER

The control of feed water is of vital importance in boiler operation. Operating personnel must be constantly alert to any indication of malfunctioning of the feed water systems, the water gage glasses, and the valves or controls by which feed water is admitted to the boiler.

Operation of Feed Systems

Boiler feed systems must always be operated in such a manner as to ensure complete reliability. Care must be taken to see that a single failure—as, for example, a defective gasket—could not result in failure of the entire feed water supply.

When two main feed systems of the pressure-closed type are installed, pressure should be kept on both of them at all times while under

way. Normally, half of the boilers in use will take feed from one system and the other boilers will take feed from the other systems.

Under certain conditions, the commanding officer of the ship may authorize the operation of one system only, instead of the two. When only one system is in operation, a standby main feed pump must be lined up and ready to take suction immediately from the main feed system that is not in operation (or, if this is not feasible, from the system that is in operation). Under these conditions, the use of only one feed tank is desirable as a means of minimizing oxygen contamination of the feed water. Where two feed tanks are installed, therefore, the cross-connection valves between the tanks should be closed; the standby tank should be kept at normal water level, ready for immediate use; and all condensate and drains should discharge to the tank that is being used.

Water Gage Glasses

Each boiler is fitted with two independent water gages or water gage assemblies. Various combinations are used; there may be two 10-inch glasses or two 18-inch glasses at about the same level, or two 10-inch glasses staggered vertically to provide a total range of more than 10 inches. The designed normal water level for most boilers is at the center of the gage or, in the case of staggered gages, midway between the top of the upper gage and the bottom of the lower gage. If the water is within sight in either glass, it is still within allowable limits. If the designed normal water level for a boiler is NOT shown at the midpoint of the gages, the location of the normal water level should be clearly marked on the gages.

The water level should always be maintained as close as possible to the designed normal level. If the water level is higher or lower than normal BUT IF IT IS STILL VISIBLE IN ONE GAGE GLASS the water level can be brought back to normal by increasing or decreasing the amount of water fed to the boiler. If the water level cannot be seen at all, an emergency situation will exist, requiring the IMMEDIATE securing of the boiler.

If water gages and indicators are not functioning, there is no way of knowing where the water level is. Gage connections are easily clogged with dirt, scale, or other solid matter. Therefore, the water gages must be blown through at frequent intervals in order to prevent

false indications of water level. Water gages on most boilers must be blown down under the following conditions:

1. Before the boiler is connected to the steam line, the water gages must be blown down in the presence of the PO in charge of the watch.
2. At the end of each watch, the gages must be blown down in the presence of the PO in charge of the watch coming on AND in the presence of the PO in charge of the watch being relieved.
3. Water gages must be blown down whenever there is any reason at all to suspect that the gages are not registering the actual water level. If the water in the gages does not fluctuate with the roll and pitch of the ship, for example, you should suspect that the gages are not showing the true water level.

The procedure for blowing down a water gage glass of the type used on most boilers is as follows:

1. Unhook the chains that connect the top and bottom valve handles.
2. Close the top cutout valve and open the drain at the bottom of the assembly. This allows water to flow through the bottom connection and clear away any obstructing material such as dirt or scale.
3. Open the top cutout valve and close the bottom cutout valve. This allows steam to flow through the top connection and clear it of any obstructing material.
4. Close the drain valve.
5. Open the bottom cutout valve. This allows water to enter the gage. Check the water level against the level shown on the other gage or on the remote water level indicator.
6. Hook the chains that connect the top and bottom valve handles.

(NOTE: The procedure for blowing down water gage glasses on some 1200-psi boilers is somewhat different than the procedure described here. Follow instructions issued by the Naval Ship Systems Command concerning the procedure for blowing down gages on 1200-psi boilers.)

After blowing down a water gage, be sure that both the valves are wide open and that the gage is indicating the correct water level. If there is any delay or sluggishness in the return of the water level to the gage, find out the cause of the trouble and correct it immediately. When checking the water level in a gage glass, be sure that the water level you see is actually the true water level. Sometimes a fine crack in the glass

or a thin line of dirt can look almost exactly like the line of a water level.

The slightest sign of oil in a water gage glass should be reported IMMEDIATELY to the PO in charge of the watch. Even a small amount of oil in the boiler water is a serious casualty requiring immediate attention.

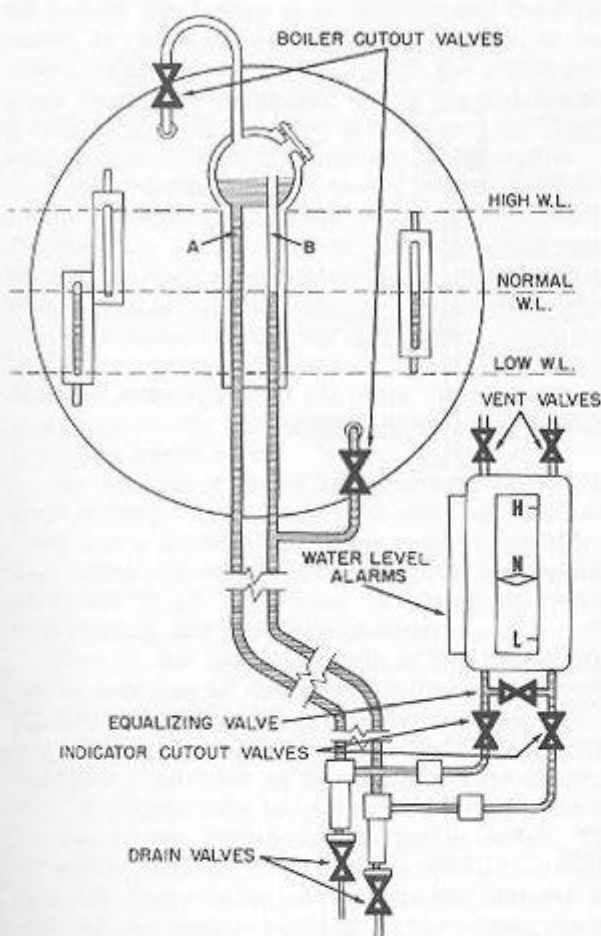
Remote Water Level Indicators

Several types of remote water level indicators are now used in the Navy. Since procedures for putting the indicators into service and for blowing them down are not the same for all types, the manufacturer's technical manual should be consulted for this information. One precaution that applies to most remote water level indicators should be noted: Do NOT allow boiler water to reach the indicating part of the unit when you are blowing down a remote water level indicator.

When two independent remote water level indicators and one water gage are installed on a boiler, the two remote indicators should be used as the controlling indicators of water level. Use the water gage glass as a check gage while the boiler is being lighted off. After the ship is underway, secure the gage glass—provided, of course, that the two remote water level indicators show the same reading.

Remote water level indicators are used on most ships to provide a means whereby the boiler water level may be observed from the lower level of the fireroom. The two types of remote water level indicators (Yarway and Jerguson) that are described here are in common use on combatant ships. A third type (Reliance) is used on some cargo ships and converted types. A fourth type (Bailey) is generally used where Bailey combustion controls or feed water regulators are installed. (NOTE: Remote water level indicators are always supplemented by at least one water gage glass.)

YARWAY REMOTE WATER LEVEL INDICATOR.—The general arrangement of the Yarway remote water level indicator is shown in figure 1-12. The main parts of the indicator are (1) the constant-head chamber, which is mounted on the end of the steam drum, as close to the vertical centerline as possible; (2) a graduated indicator, which is usually mounted on an instrument panel; and (3) two reference legs, marked A and B in figure 1-12, that connect the constant-head chamber to the indicator.



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Figure 1-12.—General arrangement of Yarway remote water level indicator.

A constant water level is maintained in leg A, since the water level in the constant-head chamber does not vary. However, the level in leg B is free to fluctuate with changes in steam drum water level. The upper hemisphere of the constant-head chamber is connected to the steam drum at a point above the highest water level to be indicated; because of this connection, boiler pressure is exerted equally upon the water in the two legs. The variable leg B is connected to the steam drum at a point below the lowest water level to be indicated; because of this connection, the water level in leg B is equalized with the water level in the steam drum.

As you can see from figure 1-12, each leg is connected by piping to the indicator. In the indicator, the two columns of water terminate upon opposite sides of a diaphragm. The pointer

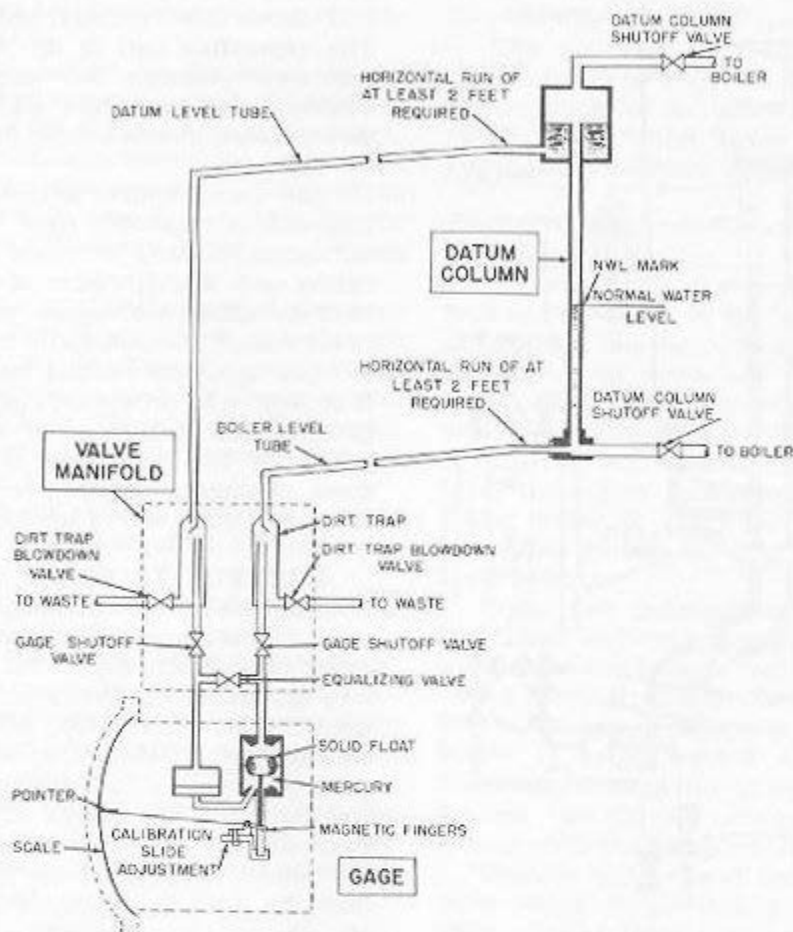
of the indicator moves over an illuminated scale that shows low, normal, and high water levels. The indicating unit of the remote water level indicator includes two magnetically actuated switches that operate a warning horn when the water level in the steam drum is too high or too low.

The manufacturer's instructions should be followed in replacing light bulbs, diaphragms, deflection plates, or other parts of the indicating unit. Recalibration of the indicator should NOT be attempted unless you are SURE that it is necessary. Occasionally it may be necessary to blow down the remote water level indicator. If blowdown is necessary, be very careful to see that the hot boiler water does not reach the indicator. The appearance of vapor in the blowdown discharge should serve as a warning to close the drain valves instantly.

JERGUSON TRUSCALE REMOTE READING BOILER WATER GAGE.—The general arrangement of the Jerguson remote water level indicator is shown in figure 1-13. Before being put into operation, the indicator must be filled with mercury and calibrated. After adding 5 pounds of mercury to the gage, add clear tap water until the gage is full. Close the shutoff valves and the blowdown valves at the valve manifold. Open the valves between the datum column and the boiler. Then open the blowdown valves and flush the lines thoroughly with steam to remove all air and foreign matter. Allow the datum column and the lines to fill with condensate. When the lines (up to about 3 feet from the datum column) have cooled down to room temperature, you can assume that they have been filled with condensate.

With the equalizing valve closed, open the gage shutoff valves. With the boiler water at normal level, the gage will read below "N" on the scale because of the excess mercury in the gage. Drain mercury through the bleeder valve until the pointer is at "N" on the scale.

Raise or lower the water level in the boiler to obtain a departure of at least 6 inches from normal, as indicated by the water gage glass. Loosen the calibration slide lock screw, and adjust the calibration slide so that the pointer reading corresponds to the water gage glass reading. After making the calibration slide adjustment, back out the pointer arm locking screw and adjust the pointer length to clear both the scale and the window. The gage will now indicate the water level throughout its range.



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Figure 1-13.—Jerguson Truscale remote reading boiler water gage.

When the boiler is secured, the valves between the datum column and the boiler should be closed in order to prevent the carryover of excessive amounts of boiler compound or other foreign matter into the datum column.

If it becomes necessary to replace any part of the instrument, be sure to follow the manufacturer's instructions carefully.

Low Pressure Feed Alarms

Automatic low pressure feed booster alarms are installed on most ships to indicate low discharge pressure of the feed booster pump. During the lighting off period, the alarm should be tested by the following procedure:

1. Start the feed booster pump and bring the discharge pressure up to normal.

2. Energize the low pressure feed booster alarm.

3. Reduce the feed booster pump discharge pressure to the pressure at which the alarm functions, so that you can tell whether or not the alarm is working.

A manually operated (pushbutton) alarm is installed on some ships. By means of this alarm, the checkman can signal "low feed pressure" to the man at the main feed pump. The pushbutton alarm should be tested by an IC Electrician at the proper intervals.

Manual Control of Water Level

When a boiler is being operated manually, the checkman controls the water level in the boiler by operation of the feed stop and check valves. The feed stop valve is kept wide open

whenever the boiler is steaming, and the check valve is used to regulate the amount of feed water admitted to the boiler. If the water level goes down, the checkman opens the check valve a little wider. If the water level rises, the checkman closes down a little on the check valve.

Adjustments of the water level should be made gradually, and only as necessary. Sudden fluctuations in the rate of feeding cause undesirable changes in boiler water temperature, steam output, firing rate, and generally reduce boiler efficiency. During lighting off, securing, and maneuvering, the water level will fluctuate to some extent. But at all other times the water level should be maintained at or very near the designed water level.

As long as a boiler is furnishing steam, the feed supply must never be shut off entirely, even for a short time. The reason for this is that water must be kept flowing through the economizer at all times in order to prevent overheating and possible casualties.

One of the hardest parts of the checkman's job is learning to regulate the flow of feed water to meet changing steam demands. One reason why this is hard to learn is that boiler water swells and shrinks as the firing rate is changed. As the firing rate is increased, there is an increase in the volume of the boiler water. This increase, which is known as SWELL, occurs because there is an increase in the number and size of the steam bubbles in the water. As the firing rate is decreased, there is a decrease in the volume of the water. This decrease, which is known as SHRINK, occurs because there are fewer steam bubbles in the water and they are of smaller size. Thus, for a fixed WEIGHT of boiler water, the VOLUME varies with the rate of combustion.

So far, swell and shrink are easy enough to understand. But things get a little more complicated when you remember that the evaporation rate also increases as the firing rate increases. When the firing rate is increased, therefore, the checkman must remember to feed MORE water to the boiler, even though the water level has already risen momentarily because of swell. On the other hand, the checkman must remember to feed LESS water to the boiler when the firing rate is decreased, even though the water level has already dropped.

The problems of priming, foaming, and carryover are closely related to the control of boiler water level. PRIMING is the term usually used to describe the carryover of large gulps

or slugs of water. Priming may occur as the result of a momentary high water level which submerges the steam separators, or it may occur as the result of foaming of the boiler water. FOAMING occurs when the boiler water contains too much dissolved or suspended solid matter. When a considerable amount of foam piles up on the surface of the boiler water, some foam is likely to be carried over.

Any type of carryover, whether large slugs of water or smaller amounts of foam and moisture, can cause extensive damage to superheaters, steam lines, turbines, and valves. Priming is particularly dangerous because large slugs of water can hit the turbine blades with such force that thrust bearings, blades, and shrouding will be damaged.

The proper control of boiler water level and the proper control of boiler water quality should almost completely eliminate priming, foaming, and carryover in modern naval boilers. While the boiler is operating, the surface blow line should be used as often as necessary to remove scum and foam from the surface of the water.

An excessive amount of condensate running down from the top connection of the water gage glass may indicate that foaming and priming are occurring. This is particularly true if the excessive condensate is noted at the same time as rapid, momentary high water levels which have no other apparent cause. Even the slightest indication of priming, foaming, or carryover should be reported immediately to the PO in charge of the watch.

Automatic Control of Water Level

Boiler water level may be controlled automatically by multi-element feed water regulators or by single-element feed water regulators. Multi-element regulators are usually used in automatic feed water and combustion control systems. Single-element regulators are installed on many boilers which are not equipped with complete automatic control systems.

The problems of swell and shrink that give the checkman some trouble are also problems for automatic feed water regulators. Single-element regulators are controlled only by the existing water level in the steam drum; therefore, they cannot compensate for swell and shrink as well as the checkman can. Multi-element regulators, on the other hand, are controlled by the existing water level in the drum PLUS other factors such as feed water flow

and steam flow or fuel oil flow. Multi-element regulators can therefore provide better control of water level than is possible with manual operation of the feed check valve.

As a rule, automatic feed water regulators vary the supply of feed water by actuating a feed-regulating valve in the main feed line between the feed stop and check valves and the economizer. When the automatic feed water regulator is in use, the feed stop and check valves must be fully open. When the automatic feed water regulator is not in use, the feed-regulating valve must be fully open so that it cannot interfere with manual feeding of the boiler.

SINGLE-ELEMENT REGULATORS.—Single-element feed water regulators are installed primarily for the purpose of regulating boiler water level during battle or under other conditions when manual feeding of the boiler might become difficult or impossible.

Single-element regulators must be cut in immediately when General Quarters is sounded. Single-element regulators may also be used at other times. If the single-element regulators are not used for normal steaming, they should be cut in at least once each day and operated for a reasonable length of time to ensure their proper operation under emergency conditions.

When single-element regulators are used under normal cruising conditions, a checkman must remain on station and be ready to take manual control of the feed check valve. The checkman is responsible for cutting in and securing the single-element regulator and for blowing it down when necessary.

The general arrangement of a single-element feed water regulator of a type commonly used in the Navy is shown in Figure 1-14. The instructions given here apply to this particular type of single-element regulator. For information on other types of single-element regulators, consult the appropriate manufacturers' technical manuals.

The single-element regulator should be blown down about once every 24 hours and, in addition, whenever the regulator is placed in service. To blow down the regulator, open the top and bottom shut-off valves and open the blowdown valve.

The outer tube of the generator, the copper tube that connects the outer generator tube to the bellows, and the bellows are normally kept full of water. This water forms a closed system

in the regulator, separate from the water and steam admitted by the top and bottom shut-off valves. When this closed system is filled with water, cutting in the regulator is a simple process:

1. Blow down the regulator, as described before.

2. Close the blowdown valve but leave the top and bottom shut-off valves open.

3. Allow time for the generator to cool off.

4. When the generator has cooled off, release the handjack so that the valve spring will be free to close the feed-regulating valve. As you release the handjack, the regulator will begin to take over and control the opening and closing of the feed-regulating valve.

5. Open the feed check valve FULLY so that the check valve will not interfere with the flow of feed water to the boiler.

The procedure for putting the single-element regulator into service is more complicated if for any reason the closed system in the regulator is NOT full of water. In this case, the procedure is:

1. Release the handjack.

2. Disconnect the end of the tubing from the metal bellows.

3. Remove the bellows guard from the bellows.

4. Place the bellows in a container filled with water.

5. With the open end of the bellows upward, compress the bellows a number of times until all the air is removed and the bellows is completely filled with water.

6. Insert the end of the copper tubing in the container of water, with the bellows.

7. Remove the generator plug and siphon water from the container through the generator. Allow the water to run until all air has been carried out; then put the generator plug back in.

8. With the bellows under water, place the bellows guard over the bellows and connect the end bellows of the tubing to the bellows. Make sure that the bellows and the end of the tubing are completely submerged during this operation so that air cannot get into the system.

9. Replace the guard and the bellows on the valve.

10. Release the handjack so that the valve spring is free to close the feed-regulating valve.

11. Remove the generator plug and allow excess water to run out.

12. Replace the generator plug. Make sure that the plug and the connections at each end of the copper tubing are made up tight.

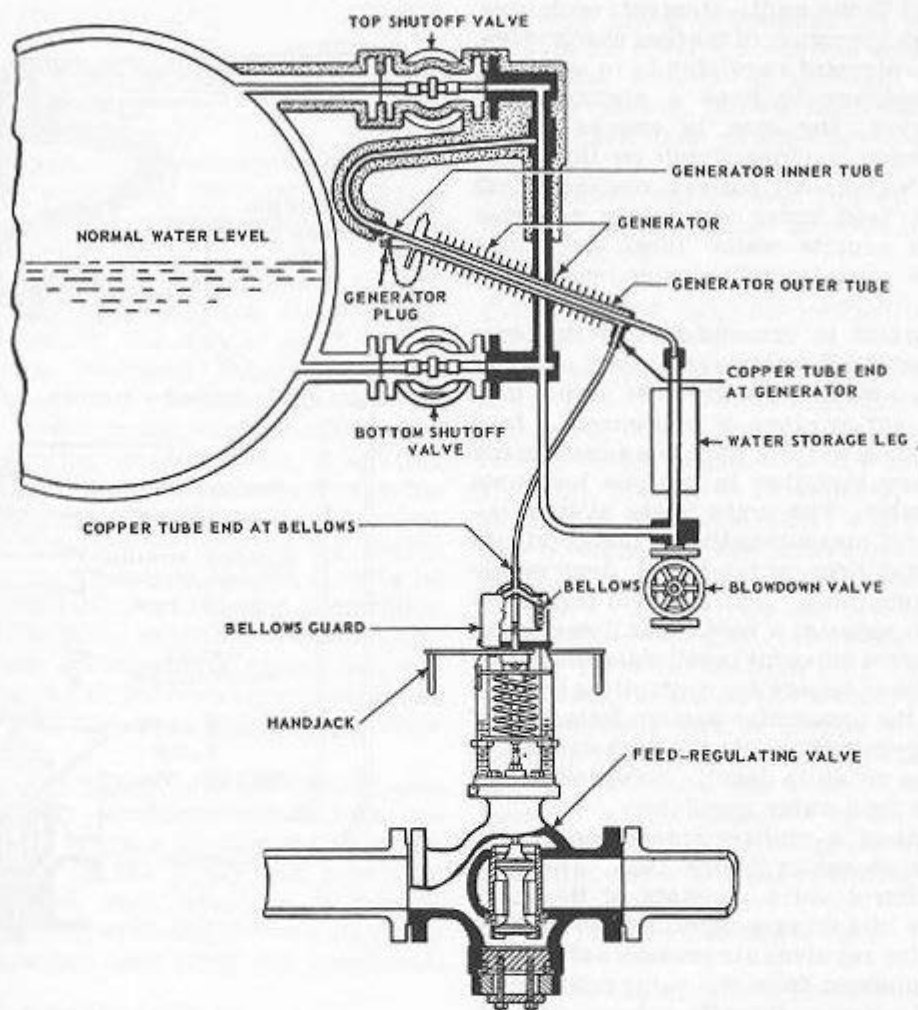


Figure 1-14.—Single-element feed water regulator.

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13. Blow down the generator (open the top and bottom shut-off valves and the blowdown valve).

14. Allow the generator to cool off.

15. Release the handjack so that the valve spring will be free to close the feed-regulating valve.

16. Open the feed check valve fully.

The single-element regulator is now in service, controlling the flow of feed water to the boiler.

To cut out the single-element regulator, the following procedure is used:

1. Close down on the feed check valve. Do NOT close the check valve completely; leave it

open enough to permit feeding of the boiler under the existing steaming conditions.

2. As the feed check valve is being partially closed, use the handjack to lock the feed-regulating valve in the wide open position.

3. Close the top and bottom shut-off valves that connect the regulator to the steam and water spaces of the drum.

The regulator is now out of service, and the water level must be controlled manually by operation of the feed check valve.

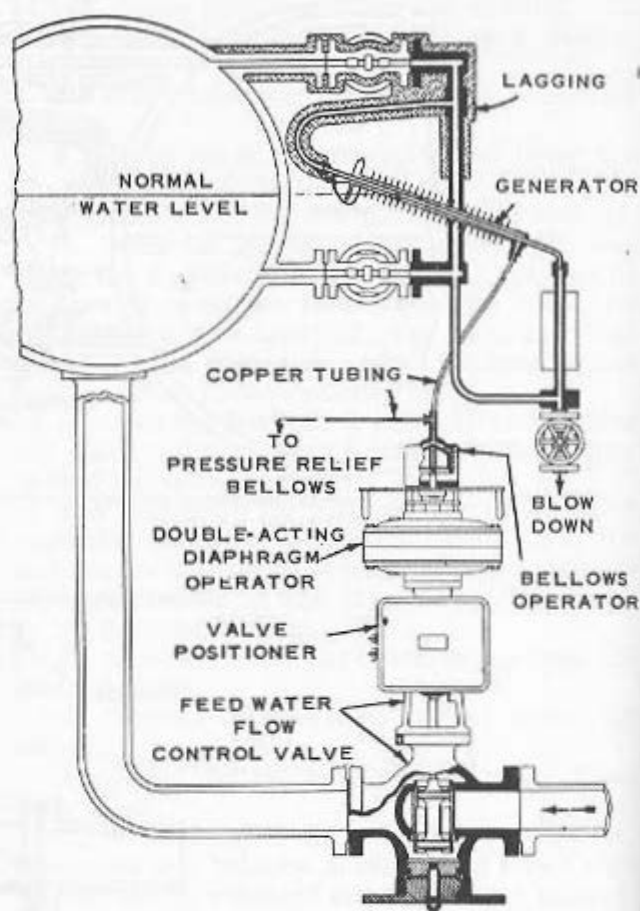
MULTI-ELEMENT REGULATORS.—When multi-element feed water regulators are installed, their use is required at all times.

Primary reliance for the control of water level must be placed in the multi-element regulators, NOT in manual operation of the feed check valve. When a multi-element regulator is in use, it is not even necessary to have a checkman on station. However, the man in charge of the watch must keep a close watch on the water level in the boiler. All boilers equipped with multi-element feed water regulators are also equipped with remote water level indicators which may be read from the lower level of the fireroom.

It is important to remember that the term "multi-element feed water regulator" actually refers to a feed water flow SYSTEM rather than to any one object or piece of equipment. A feed water flow control system includes a great many units which are installed in various locations around the boiler. The units in the system include devices for measuring the variables (steam flow, feed water flow, water level); devices for developing, combining, altering, and transmitting pneumatic signals; a feed water flow control valve and a control drive for positioning the valve; and an emergency device for controlling the feed water flow if the pneumatic system fails. All of these units together make up the feed water flow control system which is usually referred to as a multi-element feed water regulator.

Some parts of a multi-element feed water regulator are shown in figure 1-15. The feed water flow control valve consists of the valve itself and the diaphragm operator. The diaphragm operator receives air pressure above and below the diaphragm from the valve positioner. The amount of pressure from the valve positioner depends upon the pneumatic signals received by the positioner; thus the entire system acts to control the amount that the flow control valve is opened or closed.

The emergency device is also shown in figure 1-15. As may be seen, this device is very similar to a single-element feed water regulator. Under normal operating conditions, the pneumatic control system overpowers the emergency device so that the emergency device has no effect on the position of the feed water flow control valve. If the pneumatic system fails, however, the emergency device takes over and positions the flow control valve in accordance with the water level in the steam drum. Since the emergency device is controlled ONLY by the existing water level in the steam drum, it cannot control the water level as accurately as the multi-element regulator. It is therefore



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Figure 1-15.—Multi-element feed water regulator.

important to restore the multi-element regulator to service as soon as possible.

Multi-element regulators are normally operated with the system set on automatic. However, they may be operated on remote manual by manipulating the feed water selector valves at the control consoles. If a multi-element regulator cannot maintain the correct water level in the boiler, switch from automatic to remote manual. If the water level cannot be maintained by operation on remote manual, cut out the multi-element regulator, station a man at the feed check valve, and control the water level manually.

Additional information on specific feed water regulators and control systems (Bailey or Copes)

can be obtained from the manufacturer's technical manual for the installation.

AUTOMATIC CONTROL OF COMBUSTION AIR

When an automatic combustion control system is operating on automatic, the control system proportions the supply of combustion air to the amount of fuel being burned, in order to meet changing steam demands. The control system varies the supply of combustion air by automatically positioning the forced draft blower dampers and by automatically increasing or decreasing the speed of the forced draft blowers.

Even when the automatic combustion control system is operating on automatic, operating personnel may still have some control over the amount of excess air. In some systems, excess air adjustment dials are provided on the control console so that the amount of excess air may be adjusted to produce the most efficient combustion for the conditions under which the ship is operating. To increase the amount of excess air, you merely turn the dial in one direction; to decrease excess air, you turn the dial in the other direction.

If the air supply cannot be satisfactorily controlled on automatic, shift from automatic to remote manual and operate the blowers from the control console. If the air supply still cannot be properly controlled, shift from remote manual to local manual and operate the blowers manually until the trouble has been found and corrected.

CONTROL OF BOILERS FOR CROSS-CONNECTED OPERATION

Most naval ships are provided with cross-connection valves that allow either split-plant or cross-connected operation of the major engineering systems. Split-plant operation is standard for wartime operation; it is safer, since the entire engineering plant is not disabled by a casualty to one system or one piece of machinery. Cross-connected operation was until recently standard for peacetime operation, since it is far more economical than split-plant operation; however, many ships now operate split-plant under all conditions because of the safety factor inherent in split-plant operation.

When the plant is being operated cross-connected and at a comparatively steady steaming rate, with more than one fireroom in operation, there is usually one machinery space or

fireroom that is designated as the control room for each group of boilers. The boilers that are NOT in the control room are then operated with the same number of burners, the same size sprayer plates, and the same oil pressure; and minor variations of load are taken care of by changing the operation of the boilers in the designated control room. To meet larger changes of load, changes must be made in the operation of all boilers.

CONTROL OF BOILER PRESSURE

Some boilers are operated with the steam drum pressure as the constant, or controlling, pressure; others are operated with the superheater outlet pressure as the constant, or controlling, pressure. In general, boilers having pressure pilot-operated superheater outlet safety valve assemblies are operated with constant drum pressure; the superheater outlet pressure then varies according to steaming rate. However, other factors besides the type of safety valve installation may determine which pressure is best used as the controlling pressure. The engineer officer issues instructions concerning the pressure that is to be kept constant and the pressure that is to be varied. Regardless of which pressure is kept constant, the maximum steam drum pressure must not be exceeded under normal operating conditions.

LOW STEAM PRESSURE

When the ship is maneuvering (and particularly under conditions of rapid acceleration) every precaution must be taken to see that the load on the boilers does not even momentarily exceed the allowable limits. Except when a boiler is to be cut out, steam pressure must never be allowed to drop below 85 percent of the authorized operating pressure. If there is a substantial drop in steam pressure, demands for steam must be cut down drastically until the pressure has built up again to a safe point; otherwise the operation of the blowers, pumps, and other auxiliaries which control the supply of air, fuel oil, and feed water will become slower and slower, and the steam pressure will consequently drop even further. Ships have been brought to a full stop, with all fires out, as the final result of taking steam from the boiler faster than it is being generated.

A further danger in taking steam from a boiler when the pressure is below normal arises from

the fact that the specific volume (that is, the volume per pound) of steam increases as the pressure decreases. This rise in specific volume may lead to circulation difficulties in the boiler, with consequent danger of overheating.

If special circumstances should make it necessary for a boiler to continue to furnish steam after the pressure has dropped to below 85 percent of the authorized operating pressure, the boiler must NOT be operated at a rating of more than one-half of full-power capacity.

LOWERING SUPERHEAT FOR ASTERN OPERATION

On most ships it is necessary to lower the degree of superheat for astern operation, since the astern turbines are not designed for as high temperatures as the other propulsion turbines. On double-furnace boilers, the superheat is lowered by reducing the firing rate on the superheater side. On single-furnace boilers, the superheat drops as soon as steam is admitted to the astern turbines; this drop in temperature occurs because the astern turbines require a greater volume of steam than the ahead turbines, thus increasing the rate of flow through the superheater and thereby reducing the superheater outlet temperature.

Superheat temperatures to be used for astern operation vary from one installation to another. For specific information on various installations, consult chapter 9410 (41) of the Bureau of Ships Technical Manual and the technical manual furnished by the turbine manufacturer.

ROTATION IN USE OF BOILERS

From the time a ship is commissioned, care should be taken to operate the boilers on a schedule that will give approximately the same total steaming hours for each boiler. It is good engineering practice to stagger the steaming hours of the boilers between cleaning periods, so that all boilers will not require cleaning at the same time; but this can be done in such a way that the total steaming hours for all boilers will remain approximately the same.

EFFECT OF STEAM CATAPULT OPERATION

On carriers equipped with steam catapults, the operation of the ship's boilers may present special problems during catapult launchings.

Most of these problems arise from the fact that when the steam accumulators are being charged there may be sudden and very large demands for steam, similar to the demands made during rapid maneuvering. These severe demands for steam result in fluctuations of steam drum pressure, superheater outlet pressure, and water level.

Under emergency conditions, the demand for steam can be so sudden that there is a possibility of excessive moisture carryover. If the emergency steam demands are to continue for any length of time, excessive carryover can be avoided by beginning the charging operation with a water level that is very slightly (perhaps 1 to 2 inches) below normal. If this practice is followed, however, great care must be taken to see that the initial water level is not too low, since there would then be danger of the water level dropping out of sight in the gauge glass.

Part of the steam demand is, obviously, for steam to fill the accumulator of the steam catapult itself; but along with this expected requirement goes a surprisingly large increase in the steam required for the operation of the auxiliary machinery. Over a wide range, the main feed pumps, forced draft blowers, and other vital auxiliaries will be operating intermittently. Particular care must be taken, therefore, to observe the operation of these auxiliaries during steam charging operations.

Before catapult operations are begun, the settings of the automatic boiler controls should be checked to make sure that all units are set in accordance with the manufacturer's recommendations. Proper setting of the units in the control systems will ensure an adequate supply of steam to all auxiliaries controlled by the control systems and, at the same time, will ensure that the additional steam supplied to the auxiliaries is kept to the minimum that is actually required.

IN-PORT STEAMING

The procedures and precautions for in-port steaming are, in general, much the same as for underway steaming. However, a few special considerations should be noted.

Particular care must be taken during in-port steaming to keep the economizers free of soot. The sparky fires that are most prevalent at low firing rates tend to cause the rapid accumulation of soot on the economizer tubes and

gill rings. Occasionally this soot catches fire and burns, thereby melting the aluminum gill rings and causing damage to the economizer elements. Preventive measures include (1) proper control of combustion air, to prevent sparky fires; and (2) frequent removal of soot from the economizer by use of the soot blowers.

Care must also be taken, in port as well as underway, to ensure an adequate supply of water to the economizer at all times. As long as a boiler is furnishing steam, the feed supply must NEVER be shut off even for a short time.

In single-furnace boilers, all steam generated is passed through the superheater tubes; thus, the superheater is protected at low steaming rates as well as at higher rates. The superheater on a double-furnace boiler requires special protection, however, since it is possible to take auxiliary steam directly from the steam drum, without passing it through the superheater. When there is no steam flow through the superheater, particular care must be taken to see that the maximum allowable firing rate for the saturated side is not exceeded. Because of the possibility of damage to the superheater, it is desirable to maintain a steam flow through the superheater even when the superheater side is not lighted off. As a rule, therefore, ship's service generators are operated on steam taken through the superheater of the boiler even if the superheater side is not lighted off. Some ships are fitted with special turbogenerator steam lines from the superheater outlet of divided-furnace boilers. Where such turbogenerator lines are not fitted, a section of the main steam line may be used, PROVIDED that the steam piping system is so arranged that the steam can be kept from entering the gland system of the propulsion turbines.

A variety of factors tend to cause condensation in the superheater when only the saturated side of a double-furnace boiler is in use. The drain to the open drain system or to the bilges may be used during the lighting-off period; after that, the connection to the high-pressure drain system should be opened to ensure complete drainage of the superheater at all times that the boiler is under steam. As a further precaution against condensation in the superheater, particular care must be taken to see that the air registers on the superheater-side furnace are tightly closed when the superheater side is not lighted off.

SECURING BOILERS

Procedures for securing boilers are specified by the Naval Ship Systems Command, the engineer officer, and the boiler manufacturer. The following instructions for securing boilers apply in general to most modern naval boilers. Special additional instructions and precautions for various types of boilers are given after the general procedure has been indicated.

GENERAL INSTRUCTIONS

In general, these are the steps to be taken in securing a boiler:

1. Blow tubes, after permission has been obtained.
2. Close the atomizer valves, one at a time, and at the same time close the air registers.
3. Shut off the steam to the oil heater, to prevent excessive heating (and consequent carbonizing) of the oil as the flow is reduced.
4. Slow down the fuel oil service pump as the burners are being secured, to prevent an excessive build-up of pressure.
5. When all burners have been secured, stop the fuel oil service pump.
6. Slow the forced draft blowers.
7. Open the fuel oil recirculating valves and leave the fuel oil system lined up as though for recirculation, until the fuel oil heaters have cooled. This procedure will allow the hot oil in the heaters to expand without causing the relief valves to lift.
8. Remove the atomizer assemblies and clean them as soon as possible.
9. When all boilers in a fireroom are being secured, run one blower for a long enough time after the fuel oil supply has been shut off to ensure that all oil on the furnace floor is consumed and that the furnace is cleared of all gases of combustion. When all boilers in the fireroom are not being secured, it will be necessary to leave one or more blowers in operation.
10. Close the furnace tightly, to keep cool air from flowing into the hot furnace. Sudden cooling can cause extreme damage to the refractories and to the tubes. This precaution is particularly important, of course, if one or more blowers must remain in operation in the fireroom; but it should be observed even if all blowers are secured.
11. When the boiler has cooled enough so that it is no longer generating steam, open the

superheater protection outlet valve and close the boiler steam stops and fill the boiler to the three-fourths level in the water gage glass.

12. Secure the feed pumps and the feed system, when feed water is no longer needed. CAUTION: Do NOT secure the feed system while the boiler is still generating steam.

13. Flush and pump out the bilges, PROVIDED this can be done without violation of the Oil Pollution Act.

14. Clean out the accumulated oil in all drip pans, and wipe down all machinery and floor plates. Clean out any oil accumulations on the floor between the double casings, wipe down any drips on the air casings, and repair leaks.

15. When all fires are out in all boilers leading to one stack, and when the stack has cooled sufficiently, put on the stack cover.

SECURING SINGLE-FURNACE BOILERS

When securing a single-furnace boiler, it is important to open the superheater protection exhaust valve BEFORE the steam flow through the superheater has stopped. This valve should be kept open until the steam drum pressure has dropped to 100 psig or less.

SECURING DOUBLE-FURNACE BOILERS

The procedure for securing a double-furnace boiler varies slightly according to the number of boilers that are on the line at the time of securing. If only one boiler is on the line, the superheater outlet temperature should be dropped to approximately 700° F as the anchorage or mooring is approached; this gives the proper degree of superheat for backing as well as for going ahead. The superheat should be secured entirely when the main turbine and turbogenerator requirements are insufficient to ensure a safe steam flow through the superheater.

With more than one boiler on the line, the procedure for cutting out one double-furnace boiler is as follows:

1. Drop the superheat temperature to about 600° F, at the rate of about 50° F every 5 minutes.
2. Shift the load to the other boiler or boilers on the line.
3. Secure the superheater-side fires.
4. Secure the saturated-side fires.
5. Close the boiler steam stop valves.

6. Shift from the superheater high-pressure drains to the gravity (open-funnel) drains; crack the gravity drain root valve on the superheater manifold and bleed steam to the bilges until the boiler has stopped generating steam; OR

Use the steam from the boiler being secured to run the emergency feed pump or the main feed pump, to maintain the water level at three-fourths glass in the boiler being secured. This method of using the steam that is generated while the boiler is being secured is preferable in many installations, since bleeding steam to the bilges is not always feasible.

SECURING HIGH-PRESSURE BOILERS

Special instructions for securing high-pressure boilers will be found in the manufacturer's technical manuals. It is essential that all special or supplementary instructions be followed carefully, particularly for boilers having automatic combustion control.

FIREROOM SAFETY PRECAUTIONS

The importance of safety in the fireroom cannot be overemphasized. You must be completely familiar with all precautions to be observed in operating boilers and fireroom auxiliary machinery.

Safety precautions to be observed in connection with the operation of boilers and fireroom auxiliary machinery are given in the Bureau of Ships Technical Manual and in the manufacturer's technical manual for the boilers on your ship. Additional safety precautions may be prescribed by the engineer officer. Some of the most essential safety precautions relating to boilers are given here.

The following precautions must be observed PRIOR TO PLACING A BOILER IN SERVICE:

1. Make all prescribed tests of safety valves.
2. Test all automatic safety devices to make sure they are operating properly.
3. In lighting off, run the water just out of sight in the bottom of the water gage glass. Then use the emergency feed pump to bring the water up to about 1 inch in the glass.
4. Always blow through the furnace with air before lighting off. Always blow through the furnace before relighting burners, after atomizers have been extinguished.

5. Always use a torch for lighting off. Stand well clear to avoid injury from a flareback.

6. Make sure the torch pot is firmly secured and that it is not too full of oil.

7. On or before lighting the first burner on a single-furnace boiler, open the superheater protection steam valves (if fitted) or otherwise establish a positive flow of steam through the superheater.

8. Never light a burner on the superheater side of a double-furnace boiler until one or more burners are in operation on the saturated side. Never light a burner on the superheater side until you are SURE there is an adequate flow of steam through the superheater.

The following precautions must be observed WHILE THE BOILER IS IN OPERATION:

1. Do not exceed the authorized maximum steam drum pressure.

2. Do not leave disconnected atomizers in place.

3. At least once each hour, test the fuel oil heater drains.

4. Do not use fuel oil that is contaminated with water.

5. If fuel oil service pump suction is lost, close the boiler stops before the steam pressure drops to 85 percent of authorized working pressure.

6. In securing a boiler, do not close the master fuel oil valve until the pump is secured, except in an emergency.

7. As long as a boiler is furnishing steam, do not shut off the feed supply even for a short time.

8. Blow through the water gage glasses at the prescribed intervals.

9. Observe the following precautions to reduce the danger of fires and flarebacks:

a. Do not allow oil to accumulate in the furnace.

b. Wipe up spilled oil immediately.

c. If burners are suddenly extinguished, shut off the oil supply and blow through the furnace with air.

d. Do not use large amounts of excess air.

e. Always use a torch to light off the first burner. Always use a torch to light off additional burners until the furnace becomes intensely hot. Never attempt to relight burners from hot brickwork.

f. When lighting off a burner, stand clear to avoid injury if a flareback should occur.

10. Be sure there is an adequate steam flow through the superheater at all times.

11. On double-furnace boilers, do not exceed the specified rate of raising and lowering superheat—about 50° F every 5 minutes.

12. If the water drops out of sight in the water gages, shut off the oil supply or kill the fires, ease open the safety valves cautiously to relieve the boiler pressure gradually, close the boiler stop valves, close the feed check valve, and close all openings into the boiler.

13. If practicable, cut out a boiler at once if a brick falls out of the furnace wall. If it is necessary to continue the boiler in operation until another one can be brought in on the line, cut out the burners that are near the place where the brick has fallen out.

14. Never empty a boiler with bottom blow, except in an emergency. Never blow down division wall headers, water screen headers, and water wall headers until after all burners have been secured.

15. When securing a boiler, open the discharge connection to the auxiliary exhaust before closing the main and auxiliary steam stops.

16. When securing a double-furnace boiler, secure the superheater-side burners before securing the saturated-side burners. Reduce steam pressure slowly.

The following precautions should be observed AFTER THE BOILER HAS BEEN SECURED:

1. Remove atomizer assemblies as soon as possible.

2. Close all openings to the furnace after all burners have been extinguished.

3. After the boiler has stopped generating steam, fill the boiler to the three-fourths level in the water gage glass and close the feed stop and check valves.

4. Before removing any fittings or parts under pressure, and before loosening a manhole or handhole plate fitting, take steps to ensure the complete absence of pressure and the complete absence of hot water. Open the aircock and the superheater vents and drains, and test the blowdown from the upper water gage cutout valve.

CHAPTER 2

BOILER MAINTENANCE

The engineer officer must keep himself fully acquainted with the general condition of each boiler and the manner in which each is being operated and maintained. He must satisfy himself, by periodic inspections, that the exterior and interior surfaces of the boiler are clean; that the refractory linings adequately protect the casing, drums, and headers; that the integrity of the pressure parts are being maintained; and that the operating condition of the burners, safety valves, operating instruments, and other boiler appurtenances are satisfactory.

The engineer officer must assure himself that the idle boilers are properly secured at all times, and while steaming, the fuel oil used is free of sea water, and the feed water is within prescribed limits, free of salts, entrained oxygen, and oil.

All parts of the boiler must be carefully examined whenever they are exposed for cleaning and overhauling, and the conditions observed must be described in the boiler record sheet and the engineering log. All unusual cases of damage or deterioration discovered at any time should be reported to the type commander, stating in detail the extent of injury sustained, remedies applied, and the causes, if determined. If considered of sufficient importance, or technical assistance is desired from the Naval Ship Systems Command, a copy of the correspondence should be forwarded to the Naval Ship Systems Command.

Care of boiler watersides and firesides, important maintenance factors, and tests and inspections of boilers are discussed in the sections which follow.

CARE OF BOILER WATERSIDES

It is of utmost importance for the engineer officer to assure that the watersides of boilers

are maintained free from scale, oil, or accumulations of sediment. Failure to keep boiler watersides clean reduces the efficiency of the boiler and contributes to overheating which may lead to serious damage. Experience has shown that tube failures resulting from defective materials or poor fabrication are rare. The majority of all tube failures, other than those associated with water-level casualties, are caused by waterside deposits or accumulations. Some tube failures are caused by waterside deposits of hard scale. More frequently, however, tube failures occur as the result of an accumulation of relatively soft materials such as metal oxides, the residue of chemicals used for boiler water treatment, and the solids formed as a result of the reactions between scale-forming salts or other impurities and the chemicals used for boiler water treatment. (NOTE: Tube failures are discussed later in the chapter.)

FREQUENCY OF CLEANING WATERSIDES

With the exception of boilers on certain designated ships, naval boilers must not be steamed for more than 1800 (or at most 2000) hours between successive mechanical cleanings of the watersides. The engineer officer, being familiar with the conditions under which the boilers have been operating, will be able to determine if cleaning at less than 1800 hours is necessary. In addition, boilers should be cleaned on the watersides whenever there is any reason to suspect that scale or other material has accumulated in drums, headers, or tubes.

Whenever a boiler is opened for any reason, it is good engineering practice to hose down all accessible parts of the watersides. However, this type of water washing is NOT a substitute for the required mechanical cleaning of watersides. A notation must be made in the boiler record sheet each time the boiler is opened. The notation should include the reason opened,

whether washed down, and whether mechanically cleaned.

At each regular watersides cleaning period, all waterside surfaces except superheater tubes must be mechanically cleaned. Superheater tubes are usually cleaned only at alternate cleaning periods. However, they must be inspected at the other cleaning periods and must be completely cleaned if necessary.

The Naval Ship Systems Command has authorized an extended schedule of waterside cleaning for the boilers on certain ships. The "extended schedule" is not actually a schedule; the length of time between cleanings depends upon the condition of the boiler. Boilers on the extended schedule of cleaning are cleaned chemically, rather than mechanically. The extended schedule of waterside cleaning began as an experimental program which at first involved only a few ships. Several years of experience have indicated that boilers can be kept in excellent condition on the extended schedule, provided certain requirements are met. Correct water treatment is vitally important for all boilers, but particularly so for boilers on the extended schedule of waterside cleaning. As the success of the extended schedule has been demonstrated, additional ships have been included in the program. A number of combatant ships now operate on the extended schedule of waterside cleaning.

Special requirements for boilers on the extended schedule include:

1. Boilers must be clean to start with. Initial cleanliness of the boilers is obtained by boiling out, followed by chemical cleaning.

2. Boilers must be in good condition. After chemical cleaning, the boiler must be hydrostatically tested and all pressure parts must satisfactorily meet the requirements of the hydrostatic test. Leaky tubes must be renewed. All manhole and handhole gaskets must be renewed. Valves and boiler fittings must be in good condition. There must not be any active pitting or corrosion in any part of the boiler. There must not be any history of gross leakage at handhole fittings.

3. Boilers must be inspected regularly. All ships assigned to the extended schedule must continue to inspect boiler watersides after each 1800 to 2000 hours of steaming, or more frequently if considered necessary. Special inspections of boiler watersides must also be made when the ship undergoes a regular overhaul.

Details of waterside inspections are discussed later in the chapter.

4. The boiler water and the feed water must meet the special standards prescribed for boilers on the extended cleaning schedule.

5. The boiler water must be kept clean by frequent use of blowdown. Boiler water samples should be so clean that they have the appearance of drinking water. Another indication that may be used as a guide for the need for blowdown is the total dissolved solid content of the boiler water. Total dissolved solids are measured by an electrical conductivity meter on some new ships that have 1200-psi boilers. The reading obtained on the conductivity meter indicates the efficiency of the blowdowns and also indicates whether more frequent blowdowns are needed. On ships that are not furnished with conductivity meters, the results of the chemical water tests are used as a guide for the need for blowdown.

6. Oxygen must not be allowed to enter the watersides of steaming or idle boilers. Dissolved oxygen in the feed water and boiler water can be prevented by proper attention to the mechanical details of the deaerating feed tank and by proper operation of the tank. Dissolved oxygen tests made aboard ship must be checked by shipyard chemists or tender personnel. Idle boilers must be laid up in the prescribed manner in order to ensure the absence of air in the watersides of idle boilers.

7. Boiler record sheets must be carefully reviewed. If the boiler record sheet is accurately maintained and carefully analyzed, it should reveal waterside difficulties long before there are any visible effects on the boiler watersides.

8. Ship's personnel must inform official boiler inspectors and shipyard personnel that the boilers are on the extended, rather than the regular, schedule of watersides cleaning. Advance information on this point enables shipyard personnel to plan for the chemical cleaning that is required for boilers on the extended schedule.

PROCEDURES FOR CLEANING WATERSIDES

The watersides of naval boilers may be cleaned in two ways: (1) mechanically, by thorough wirebrushing of all drums, headers, and tubes, and (2) chemically, by circulating chemical cleaning solutions through the boiler.

Mechanical Cleaning

Before mechanical cleaning of watersides is begun, the internal fittings must be removed

from the steam drum. The fittings (particularly the steam separators and apron plates) must be marked or otherwise identified as to position in the steam drum to ensure their correct reinstallation. All internal fittings must be wirebrushed and cleaned before they are reinstalled. Additional information concerning internal fitting is given later in the chapter.

At present three types of tube cleaners are approved for use in cleaning boiler watersides. Two types are approved for general shipboard use; the third type is used only at naval shipyards and on repair ships and tenders.

The Type 1 cleaner is electrically driven. It consists of an electric motor, a flexible shaft in a flexible casing, a flexible brush holder, and an expanding wire bristle brush. This type of cleaner is provided for general use.

The Type 2 cleaner is driven by an air motor. This cleaner consists of the air motor, an air hose, a flexible brush holder, and an expanding wire bristle brush. The Type 2 cleaner is usually the preferred cleaner for general use.

The Type 3 cleaner is also driven by an air motor. This cleaner is about the same as the Type 2 cleaner except that solid steel cutting wheels with serrated edges are used in the Type 3 cleaner. Type 3 cleaners are supplied only to repair ships, tenders, and naval shipyards. An inexperienced operator can do serious damage to boiler tubes with a Type 3 cleaner, so the use of this cleaner is discouraged.

Operating procedures are much the same for the three types of tube cleaners. The discussion

in this chapter deals only with the operation of the Type 2 cleaners. A Type 2 tube cleaner is shown in figure 2-1. Figures 2-2 and 2-3 show two types of wire bristle brushes that may be used in the Type 2 tube cleaner. Figure 2-4 shows a brush refill for the brush shown in figure 2-2.

Before beginning to clean tubes, be sure that adequate ventilation and lighting have been arranged. (If portable lights are used, they must be of the approved explosion proof type.) In addition, be sure that the air motor, the flexible shaft, and the wire bristle brushes are tight, clean, and in good operating condition. A written checkoff list of all tools and equipment taken into the watersides should be maintained, and the tools removed from the watersides. There have been many tube failures immediately after a cleaning job, as the result of tools or rags being left in the boiler.

With the air shut off, insert the tube cleaner in the tube until the brush is about even with the far end of the tube. Wrap friction tape, a rag, or some other marking material around the hose to indicate how far the tube cleaner can be inserted without having the brush protrude beyond the far end of the tube. Then remove the cleaner from the tube. Although there are many rows of tubes of various lengths, the tubes in each horizontal row will be the same length. Therefore, separate markings will have to be made on the hose for each row of tubes.

After the hose has been marked, insert the brush in the tube and turn on the air to start the

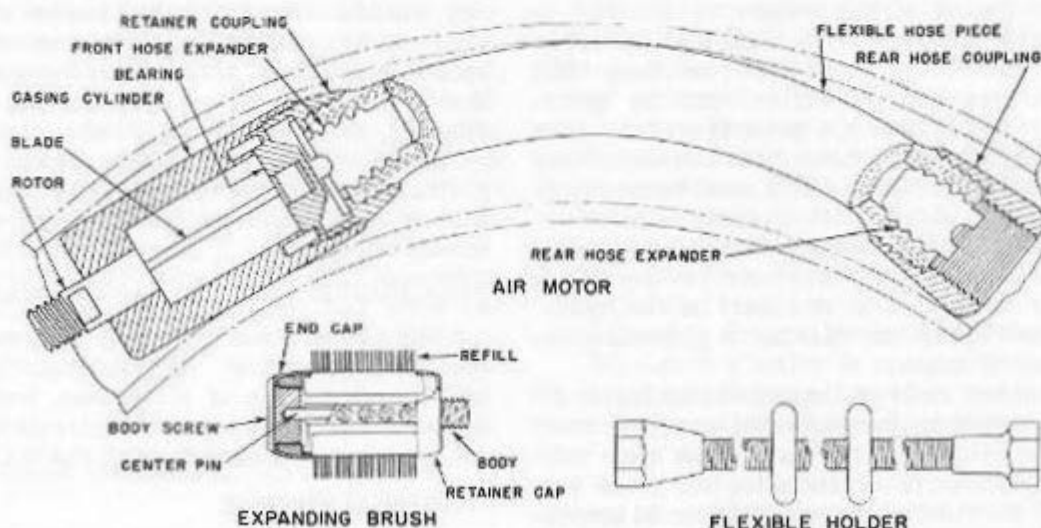
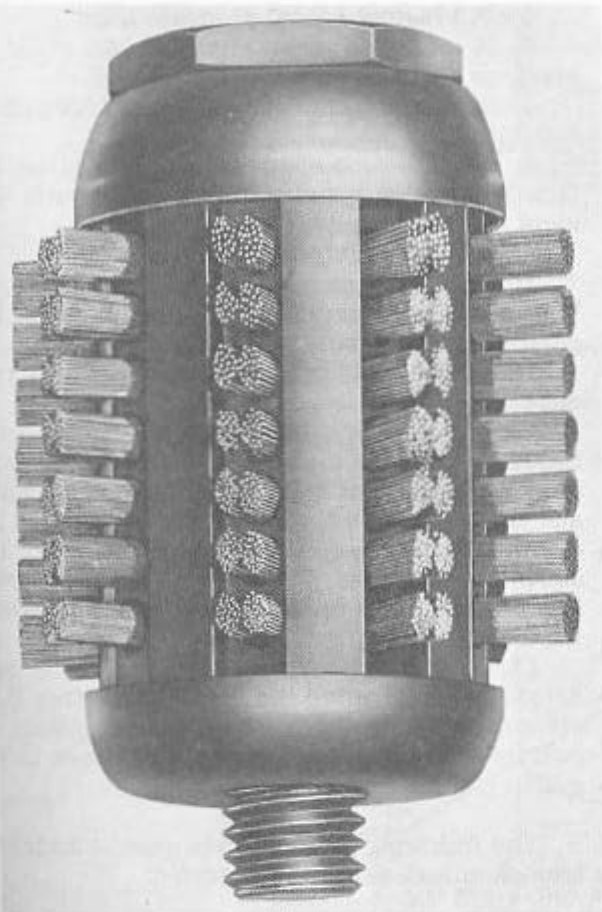


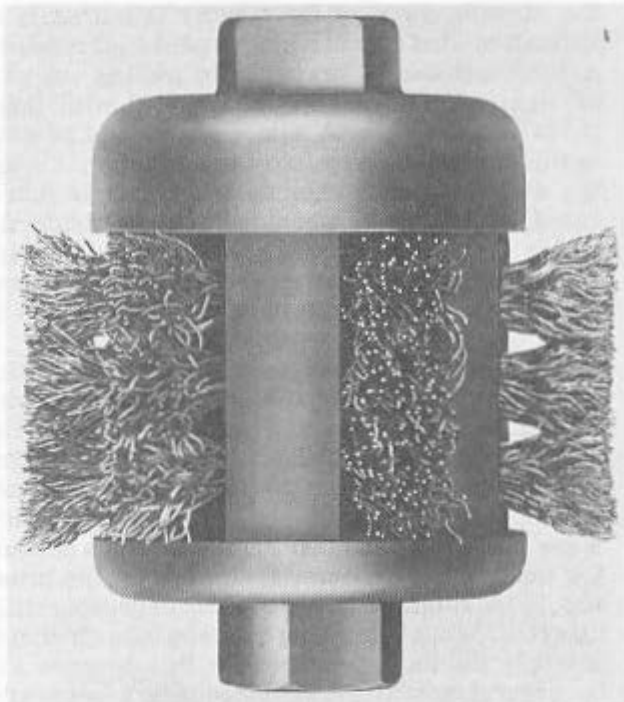
Figure 2-1.—Boiler tube cleaner (Type 2).



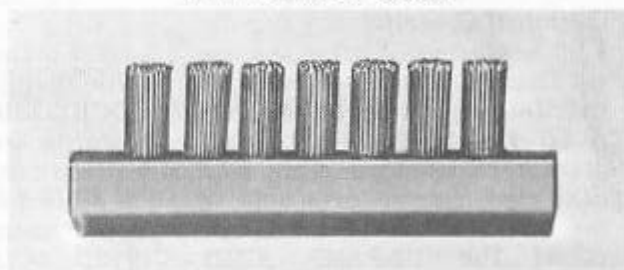
38.193
Figure 2-2.—Wire bristle brush for cleaning generating tubes.

brush rotating. Pass the brush **SLOWLY** along the length of the tube until the identifying mark has been reached. Then slowly draw the brush back, withdrawing the cleaner from the tube. Proceed in the same way with the rest of the tubes in the row. It is not necessary to shut off the air to the tube cleaner each time the cleaner is withdrawn from a tube. However, be sure to steady the brush assembly with your hand to keep the cleaner from whipping. Allowing the brush to whip at either end of the tube is the most common cause of broken tube cleaners.

Establish a new mark for the next row and proceed with the cleaning. Make as many passes as necessary through each tube to ensure adequate cleaning. Be careful not to stop the tube cleaner in any one place in the tube, as the continued rotation of the brush in one place might damage the tube.



38.194
Figure 2-3.—Wire bristle brush for cleaning large tubes.



38.195
Figure 2-4.—Brush refill.

Tube cleaning is most easily accomplished from the steam drum. However, some rows of tubes are not accessible from the steam drum and must be cleaned from the water drum or header. The lower ends of **ALL** tubes must be cleaned from the water drum or header. However, if tubes are bent in such a way that brushes cannot be forced around the bend without breaking the tube cleaner, these tubes will be cleaned from both ends.

The air motor of the Type 2 cleaner requires lubrication after about 10 minutes of operation. By noting the speed of operation, it can be determined that the air motor needs lubrication;

the slowing down of the cleaner is normally an indication that the air motor needs lubrication. A lubricant can be prepared by mixing one part of light machine oil (symbol 2110) with three parts of kerosene. A squirt can should be used to inject this mixture into the air motor, through the exhaust ports. After the air motor is lubricated, the cleaner should be held outside the boiler drum and operated until there is no sign of lubricant in the exhaust stream. Be very careful that no lubricant gets in the boiler tubes or drums.

Tube cleaners must be kept in good operating condition. The rotor and blades of the air motor should be kept clean and well lubricated. The hose connections should be kept tight and free from leaks. The whips or flexible shafts should be inspected frequently and renewed if they show signs of wear or damage. If the brushes become too worn to work efficiently, the body of the brush should be retained and a new set of brush refills inserted. When replacing parts on tube cleaners, use only the tools provided for this purpose and be careful not to exert unnecessary pressure. Store tube cleaners in a clean, dry container. Wrap the turbine rotor and casing in a slightly oily rag to prevent rusting.

Chemical Cleaning

There are two methods approved for chemical cleaning of watersides. The HYDROCHLORIC ACID method is used by naval shipyards and private contractors. This method utilizes concentrated hydrochloric acid which is diluted to the required strength through a proportioning valve. The SULFAMIC ACID - CITRIC ACID method is designed for use by forces afloat. Only the sulfamic acid - citric acid method is discussed here.

The following equipment is required for cleaning watersides by the sulfamic acid - citric acid method. Detailed information on sizes, materials, and federal stock numbers of this equipment is given in the latest Naval Ship Systems Command instruction that deals with chemical cleaning of boiler watersides.

1. A motor-driven acid-resistant pump.
2. A 20-foot length of acid-resistant suction hose.
3. A 250-foot length of acid-resistant discharge hose.
4. A 450-foot length of acid-resistant return hose.

5. A 175-foot length of steam hose.
6. A portable acid mixing tank, stainless steel, or the type shown in figure 2-5.
7. A "spent acid" tank of about 1500 gallons capacity.
8. Enough rubber aprons, rubber gloves, and face shields or goggles to protect all men who must handle the acid.
9. A combustible gas indicator.
10. A hydrogen vent hose, 3/4-inch ID and long enough to meet the requirements of the particular situation.
11. Cylinders of water-pumped (oil-free) nitrogen.
12. Appropriate quantities of the chemicals required to make the strong descalant solution, the mild descalant solution, and the passivating and neutralizing solution. Table 2-1 shows the quantities of chemicals required to make the descalant solutions; table 2-2 shows the quantities of chemicals required to make the passivating and neutralizing solution.
13. Appropriate quantities of sodium hydroxide to neutralize the spent acid before it is discharged overboard. Two hundred pounds of sodium hydroxide are required for each 1500-gallon tankful of spent acid.

The following preparations must be made before chemical cleaning is started:

1. Close, tag, and lock (or securely wire) all valves that allow water or steam to enter the boiler.
2. Drain the boiler.
3. Open the boiler and inspect it carefully for the presence of oil. If any oil is found, remove it by boiling out the boiler in accordance with prescribed procedures.
4. Blank off the superheater and the economizer, unless inspection reveals that scale is present in the tubes. (This is not very likely.) Stainless steel superheaters must not be chemically cleaned without prior approval of Naval Ship Systems Command.
5. Blank off all gages and valves that will not be used during the acid circulation.
6. Remove the safety valves.
7. If the desuperheater is made of a 16 percent chromium and 1 percent nickel alloy, remove the desuperheater. Protect the nozzle by applying two coats of a special paint (specification MIL-P-23236, Type I, class 2) to the surfaces of the 16-1 flanges and to the adjacent stainless steel welds. Allow the first coat to

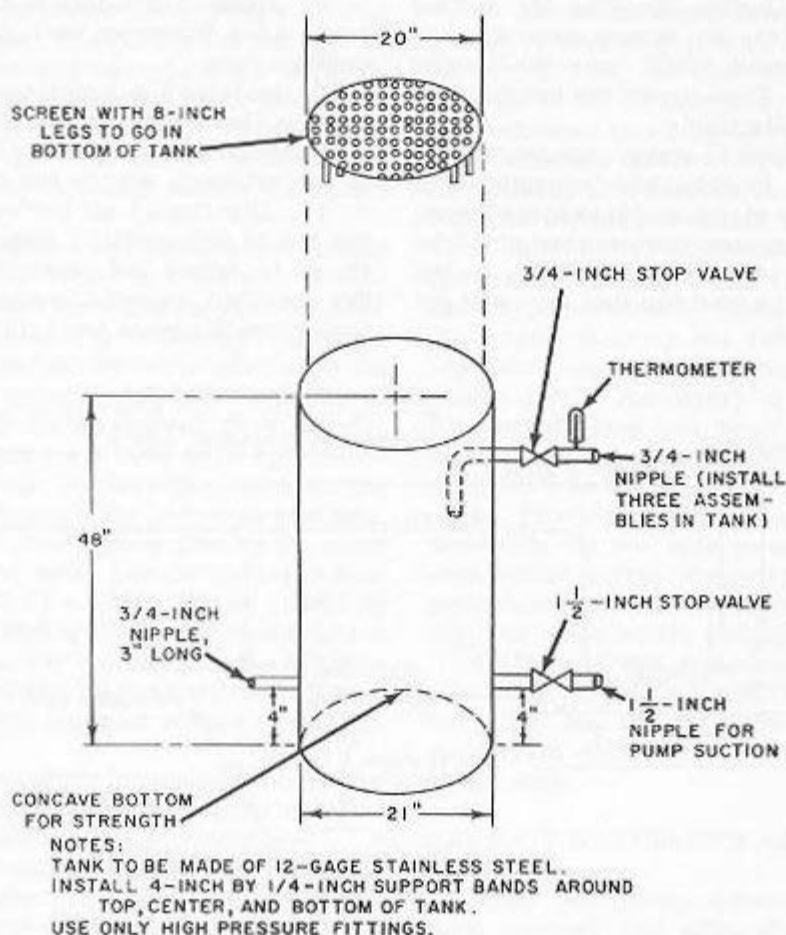


Figure 2-5.—Acid mixing tank.

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Table 2-1.—Chemicals Required for
Descalant Solutions.

98.66.0

CHEMICAL	QUANTITY REQUIRED FOR EACH 1000 GALLONS REQUIRED TO FILL BOILER	
	Strong Solution (12 percent)	Mild Solution (0.24 percent)
Sulfamic acid.	900 pounds	18.0 pounds
Citric acid	60 pounds	1.2 pounds
Diethylthiourea	40 pounds	0.8 pounds

Table 2-2.—Chemicals Required for
Passivating and Neutralizing Solution.

98.66.0

CHEMICAL	QUANTITY REQUIRED FOR EACH 1000 GALLONS REQUIRED TO FILL BOILER
Sodium nitrite	42 pounds
Monosodium phosphate	21 pounds
Disodium phosphate	21 pounds

dry for 24 hours before applying the second coat; or, to shorten the drying period, blow warm dry air at about 100°F over the flanges for about 6 hours. Then apply the second coat and allow it to dry similarly.

8. Dismantle several steam separators and ALL apron plates, to facilitate inspection both before and after the cleaning. Place these items, together with a representative screen row tube that has been cut into 3-foot sections, in the steam drum in such a position that they will not cover the tube holes.

9. Attach a 3/4-inch hose to the air cock to serve as a hydrogen vent. Lead the hose to the weather deck.

10. Install a 3/4-inch tee on a safety valve connection. One branch of the tee serves as an acid recirculating line; the other branch is connected to the nitrogen supply for emptying the boiler.

11. Disconnect all bottom blow valves from the boiler and install a temporary manifold, as shown in figure 2-6. Install a tee at one end of the manifold, valved to permit the alternate introduction of steam and acid solution.

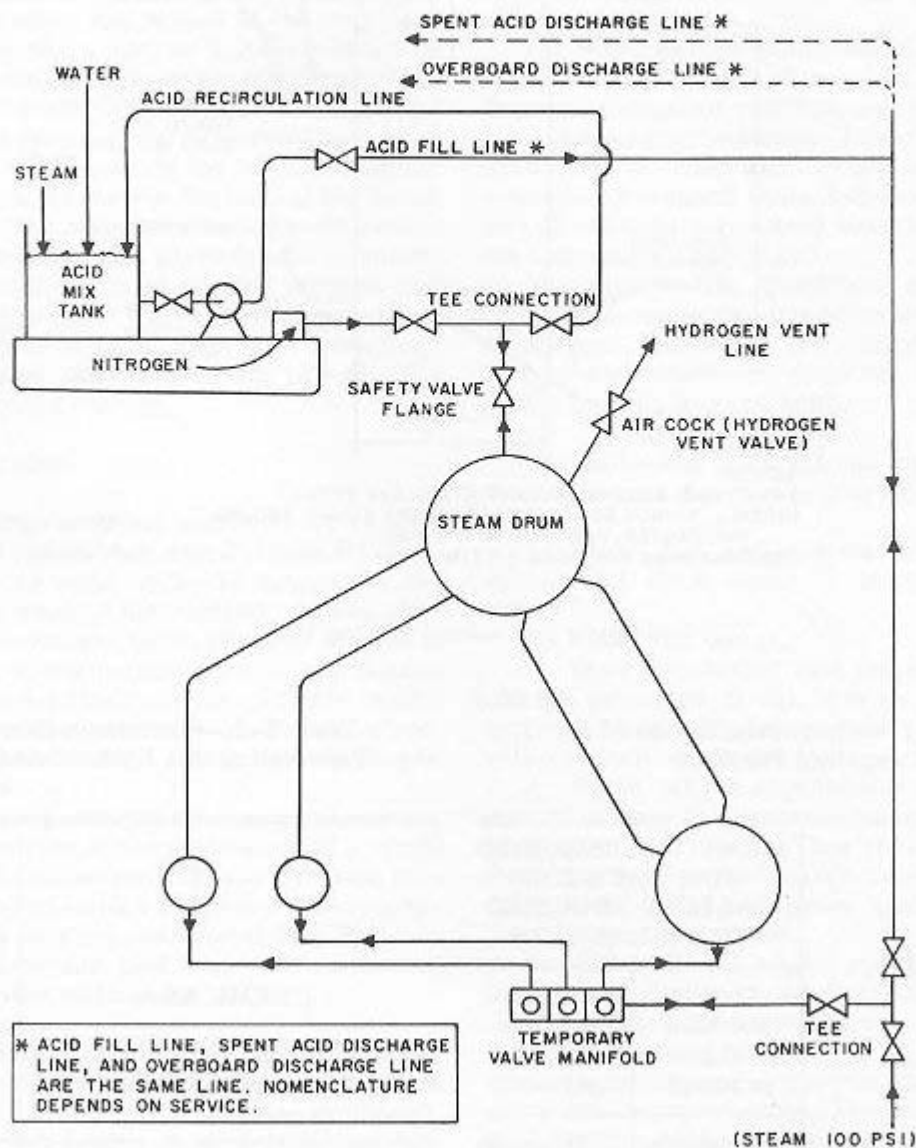


Figure 2-6.—Arrangement for chemical cleaning of watersides by sulfamic acid—citric acid method.

98.67

12. Close up the boiler and give it a hydrostatic test to 150 psi. The purpose of this test is to make sure there will be no leakage when the acid solution is being circulated. When the economizer and the superheater are not to be cleaned (as is usually the case) fill them with deaerated feed water and keep them full during the entire cleaning operation.

13. Drop the boiler water to normal steaming level and preheat the boiler to $175^{\circ}\text{F} \pm 5^{\circ}\text{F}$ by admitting steam through the temporary bottom blow manifold. Take temperature readings by placing a dial thermocouple against bared places on the steam drum, the water drum, and the headers. The boiler should be preheated very evenly. Maintain the preheat for 1 hour before proceeding to the next step. Relieve pressure on the boiler by venting through the hydrogen vent line.

14. Locate the acid mixing tank on the most convenient weather deck. Locate the large tank for the spent acid in a place where it will be convenient for receiving the discharged solution from the boiler and for discharging the solution overboard. Connect the lines as shown in figure 2-6, keeping the acid lines as short as possible.

After all preparatory measures have been taken, clean the boiler in accordance with the Naval Ship Systems Command procedures.

The following safety precautions must be observed when boilers are being cleaned by the sulfamic acid—citric acid method:

1. The boiler to be cleaned must be isolated from all other feed and steam systems. All leaky valves must be blanked off. Any valve that would have steam on one side and the descalant solution on the other side must be blanked off from the solution. All controls and instruments must be isolated from the descalant solution.

2. Appropriate measures must be taken to protect personnel from contact with the chemicals. All of the chemicals used could be harmful, particularly to eyes and skin. Face shield should be worn by any person who is dumping the chemicals into the mixing tank. Rubber shoes, rubber gloves, rubber aprons, and hats should be worn by all personnel concerned with the cleaning operation. Foul-weather gear is suitable.

3. Obtain medical attention immediately if acid gets into the eyes. Be sure that a plentiful supply of fresh water and baking soda is available in the fireroom and near the acid mixing tank to wash off any acid that gets on the skin.

4. All precautions must be taken to prevent hydrogen explosions. The boiler must be filled to overflowing, so that the descalant solution returns to the mixing tank, in order to push out any hydrogen that may be released by the chemical cleaning. The hydrogen must be vented to atmosphere at a safe location; the vent line must NEVER terminate inside the ship's hull. The vent must be installed at the highest point of the boiler, as shown in figure 2-6. Smoking, burning, and welding must not be permitted in the fireroom or in the immediate vicinity, or anywhere near the acid tanks or other equipment. If it is necessary to enter the boiler before passivating has been completed, use non-sparking tools, clothes, and lights. Naked lights must NOT be used.

5. Provide continuous safety watches in the fireroom, at the acid mixing tank, and at the vent outlet during the entire chemical cleaning procedure, to enforce the no smoking, no welding, and other safety precautions.

6. During the chemical cleaning process, run the fireroom ventilation supply blowers on low speed and the exhaust blowers on high speed, to prevent dispersal of the fumes into the rest of the ship.

CARE OF WATERSIDES AFTER CLEANING

After all tubes, drums, and headers have been cleaned, and after all tools have been removed from the watersides, blow through the tubes with air; then wash out the drums, tubes, and headers with fresh water. Be particularly careful to remove all accumulations of dirt from handhole seats. Then examine the seats for scars, pits, or other defects that might cause leakage. All bottom blow, header blow, and test cock valves should be inspected and repaired, in accordance with manufacturer's instructions during each waterside cleaning period.

After the washing has been completed, thoroughly dry out the boiler watersides. Inspect the watersides to determine the condition of the metal and to see if the cleaning was satisfactory. Also, inspect the boiler to be sure that all parts are tight. Be sure that all openings between drums and gage glasses, blow valves, and safety valves are clean and free of foreign matter. These openings are sometimes overlooked. After the inspection has been completed, close up the boiler as soon as possible and "lay up" in accordance with the Naval Ship Systems Command instructions.

FREQUENCY AND PROCEDURES FOR BOILER BLOWDOWNS

The surface and bottom blow valves are intended for use in freeing a boiler of internal accumulations of dirt and grease, and for reducing the salinity of a steaming boiler. These valves should not be used without receiving permission from the engineer officer.

Guarding valves are installed in the blow-down systems of recently constructed boilers. A guarding valve is usually located in the common blowdown line from each boiler, between the boiler blowdown valves and the overboard discharge valves. The guarding valve provides additional protection against leakage from a boiler, and also prevents the entry of saltwater into the boiler while secured or under overhaul.

To blowdown a boiler when guarding valves are installed, it is first necessary to open the guarding valve and then the bottom or surface blow valves. The overboard discharge valve is then opened wide and operated quickly. The reverse procedure should be followed in handling the valves when the blowdown operation has been completed.

Surface Blow

A boiler is given a surface blow to clear the water in the steam drum of scum from oil or grease, to rid the boiler of excessive solids and dissolved salts, and to maintain the boiler water at the proper chemical limits while the boiler is steaming. When the surface blow is to be used, the water level should be raised 2 to 3 inches above the normal water line, and then, after waiting two minutes, the surface blow valve is opened wide. When the water is no longer blowing through (the level in the drum drops below the surface blow take-off pipe), the surface blow valve is closed. The boiler should be given a surface blow daily to maintain the water in the boiler crystal clear, and the amount of chlorides in the boiler water below 1.0 epm.

Bottom Blow

A boiler is generally given a bottom blow to reduce the total solid concentration in the boiler water. Whenever blow valves are used, they must be opened wide and the valve must be operated quickly. Also, when blowing, the water level must NEVER get below the bottom of the gage

glass. Emptying a boiler under steam pressure by blowing down must NEVER be resorted to except in an emergency.

Use of the bottom blow has a slight effect on the removal of the sludges while the boiler is steaming, since circulation of the boiler water disperses the material throughout the boiler. To remove the largest amount of the materials in the boiler, large amounts of water must be blown out of the steam drum. Water drums not connected to headers by floor tubes may be blown, if absolutely necessary, while the boiler is generating steam. Division wall headers, water screen headers, water wall headers, and water drums connected to headers by floor tubes should NEVER be blown down until all burners on the boiler have been secured. The division wall headers, water screen headers, and water wall headers used in boilers of recently built ships must NEVER be blown down until after all burners on the boiler have been secured. Blowing down these headers with burners in operation will interrupt and possibly reverse normal water circulation in the tubes served by these headers, causing overheating and failure of these tubes. To remove accumulations incident to building on newly commissioned ships, these headers should be blown down when securing the boiler after each period of steaming until the first regular boiler cleaning period. Thereafter, blowdowns should be made daily, and when required, to maintain the water in the boiler within the prescribed chemical limits.

In general, it is impossible to wash out all the fine dust and dirt which results from cleaning the watersides during boiler overhaul. A bottom blow should be given about one hour after a freshly cleaned boiler has been secured, following steam testing, or at the first available opportunity.

SAFETY PRECAUTIONS FOR WATERSIDE WORK

When working in the watersides of a boiler, take all possible precautions to keep tools, nuts, bolts, cigarette lighters, and other small objects from sliding down into the tubes. Some required precautions are:

1. Remove all small objects from your pockets before entering the boiler.
2. Keep an inventory of all tools and equipment taken into the boiler and be sure that each item is checked out before the boiler is closed up.

3. Do not set tools or other articles down in places where they are likely to be forgotten. For example, do NOT leave tools on top of the steam separators or in other places that are easy to reach but hard to see.

4. If some article is lost in the boiler watersides, do not close up or operate the boiler until the article has been found and removed. Even a very small article may interfere with boiler circulation and cause tube ruptures.

5. Close and wire and tag all steam, water, and air valves that could possibly admit these fluids to the boiler. Disconnect (or otherwise render inoperative) the remote operating valves as well.

6. Be sure that adequate ventilation is provided before entering the watersides of a boiler.

7. Be sure that all portable extension lights are of the watertight globe type, with the globe encased in a rubberized metal cage. Be sure that all lights are grounded and that wires are not broken. Examine the wires from end to end to be sure that the insulation is not broken or cracked, exposing the bare wire.

8. Station a man outside the drum whose ONLY duty is to act as tender and to assist the man or men who are working in the drum.

BOILING OUT BOILERS

The approved method for boiling out boilers is the trisodium phosphate method. This method is used when boiling out for the removal of oil and when boiling out in preparation for chemical cleaning.

The following procedure should be used when boiling out by the trisodium phosphate method for the removal of oil or in preparation for chemical cleaning of the boiler:

1. If the superheater is made of stainless steel, fill the superheater with feed water and keep it filled throughout the entire boiling-out process. If the superheater is not made of stainless steel, it need not be filled with feed water; however, every precaution must be taken to see that the boiling-out solution does not carry over into the superheater.

2. To allow proper circulation of the solution through the boiler, remove the apron plates and stack them loosely in the steam drum. Be sure that the plates do not cover the tube holes. It may be necessary to remove the desuperheater and the internal feed line in order to remove the apron plates; if this step is taken, blank off

the drum connections for the desuperheater and the internal feed line or reinstall the desuperheater and the internal feed line and make them up tight before the boiling out procedure is performed.

3. Provide steam connections from the 150-psi auxiliary steam line to all lower water headers, by way of a drain or a blowdown connection, and to the water drum bottom blow connection. Provide a separate steam connection to the economizer outlet header drain. In all cases, be sure to use steam hose of the appropriate pressure and temperature rating.

4. For every 1000 gallons of water required to fill the boiler to steaming level, put into the steam drum 250 pounds of trisodium phosphate and 5 quarts of wetting agent.

5. Fill the boiler to normal steaming level, using the normal feed line. The chemicals will mix and dissolve most effectively if the feed water is hot.

6. Cut in the steam to the connections provided, and allow pressure to build up to and remain at 50 to 100 psi.

7. The length of time required for the boiling out depends upon the degree of oil contamination and the amount of soft sludge deposits that are present. If the boiler is not heavily contaminated with oil, and if there is no soft sludge, 12 hours of boiling out will probably be enough. If the boiler is heavily contaminated with oil, or if soft sludge is present, 48 hours of boiling out may be required.

8. For 10 to 15 minutes of each hour, secure the steam to the lower water headers and water drum but NOT to the economizer. During this period use the emergency feed pump or another suitable pump to circulate the boiling-out solution.

9. Allow the steam drum to vent continuously, but restrict the flow so that the boiling-out solution will not be blown out or carried over to the superheater.

10. When the water level in the steam drum is 3 inches above normal steaming level, give a surface blow sufficient to bring the water level down to about 1 inch below normal. Secure all steam except that going to the economizer outlet drain before giving the surface blow. (When giving a surface blow, be sure the pressure in the boiler is maintained at about 25 psi above the sea water pressure on the overboard discharge valve, to prevent back flow of sea water into the boiler.) Do NOT use the surface blow while the solution is being circulated.

11. At the end of the boiling-out period, shut off the steam supply, vent the boiler to relieve the pressure, and pump the solution overboard through the hose connection in the bottom blow line.

12. Before the boiler has had time to dry out, flush the tubes and headers with a high velocity stream of feed water.

13. To determine the effectiveness of the boiling out, run clean dry turkish toweling through several tubes and examine the cloth for signs of oil. Be SURE that all rags are accounted for and that none are left in the boiler. Examine the interior of the steam drum, the water drum, the headers, and the internal feed pipe.

14. If only very slight traces of the oil are present, and if they are present only in the steam drum, they may be wiped clean with turkish toweling.

15. If a 48-hour boiling-out period has been prescribed (because of the presence of a lot of oil and soft sludge deposits) all tubes must be mechanically cleaned after it has been definitely ascertained that the boiler is completely free of oil. The mechanical cleaning should remove all loosely adhering material that is not removed by the boiling out.

16. Flush out the superheater, if it is not blanked off or filled with feed water.

If the boiler is still not clean, the entire boiling-out process must be repeated.

It should be noted that the presence of oil in a boiler means that oil is also present somewhere else. If the boiling out is to have any beneficial results, the entire condensate and feed system, from the condenser to the boiler, must be cleaned and made free of oil. Also, the source of oil contamination must be located and the trouble must be corrected. Any oil, anywhere in the system, must eventually find its way to the boiler. It's a waste of time to remove oil from the boiler without also removing it from the rest of the system.

LAYING UP IDLE BOILERS

To prevent rust and pitting, idle boilers must be laid up in strict accordance with the procedures authorized by the Naval Ship Systems Command. Two dry methods and five wet methods are approved. However, not all methods are applicable to all boilers; the method or methods to be followed on any particular ship will be specified by the engineer officer on that ship.

Dry Methods

Boilers may be laid up dry in two ways. In one method, a desiccant is used to keep the boiler dry. In the other method, heated air is circulated through the watersides and firesides as long as the boiler is idle.

DESICCANT METHOD.—When using a desiccant, the procedure for laying up an idle boiler is as follows:

1. Empty the boiler.
2. Open the handholes and manholes.
3. Blow out all horizontal tubes with compressed air.
4. Wipe out the boiler, making sure that there are no pockets of water left in the boiler.
5. Place bags of desiccant in the steam drum and in the water drum. Use about 16 pounds of desiccant for every 1000 gallons of water capacity of the boiler.
6. Place humidity indicator cards in the drums to indicate the humidity of the air in the boiler.
7. Close the manholes and handholes.
8. Inspect the humidity indicator cards every other day. When a card indicates a humidity of 90 percent, remove the old desiccant and replace it with the same amount of fresh desiccant.

HEATED-AIR METHOD.—When using heated air, the procedure for laying up an idle boiler is as follows:

1. Empty the boiler.
2. Open the handholes and the manholes.
3. Blow out all horizontal tubes with air jets.
4. Wipe out the boiler, making sure that there are no remaining pockets of water. Inspect the boiler to make sure it is completely dry.
5. Blow heated air into the boiler through the water drum manhole and one handhole in each header. Vent the air through the steam drum manhole. Connections to the drum and headers may be made by using sheet metal, shaped to the openings, with the hose connection in the middle. In addition, blow heated air through the firesides, using any suitable opening to the furnace or furnaces.

Wet Methods

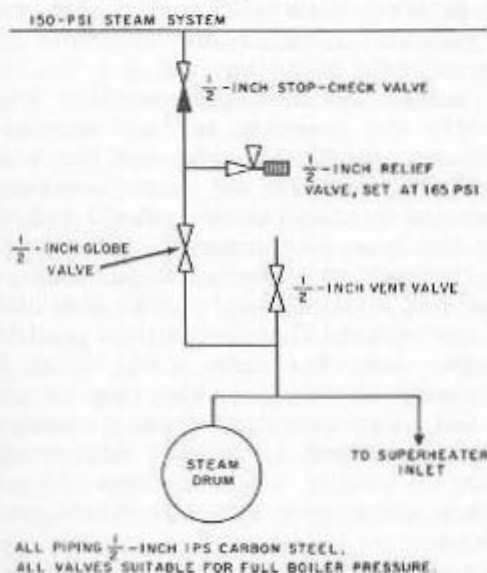
In following any of the wet methods of laying up an idle boiler, remember that the proper chemical control of the boiler water must be maintained.

FIRST WET METHOD.—When an idle boiler is to be laid up with the entire boiler, including the superheater, filled with deaerated water, the procedure is:

1. After the boiler pressure falls to 50 psig, add deaerated feed water through the normal feed connections. Continue to fill the boiler until water comes out of all vents.
2. As the water cools, it will contract. Add more water as necessary to compensate for the contraction. Continue until the boiler is at fire-room temperature and is entirely full of water.
3. Close all vents.
4. Maintain a pressure of 50 psig on the boiler.

SECOND WET METHOD.—The second wet method involves laying up a boiler under a steam blanket, with the superheater NOT drained. An arrangement for steam-pressurizing an idle boiler so that this method can be followed is shown in figure 2-7. The procedure for laying up a boiler under a steam blanket, with the superheater NOT drained, is as follows:

1. Open the low pressure steam supply valve to the boiler when the boiler pressure has fallen to that of the low pressure supply steam.
2. Close all vents and drains.
3. Allow the boiler (including the superheater) to fill with condensate.
4. Maintain the supply of low pressure steam to the boiler as long as the boiler is idle.



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Figure 2-7.—Arrangement for steam-pressurizing an idle boiler.

THIRD WET METHOD.—In the third wet method, the boiler is laid up under a steam blanket but the superheater IS drained. The procedure is as follows:

1. Open the low pressure steam supply valve to the boiler, when the boiler pressure has fallen to that of the low pressure supply steam.
2. Close all vents and drains except the trapped drain to the fresh water drain system at the superheater outlet.
3. Allow the boiler to fill with condensate, while allowing the superheater to drain continuously.
4. Maintain the supply of low pressure steam to the boiler as long as the boiler is idle. The water level may be maintained at the steam drum by blowing down the boiler. This will permit faster lighting off of the boiler because the steam drum will not require as much emptying.

FOURTH WET METHOD.—On some ships, it is possible to lay up boilers, wet, under a blanket of pure nitrogen. The procedure is:

1. Close all vents and drains on the boiler.
2. Maintain the water at normal steaming level.
3. While the boiler is still under a pressure of about 5 to 10 psi, allow nitrogen (water pumped, 99.5 percent pure by volume) to enter the boiler. As a rule, one cylinder of compressed nitrogen is sufficient to maintain a pressure of 5 psi on the boiler, provided the boiler is tight.
4. Maintain the 5-psi pressure with nitrogen as long as the boiler is idle.

FIFTH WET METHOD.—The fifth wet method involves laying up the boiler with the entire boiler (including superheater) filled with deaerated feed water and maintained under steam pressure. The procedure for this method is as follows:

1. Maintain the deaerating feed tank under auxiliary exhaust pressure (15 psig).
2. Close all boiler drains.
3. When the boiler pressure falls to 15 psig, fill the boiler from the deaerating feed tank. Use a jumper connection and fill THROUGH the superheater and into the steam drum.
4. Close all vents.
5. Keep the boiler under pressure by maintaining the auxiliary exhaust pressure (15 psig) on the deaerating feed tank as long as the boiler is idle.

INSPECTION OF WATERSIDES

When watersides are inspected, at least one handhole plate must be opened on each pass of the superheater (except at each alternate cleaning period, when the entire superheater must be opened up). The drums and headers must be opened up completely and the internal fittings must be removed. The internal fittings (especially the steam separators and the plates) must be marked to indicate their position in the steam drum. If this is not done, it will be extremely hard to reinstall the fittings correctly.

Since a wet boiler usually gives false indications of its real condition, dry out the boiler very thoroughly before beginning a watersides inspection. Note and record the general appearance of all visible areas of the boiler watersides. In particular, look for accumulations of sludge and for indications of scale, rust, general corrosion, and oil or grease marks. Insofar as possible, determine the extent of all defects as well as their nature.

When oil contamination is suspected, a better idea of the extent and nature of the contamination can be obtained by examining the watersides while the boiler is still wet. When inspecting for oil, take samples of water from the steam drum and from the economizer headers before the boiler is completely emptied. Analysis of these samples should enable you to determine what type of oil contamination (lube oil or fuel oil) has occurred. If the samples do not show any signs of an oil film, it may be that the contaminating oil has not yet reached the boiler. On the other hand, it may be that the oil contamination has been stopped and that all oil has either been deposited or removed by distillation.

To prevent oil contamination of a boiler, the drain inspection tanks must be inspected at least once each hour and more often if there is any reason to suspect that oil contamination might occur. If an oil film or any cloudiness is observed in the contents of a drain inspection tank, the drains must be shifted to the bilges and a search must be started to determine the source of the contamination. When oil appears in the gage glass of a boiler, a condenser, a deaerating feed tank, or a fresh water drain tank, the feed system has been contaminated by oil.

It is important to determine, as soon as possible, the kind of oil that is contaminating the system. Action should be taken immediately to check the sources of fuel oil contamination,

including the fuel oil heater drains and the heating coil drains. Then all possible sources of lube oil contamination should be checked, including such things as leaky oil seals on condensate pumps, contaminated open-funnel drains in the engineroom, accumulations of oily bilge water leaking directly into fresh water drain tanks or into the condensate system, and ineffective or defective deflector seals on the low pressure turbine. Samples should be taken from all possible sources of fuel oil or lube oil contamination, to help pinpoint the location of the trouble. Further contamination of the feed system should be stopped as soon as possible.

Deposits resulting from oil contamination may take various forms. They are not always easy to identify, since they do not always contain free oil—that is, oil in a form that will make an oily stain on a surface. The deposits may be wet or dry. Dry deposits include sludges, hard coke, and scale. Wet deposits may be soapy, tarry, tacky, or greasy. Some deposits contain free oil, but others do not.

The following inspection procedures should be used for examining a boiler which has been contaminated with oil, or one in which oil contamination is suspected:

1. Draw swabs through the tube ends of the boiler and the economizer to find out whether there is any free oil present.
2. Inspect the tube ends and not the nature and thickness of any deposits.
3. Select various tubes at random and inspect them carefully to determine the nature and the thickness of the deposits.
4. Inspect the drums and headers. Find out how thick the deposits are and whether they contain any free oil. A deposit that contains free oil will make an oily, translucent stain on a piece of hard-finished writing paper. If a boiler has been contaminated with either lube oil or fuel oil, a black ring, rather like a dirty bathtub ring, will appear at steaming level in the steam drum. The ring will be particularly noticeable near the ends of the drum. If the contaminant is fuel oil, the ring is usually thick and tarry and about 3 or 4 inches wide. If the contaminant is turbine lubricating oil, the ring is usually not more than 1 inch wide; it is thin and loaded with fine solids, but it is not tarry.

The action to be taken in any particular case of oil contamination depends chiefly on two things; first, the KIND of oil that is found (fuel oil or lube oil); and second, the CONDITION in

which the oil is found. In all cases of oil contamination, it is best to secure the plant and completely remove all traces of oil from the boiler and from the condensate and feed system. The following guide lines may be used to interpret the results of the inspection and to determine whether or not it is possible to steam the affected boiler if the operating situation so requires.

1. If free oil resulting from fuel oil contamination is found in the economizer and/or boiler, action must be taken IMMEDIATELY to boil out the boiler and to brush out all affected parts of the boiler.

2. If fuel oil contamination is suspected because of fuel oil findings in the contaminated drain system, but if there is no indication of free oil or of deposits containing free oil in the boiler, no emergency action is indicated PROVIDED the inspection of tubes shows the deposits to be very thin, dry, and uniform.

3. If inspection of the tubes shows that there are thick deposits resulting from fuel oil contamination, boiling out and brushing out are mandatory and must be repeated as often as necessary to remove the deposits. If removal of the deposits is particularly difficult, a solvent boiling-out solution may be required.

4. If free oil resulting from turbine lubricating oil contamination is found in the economizer and/or boiler, this indication alone does not require immediate boiling out. If the lube oil contamination has been stopped at its source, and if the boiler is free of scale and sludge, the thin film of lube oil existing in the boiler and economizer after they have been drained will probably distill off cleanly when the boiler is steamed again.

5. If no free oil and no deposits containing free oil are found in the boiler, but if it is known that the feed water has been contaminated by turbine lubricating oil, the action required depends on the thickness of the deposits found in the tubes. If the tube deposits are thin, the boiler may be closed up and steamed again, after it has been washed down or otherwise cleaned as well as possible in the time available. If the tube deposits are thick, the boiler should be thoroughly cleaned in the normal manner before it is steamed.

6. Although free oil is not usually found in the superheater and coked oil is found only if the contamination by fuel oil or lube oil has been exceptionally heavy over a long period of time, the superheater should always be included in the inspection for oil contamination.

If oil deposits are found in the superheater, the superheater must be boiled out and brushed out as necessary. If only dry deposits (whether carbonaceous or not) are found in the superheater, and if the deposits are thin and even, no immediate action is required. If thick deposits are found in the superheater, the superheater must be brushed out and/or boiled out to obtain clean surfaces.

CARE OF BOILER FIRESIDES

Keeping the firesides clean will actually save work, as well as save the boiler. Clean tubes do not collect deposits as readily as dirty tubes do. It is much easier to clean the firesides when they are only slightly dirty than it is to clean them when they are heavily coated with soot or carbon.

The burning of any petroleum product tends to be incomplete, thus causing carbon deposits on the boiler firesides. These deposits seriously reduce the efficiency of a boiler. Slag contributes greatly to failure of such parts as superheater support plates, baffles, protection plates, and soot blowers. Deposits also act as insulation and prevent the transfer of heat to the water or steam in the tubes.

Accumulations that block the gas passages through the tube banks require the use of high air pressures to force the combustion gases through the boiler, thus reducing fireroom efficiency. Accumulations that block the gas passages also interfere with the designed flow of combustion gases and cause extremely hot gases to flow over protection plates, baffles, seal plates, and other parts that are not designed for such high temperature gases. In some cases, early failure of these parts can be blamed directly on blocked gas passages and the resulting overheating of the parts.

If soot is allowed to remain on the boiler firesides for any length of time, the sulfur in the soot combines with moisture and forms sulfuric acid. This acid attacks tubes, drums, and headers. The extent of the damage caused by acid attack depends upon the length of time the soot remains on the tubes and upon the amount of moisture present during this interval. Moisture may be present because of high atmospheric humidity, rain or snow coming down the stack, leaky boiler tubes, and steam or water leakage through the boiler casing joints, particularly from machinery and piping installed above the

boiler. One indication of soot corrosion may be the development of pinhole leaks at the point where the tubes enter the water drums and headers and at other points where it is difficult to clean the tubes properly. If soot corrosion is allowed to proceed unchecked, the result will be extensive deterioration of the boiler metals.

FREQUENCY OF CLEANING FIRESIDES

Boiler firesides must be cleaned after each 600 hours of steaming. If it becomes necessary to exceed the 600 hour cleaning interval, the type commander must be notified and reason for such action reported. Complete hand cleaning must be accomplished either by waterwashing or mechanical means. Although waterwashing is the preferred method for a complete job, mechanical means may be used if time or conditions do not permit waterwashing. (However, mechanical means is NOT permitted for cleaning firesides at two successive 600 hour cleaning periods for any reason.)

It is good engineering practice to enter the furnace after each steaming period at sea or in port, if practicable, to accomplish as much cleaning as necessary; this prevents serious accumulations of soot, slag, or carbon from developing on the fireside surfaces. The engineer officer should devise a cleaning schedule that takes into consideration the operation of the ship. Boilers, including uptakes, may be cleaned while at sea only if the fireroom is secured. Depending upon the number and arrangement of boilers and ship operations, either partial or complete cleaning of boilers may be accomplished at sea.

In addition, each boiler should be thoroughly waterwashed a few weeks before undergoing shipyard or major tender overhaul. The washing must be performed at a time when it can be followed by an extended steaming period as near to the full power rating as possible. The refractory will retain a large amount of water, therefore making it necessary to fire the boiler so that the heat passes through the refractory to the casing to evaporate all moisture. Firing rates of less than 50 percent require that the boiler be steamed for at least 100 hours. Firing rates of less than 10 percent are completely ineffective and result in moisture remaining in the refractory and causing damage. This will ensure that the boiler is clean and dry upon being secured for overhaul. Refractory covered sidewall stud tubes should not be waterwashed

because water causes corrosion of tubes. Therefore, only the mechanical cleaning method should be used to clean sidewall stud tubes.

PROCEDURES FOR CLEANING FIRESIDES

Mechanical cleaning, hot-water washing, wet-steam lancing, air lancing, and various combinations of these methods may be used to clean firesides. Before starting to clean firesides by any method, all required tools and equipment should be assembled. Only approved types of equipment, in satisfactory condition, should be used for fireside work.

Be particularly careful about the kind of portable extension lights that are used. All lights, which must be properly grounded, must be checked by an electrician before they are used.

For mechanical cleaning of boiler firesides, scrapers, wire brushes, and probes are required. Special tools for reaching into the tube banks may be made up aboard ship from sheet metal strips, rods, or similar material. Tools with sharp points or sharp edges must never be used for fireside cleaning.

Lances suitable for water lancing, steam lancing, and air lancing are shown in figures 2-8, 2-9, and 2-10. The lance shown in figure 2-8 is designed for cleaning superheater tubes. To use this lance, stand outside the boiler and apply the lance through the superheater access door. The lance shown in Figure 2-9 is designed for cleaning superheater tubes and generating tubes. This lance may be used either from inside the boiler or from outside the boiler. The lance shown in figure 2-10 is used for lancing economizers and downcomers.

Other tools and equipment that may be required for fireside work include hoses, canvas shields, drain pans, litmus paper, gloves, goggles, slickers, respirator masks, and venturi-type injectors.

Mechanical Cleaning

In order to clean firesides mechanically, it is necessary to remove access doors on the boiler. In some cases bolted sections of boiler casings will have to be removed in order to gain access to the corners and pockets where soot and carbon tend to accumulate. However, bolted sections of casing should not be removed unless absolutely necessary. One or more registers may be removed from the boiler front if necessary to make it easier to pass tools into the

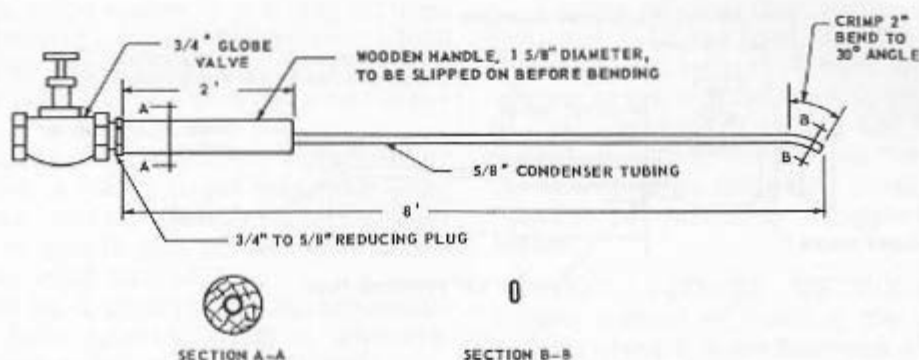


Figure 2-8.—Lance for cleaning superheater tubes (operator outside boiler).

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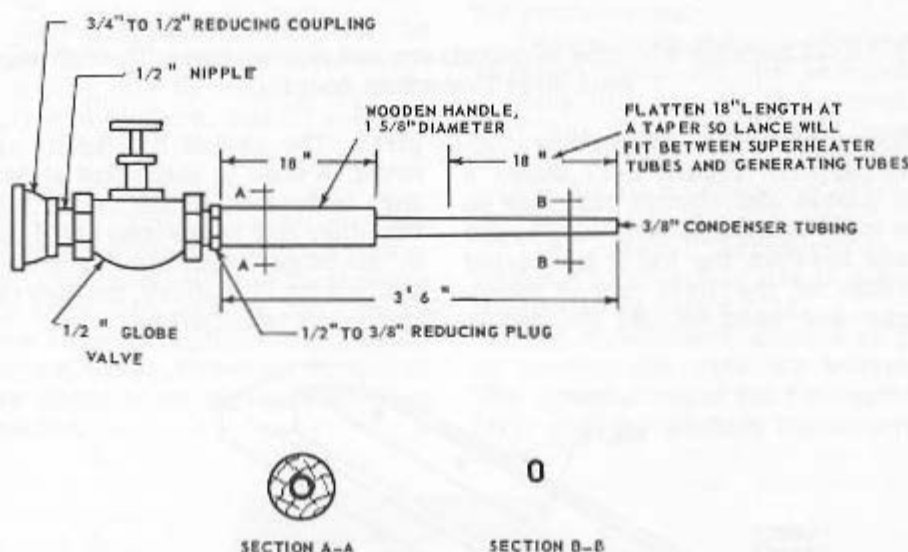


Figure 2-9.—Lance for cleaning superheater tubes and generating tubes (operator inside or outside boiler).

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furnace and to provide additional light and access.

After the soot, carbon, and other deposits have been loosened by mechanical scraping, wire brushing, and probing, they may be blown out of the tube banks with air lances.

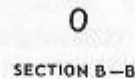
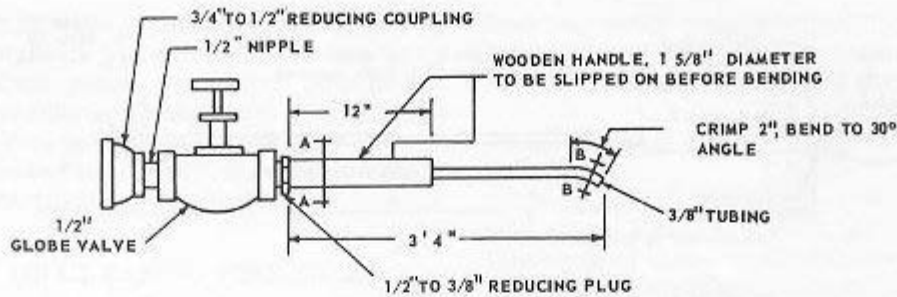
When cleaning firesides mechanically, a respirator mask is used. The dust that is stirred up by mechanical cleaning of firesides is toxic.

Hot-Water Washing

Hot-water washing must NOT be used for cleaning side and rear wall tubes. Before beginning to wash firesides, be sure that the following preparatory measures have been taken:

1. Open, remove, or loosen access doors or panels to provide access to the firesides and to allow drainage from around tubes and headers. Do not open any more doors or panels than necessary. If the boiler is opened up too much, water will splash onto adjacent machinery and equipment. It may even be necessary to replace some of the access doors or panels that were previously removed for mechanical cleaning.

2. Install canvas shields, if practicable, to prevent excessive wetting of the refractories. Refractory corbels at the water drums should be protected as carefully as possible, since there is a tendency for water to run down between the corbel and the drum. In many boilers it is difficult to make a tight joint or seal in this

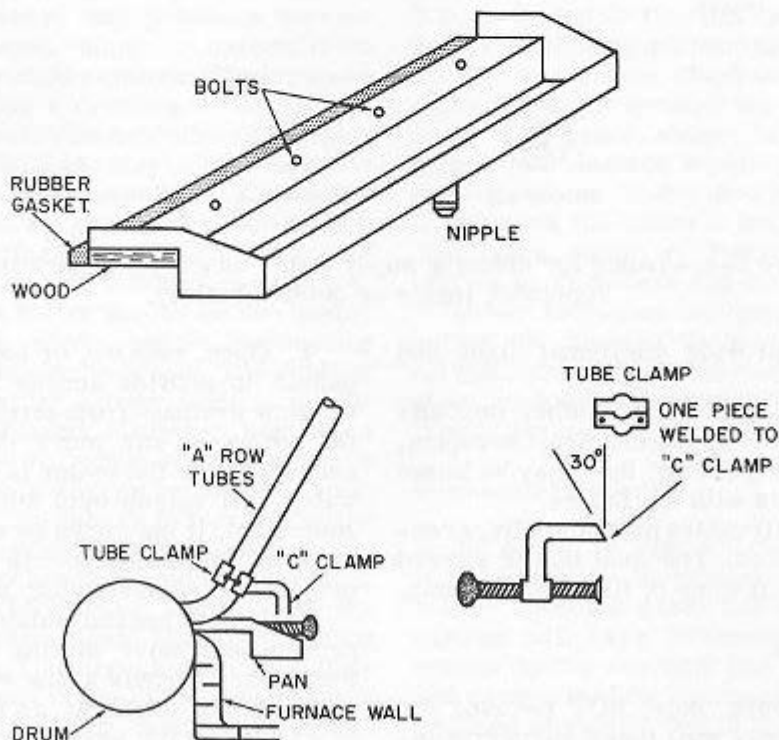


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Figure 2-10.—Lance for cleaning economizers and downcomers (through superheater seal plate inspection doors).

location; a rubber strip gasket, properly braced, may serve the purpose. Figure 2-11 shows a drain pan with gasket and clamps that may be made up to use when washing firesides. The pan slides into place between the top of the corbel and the underside of the first row of tubes. Large C-clamps are used to hold the pan in

place. The gasket fits tightly against the water drum. A hose is connected at one end to a nipple that is brazed to the center of the drain pan; the other end of the hose is led out of the furnace to the bilges. Although the drain pan, as shown, will not fit all boilers, the idea can be adapted to suit many installations.



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Figure 2-11.—Drain pan for protection of water drum and refractory corbel.

3. Provide some means of draining off used water. If necessary, rig canvas gutters to lead the used water out of the furnace. Line up a fire and bilge pump for pumping the water overboard.

4. Rig canvas over electrical equipment or machinery that is likely to get splashed. Many firerooms have been disabled by failure of electric motors or panels that got wet when boiler firesides were being washed.

5. See that all appropriate protective equipment is on hand (gloves, goggles, slickers, respiratory masks, and watertight lights).

6. Have litmus paper available for testing the acidity of the waste water. (Acid turns blue litmus paper red.)

7. Line up all the equipment that is to be used and attach water hoses as necessary.

Hot-water washing may be done by using (1) water lances, (2) soot blowers, and (3) venturi-type injectors.

WATER-LANCE METHOD.—Of all methods of hot-water washing boiler firesides, the water-lance method is most economical of fresh water and is probably least damaging to the refractories, since the water is applied locally to the areas that require cleaning. However, the water-lance method is likely to be the least effective of the three methods.

Lances of the type shown in figures 2-8, 2-9, and 2-10 are used to water lance different parts of the boiler. Always start the water lancing at the top and work down. Use hot water at a temperature of 150° to 200°F. Use hot water pressure of 150 to 200 psi for water lancing the economizer; somewhat lower pressures will usually be sufficient for other parts of the boiler.

SOOT - BLOWER METHODS.—The soot-blower method of washing the boiler firesides usually gives a more thorough cleaning than that obtained by water lancing. However, the soot-blower method requires a great deal of fresh water and is likely to cause extensive wetting of the refractories.

Before using the soot blowers for hot-water washing, blank off the elements on all soot blowers that are not to be used. This must be done in order to prevent leakage of water through defective soot blower valves. The root valves for all soot blowers not being used should be CLOSED.

The general arrangement for hot-water washing firesides by use of the soot blowers is illustrated in figure 2-12.

The soot-blower method is frequently used in combination with the water-lance method. The combination of the two methods is particularly good for washing superheaters.

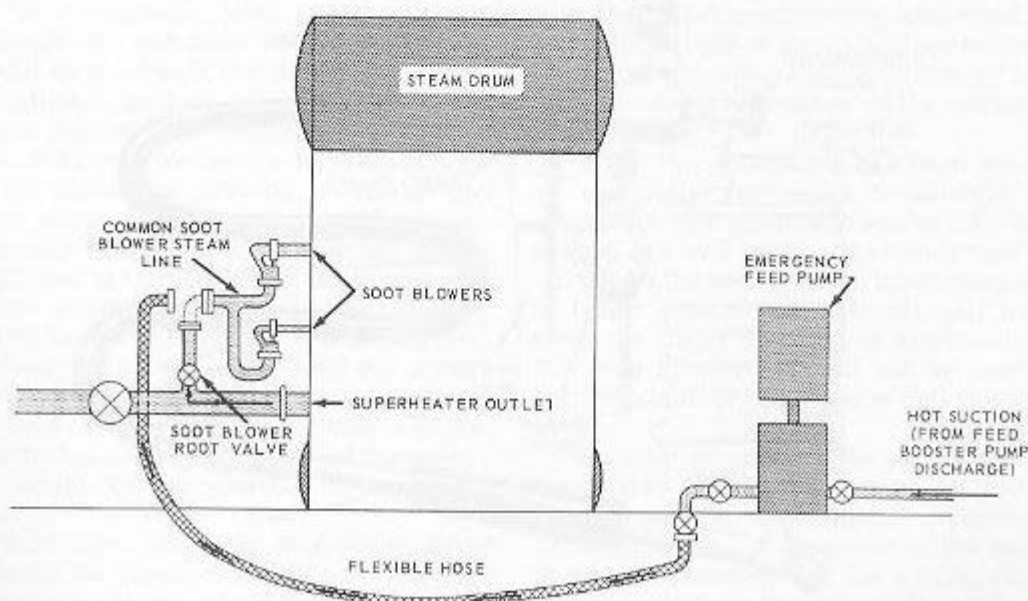


Figure 2-12.—Arrangement for hot-water washing boiler firesides by use of soot blowers.

VENTURI-INJECTOR METHOD.—The venturi-type injector, now authorized for use on all ships, is probably the most effective device available for washing firesides. The injector delivers a large volume of water in a solid stream, at high pressure and high temperature. The scrubbing action of the water is very effective in removing fireside deposits. A venturi type injector is shown in figure 2-13.

To operate the injector properly, an adequate supply of steam must be available at the designed pressure; at least a 1 1/4-inch steam supply line and 90 to 125 psi steam pressure will be required. This will produce a 200 psi discharge pressure. An adequate supply of water will also be required at a temperature not to exceed 90°F.

To place the injector in operation, first open the water valve until a good flow is obtained out of the waste pipe or overflow opening. Then fully open the steam valve and close the water valve until the overflow stops. After a few seconds the steam line will have lost its accumulated condensate, and more water will be required. Open the water valve slowly until the jet has obtained the maximum amount of water it will take without overflowing. With the jet set in these conditions, the greatest hose pressure

(and thus the greatest cleaning action) is obtained.

The venturi-type injector is suitable for washing all parts of the boiler firesides, including the uptakes and smokepipes.

Wet-Steam Lancing

Cleaning boiler firesides by wet-steam lancing is more difficult than cleaning by hot-water washing. In some cases, however, the wet-steam method may give good results. The boiler must be COLD when firesides are to be cleaned by wet-steam lancing. Otherwise the wet steam would dry up immediately upon contact with the hot metal and the dissolving action of the moisture in the steam would be lost.

To clean firesides by wet-steam lancing, it is necessary to have a 1-inch branch connection on a 70- to 150-psi auxiliary steam line in the fireroom. From this branch connection, run a temporary pipeline to the boiler front. This pipeline should be uninsulated and should have a loop or coil that can be submerged in a 30-gallon drum of water. As the steam passes through the submerged coil or loop, some of the steam condenses and gives the desired moisture

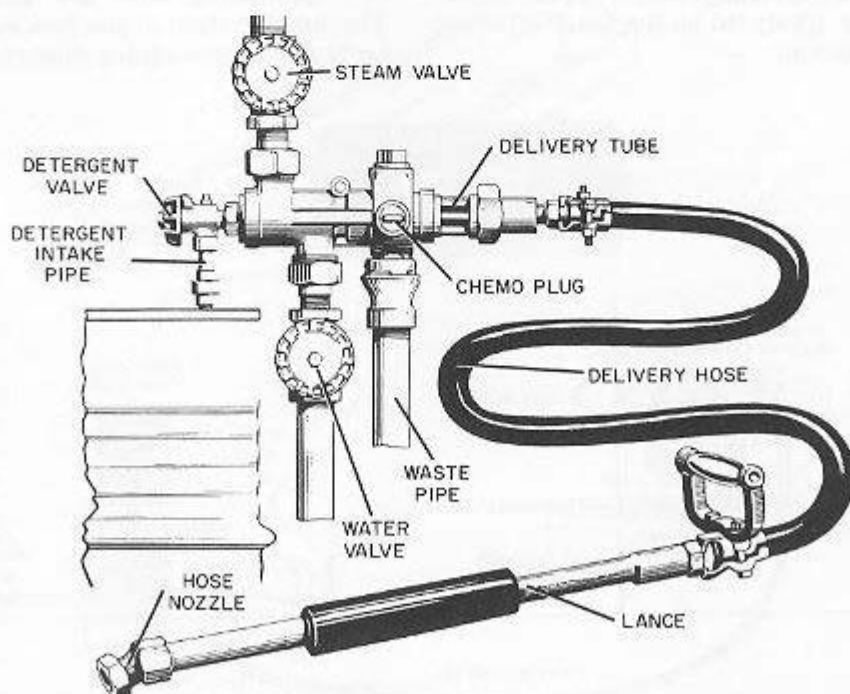


Figure 2-13.—Venturi-type injector for hot-water washing boiler firesides.

content to the steam. The temporary pipeline should have two hose connections at the boiler end for attaching steam hoses and lances. Lances of the types shown in figures 2-8, 2-9, and 2-10 are used for wet-steam lancing.

Air Lancing

Air lancing is often used in connection with the other fireside cleaning methods. In some cases, air lancing alone is sufficient to remove light, powdery deposits from the firesides. The lances shown in figures 2-8, 2-9, and 2-10 are suitable for air lancing as well as for water lancing and wet-steam lancing.

DRYING OUT THE BOILER

Immediately after hot-water washing or steam lancing the boiler firesides, the boiler should be dried out as follows. Drain all excess water from the boiler and remove all scale, dirt, or other material from drums, refractories, and tubes. If soot blowers were used, restore the soot blower piping to its service condition. Close up the boiler and light off with one burner, using the smallest sprayer plate available and 200-psi oil supply pressure to ensure good atomization for straight mechanical burner systems. For 1000 psi wide range systems, a recommended return oil pressure, in accordance with the Naval Ship Systems Command and manufacturers instructions, should be used with the lighting off plate. Every 15 minutes secure the burner and keep it idle for a period of 15 minutes, to allow the moisture in the refractories to evaporate slowly. Continue the alternate periods of firing and securing for about 5 hours, occasionally changing the burner that is used. Allow the boiler to stand idle for air drying for 1 hour, and then light off and steam the boiler to an auxiliary load for 100 hours if possible. If it is not possible to steam to an auxiliary load for a reasonably long period of time, continue the alternate firing and idle periods for another 8 hours. During the drying-out period, protect the superheater by establishing a positive flow of steam through it.

After the boiler has been thoroughly dried out, it should be secured so that the furnace may be opened for inspection of the refractories. The refractories should be inspected for signs of shrinkage or other damage caused by wetting

or by too rapid evaporation of the water. Particular attention should be paid to the refractory corbels. When firing the boiler later, watch carefully for any signs of damage to the refractories.

USE OF METAL CONDITIONING COMPOUND

When mechanical cleaning, water washing, or wet-steam lancing is not sufficient to clean the firesides completely and thoroughly, an approved metal conditioning compound may be used. (NOTE: Approved fireside additives may be used, if authorized.) However, metal conditioning compound should not be applied unless the operating schedule of the ship allows time for the boiler to be laid up long enough for the compound to take effect. A conditioning period of at least 1 week and preferably 3 weeks is needed for the compound to penetrate rust, scale, and other fireside deposits.

Before metal conditioning compound is applied, the firesides must be thoroughly cleaned of all loose soot, dust, scale, and other foreign material. If this loose material is not removed, it will absorb the compound and keep it from reaching the hard scale, carbon, or corrosion products it is intended to remove.

After the firesides have been cleaned, spray the fireside surfaces of the tubes and drums with the metal conditioning compound. Use from 15 to 25 gallons of compound per boiler, depending upon the size and condition of the boiler. Wear a respirator mask while working with the compound.

After the compound has been applied, close up the boiler firesides completely. After the compound has been allowed to take effect for a period of 1 to 3 weeks, the boiler may be lighted off. When the boiler is hot, tubes should be blown. A large amount of material will be removed from the boiler when tubes are blown; therefore the soot blowers should not be used until the ship is clear of other ships and has a favorable wind.

As soon as practicable after tubes are blown, the boiler should be opened up and the firesides should be mechanically cleaned again. All accumulations not removed by the soot blowers should be brushed out. As a rule, any material that remains on the tubes after the metal conditioning treatment will be soft and easy to remove.

Metal conditioning compound is flammable under certain conditions. The following precautions must be observed while using the compound:

1. Be sure the fireroom is well ventilated while the compound is being applied.
2. Do not allow smoking in the fireroom while the compound is being applied.
3. Do not allow the use of naked lights in the fireroom while the compound is being applied.
4. Do not apply compound to a boiler while another boiler in the same fireroom is steaming.
5. Do not apply compound to a boiler which is connected to the same stack as a steaming boiler, unless division plates are installed all the way to the top of the stack to prevent the mixture of gases from the two boilers.
6. Do not use excessive quantities of the compound; use only as much as is necessary to clean the boiler. Excess compound tends to collect in inaccessible pockets and corners and constitutes a fire hazard when the boiler is lighted off.
7. When the boiler is first steamed after compound has been applied, be particularly alert to detect any fires that might occur as the result of the compound soaking through casing joints into the drum insulation.
8. Do not allow anyone to enter the boiler during the period between the application of the compound and the steaming of the boiler, unless such entry is required for the performance of emergency work.
9. When using metal conditioning compound in a boiler, do not lay up the boiler under a steam blanket. The heat of the steam blanket might cause the metal conditioning compound to smoke. The fumes produced by smoking metal conditioning compound are highly irritating and obnoxious.

FREQUENCY AND PROCEDURES FOR BLOWING TUBES

Soot is a very effective heat insulator. If a boiler is to generate steam efficiently, soot deposits must be thoroughly removed from its firesides at frequent intervals. In addition, soot deposits allowed to remain on top of the lower drums or between the tubes will absorb moisture from the air. This moisture will cause the sulphuric acid (contained in the soot) to become active and highly corrosive. Furthermore, such undisturbed soot deposits in a comparatively

short time will pack into a mass, too solid to be removed by soot blowers. Therefore, in order to keep the boiler firesides in proper condition, the frequent and regular use of soot blowers is mandatory. Where boilers are fitted with permanently installed soot blowers, the following MINIMUM requirements (as to their use) must be met:

1. While underway, blow tubes on all steaming boilers once each watch.
2. While at anchor, blow tubes in all steaming boilers at least once each day.
3. When practicable, blow tubes just after the making of heavy smoke from any cause (lighting off, smoke screens).

In addition to the minimum requirements for the frequency of soot blowing, tests conducted under closely controlled conditions indicate that, for most economical operation, the soot blowers should be used once each 4-hour watch underway and twice each day in port. When blowing tubes, consideration must be given to the effect on the upper decks. Permission must be received from the OOD before the operation is undertaken.

Steam soot blower elements should be rotated at a rate of 10 to 15 seconds per 90 degrees of rotation, making from 1 to 3 complete traverses with each element, depending upon the condition of the firesides. Whenever practicable, and shortly before burners are secured, the firesides (tubes, baffles) should be cleaned of accumulated soot through the use of soot blowers. A high air pressure will materially assist in the cleaning. Steam soot blowers are used only while fires are lighted.

In order to ensure maximum efficiency of the soot blowers, the uppermost row of economizer tubes of air heater tubes should be cleaned of all soot deposits. This should be done during the regularly scheduled boiler fireside cleaning periods, in accordance with the Naval Ship Systems Command recommendations. Once the uppermost row of economizer tubes has been cleaned and the passage cleared, the sequence of soot blower operation should be changed to blow the top soot blowers first. This will clear the gas passage of any soot that has collected since the last blowing of tubes or cleaning. After blowing the top soot blowers, the regular sequence of blowing soot blowers as outlined in the specific technical manuals should be followed. The uppermost soot blowers, economizer or air heater, as applicable, are used at the beginning and at the end of the sequence.

INSPECTION OF FIRESIDES

When inspecting tubes, look for signs of warping, bulging, sagging, cracking, pitting, scaling, acid corrosion, and other damage. All visible tube seats—especially superheater tube seats—should be inspected for signs of leakage. Additional information on the inspection of boiler tubes is given in a later section of this chapter.

The exteriors of all boiler drums and headers should be inspected for signs of corrosion under the insulation. Rusty streaks or signs of corrosion on or around the edges of the covering, the drum pads, or the tubes indicate possible corrosion of the drum, and should be investigated immediately. If machinery or piping is installed over the boiler, water may drip down on the boiler and work its way under the insulation. In such installations, the boiler drum coverings must be removed and the exteriors of the drums must be inspected carefully at intervals specified by the Naval Ship Systems Command.

All corrosion-resisting steel plates such as baffle plates, seal plates, superheater support plates, steam drum protection plates must be carefully inspected whenever firesides are opened. These steel plates are subject to damage from overheating, particularly if clogged gas passages interfere with the designed flow of combustion gases and allow extremely hot gases to flow over the plates. Since failure of these parts could have extremely serious consequences, the plates should be inspected at every opportunity and should be renewed when necessary.

Burner impeller plates, air doors, drip pans, and the burner cone openings should be inspected and cleaned after every steaming period at sea or in port. Access to the burners may be gained by removing one or more burners or, if necessary, by removing a furnace access door or panel.

MAINTENANCE OF BOILER PARTS

Effective boiler maintenance requires considerable knowledge of the history of the boiler, the condition of its parts, and the sources of information to which one can turn for guidance in making repairs. All available information concerning maintenance should be reviewed before work commences, starting with the

manufacturer's technical manual which probably is the most valuable source of information.

The Bureau of Ships Technical Manual (chapter 9510) gives information that applies in general to most boilers now in the service. The blueprints and drawings that pertain to the ship's boilers are kept in the engineering log room; these drawings should always be consulted before any major repair job is undertaken. In addition, the machinery history should be consulted; this source contains valuable information on the past history of the boiler and may provide clues as to the basic causes of recurring troubles.

DRUMS AND HEADERS

The exteriors of boiler drums should be observed closely for indications of corrosion under the coverings. All signs of rusty streaks or corrosion around the edges of the covering should be thoroughly investigated. When machinery or piping joints are located above the boiler drums, the boiler drum coverings must be removed for inspection purposes at intervals not exceeding five years.

Whenever there is reason to believe that a boiler drum or header is unduly corroded, the part shall be drilled and its thickness determined.

Scale must not be permitted to accumulate on the sides of the front and back headers of a header-type boiler. Corrosion between these headers may force them apart and cause distortion of the nipples and tubes. The gradual growth of corrosion and the method of packing the headers make it difficult to determine the exact condition that exists. To prevent advanced corrosion, a portion of the packing between the headers should be removed for inspection at least once a year. A sufficient amount of packing must be removed to determine the general condition of the headers. Headers may also be trammed to determine the degree of corrosion between them. Detailed instructions for this procedure are contained in chapter 9510 of the Bureau of Ships Technical Manual.

All pits in boiler drums or headers should be thoroughly cleaned down to bare metal. Pits should not be filled with cement or smooth-on paste. Such filling does not prevent further corrosion but it does prevent the condition being readily judged on subsequent inspections.

AIR CASINGS

Air should not be allowed to enter the furnace of an operating boiler at any place except through the air registers. Every effort must be made to keep the inner casing airtight at all times. Air that leaks into the furnace through the inner casing does not become intimately mixed with the fuel oil and therefore does not aid in combustion. On the contrary, air entering the furnace through openings other than the air registers has a decidedly chilling effect on the heating surfaces and on the gases of combustion, thereby contributing directly to lowered efficiency.

Air leakage through the inner casing into the furnace is actually a common occurrence. In some cases, waste of fuel oil amounting to 10 percent or more has been directly traced to air leakage through the inner casing.

The tightness of outer casings is also important from the standpoint of boiler efficiency. Leaky outer casings can reduce the efficiency of the forced draft blowers to such an extent as to actually make it impossible to achieve the combustion rates required for full power. Even at lower firing rates, air leakage through the outer casing wastes auxiliary steam because the forced draft blowers must be run at a higher speed in order to maintain the necessary air pressure at the burner front.

The most frequent cause of air leakage through the boiler casings is improper sealing of the casings. This trouble may be found on newly installed boilers or—more commonly—on recently overhauled boilers. Improper sealing may result from failure to use the correct sealing compound on joints and seams or from the use of defective gaskets or gaskets that do not conform to the design of the boiler. In any case, it is obviously impossible to keep the boiler airtight unless the seams are properly made up and the gaskets are properly installed.

Corrosion of the casing, caused by water dripping down onto it, is another common cause of air leakage. Water may drip onto the casing from leaky air vents, or it may run out of the vents and onto the casing when the boiler is being filled. To prevent this, a drip pipe should be installed from the air vents to carry drips away from the top of the boiler casing.

Overhauling boiler casings is tedious and difficult work because every joint and every opening—no matter how small—must be checked

for proper sealing. Since the work is tiresome, there is often a tendency to ignore small leaks and to neglect the repair of burned or corroded sections of casing. If the work is done carefully, however, most boilers will show a marked reduction in fuel oil consumption.

Whenever the refractories are removed, check the inner casing around the padeyes. Sometimes the padeyes pull out, making holes in the inner casing. If a hole is found, a patch can be brazed or welded over the hole. Be sure that the patch is of the same material as the casing.

When floor refractories are removed, check the inner casing around the furnace drain. If corrosion has caused cracks or breaks in the casing in this area, clean the metal thoroughly and then patch by brazing or welding.

The inner casing around peepholes may become burned if the plastic refractory falls out. If burned spots appear on the inner casing near the peepholes, the area should be replaced or patched.

The rear and side walls of some 1200-psi boilers may develop "hot spots" on the inner casing in areas where tangent tubes cannot be installed or where exposed portions of the refractory waste away from slag attack. Careful maintenance of the refractories is the only way to prevent these hot spots. Deep crevices in exposed firebrick should be filled with plastic chrome ore, plastic fireclay, or castable refractory. If gaps of 1/2 inch or more are found between tangent tubes, the exposed insulation should be protected with a brush coating of airsetting mortar or with packed plastic refractory.

The gaskets and studs on the superheater access doors should be kept in good condition and replaced whenever necessary. Imperfect closure of these access doors is a major cause of air leakage.

Air leakage through the outer casing is most likely to occur as a result of bad gaskets or loose seams or joints. In particular, the bolted flanges that cover the ends of drums and headers may become loose, due to corrosion or vibration, and thus allow air to leak out of the outer casing. If one of these flanges becomes corroded, the flange section must be removed and replaced with a new piece made of the same material.

Access doors or panels in the outer casing sometimes require repair. The insulation on these doors or panels must be kept in good condition to keep the outer casing from overheating.

UPTAKES AND SMOKEPIPES

The uptakes and smokepipes must be kept in good condition and free of leaks that would allow water to run down onto the boiler. Leaks around the base of the stack may allow water to seep down inside the boiler casing. These leaks can be stopped by calking with a mixture of asbestos wicking and red lead or, if the leak is very small, by coating with smooth-on cement.

Where smokestack rain gutters are installed, they should be inspected frequently. Remove all soot accumulations and make sure the drains are not plugged.

The expansion joints in the uptakes require special maintenance on some destroyers and frigates. A soot seal was installed to keep soot from entering the expansion joint in the uptakes. The soot seal turned out to be something less than 100-percent effective, so the expansion joints tend to fill up with soot. The soot seals are being removed on these ships, but the problem of soot in the expansion joints remains. In order to prolong the life of expansion joints, all soot should be removed BEFORE boiler firesides are washed. After the firesides washing has been completed, the expansion joints must be cleaned again to remove any wet soot that may have gotten into them during the water washing. The expansion joints should be absolutely free of soot after the firesides cleaning is completed.

FUEL OIL BURNERS

Fuel oil burners must be correctly installed, maintained in proper position and alignment, and kept clean and free of defects. If the burner is not lined up properly with respect to the burner cone opening, flame impingement, damage to refractories, and poor combustion will probably result.

Leakage must NEVER be allowed to occur at any of the threaded joints in the atomizer assembly. The gooseneck may work loose in normal usage; it should be tightened before being put into service. The nozzle, sprayer plate, and tip assembly must also be kept tight. Leakage of oil through the threads where the nozzle screws onto the burner barrel or where the tip screws onto the nozzle will interfere with combustion and will probably cause oil to accumulate on the movable air doors.

Before using any sprayer plate, check it for etching, scratches, scoring, nicks, and other defects. Any defect in a sprayer plate can seriously interfere with atomization.

The position of the atomizer barrel in the distance piece should be checked from time to time and adjusted when necessary. To make this adjustment, screw the distance piece in or out until the proper relationship exists between the face of the atomizer tip nut and the diffuser plate. This setting of the atomizer barrel with respect to the distance piece varies for different types of burners. Figure 2-14 shows the atomizer position for several types of burners. Always consult the manufacturer's technical manual to get the correct setting for any particular burner.

The distance piece should be marked so that the position of the atomizer and distance piece assembly with reference to the burner throat can be determined from the fireroom.

It should be noted that the adjustment of the atomizer barrel with respect to the distance piece is very rarely required. Do not confuse this relatively permanent adjustment with the adjustment of the entire assembly (distance piece, atomizer, and diffuser plate) that must be made each time the burner is lighted off.

The diffuser plate, bolted onto the furnace end of the distance piece, plays a very important part in the mixing of oil and air. Keep the slots in the diffuser plate clean and free of accumulations of carbon, dirt, or oil. Any blocking of these slots can cause serious interference with the mixing of oil and air. Always check the diffuser plates for cracking and for loosened bolts when you inspect the furnace. If a diffuser plate shows signs of damage such as burned edges or badly rusted sections, it should be repaired or replaced.

INTERNAL FITTINGS

The internal fittings in the steam drum require routine maintenance and upkeep. The fittings normally installed in the steam drums usually include equipment for distributing the incoming feed water, for separating and drying the steam, for giving surface blows, and for directing the flow of steam and water within the steam drum. In addition, boilers which do not have controlled superheat have equipment for desuperheating steam used for auxiliary purposes; the desuperheater is usually installed in the steam drum, but may be installed in the water drum in some new boilers. Internal fittings

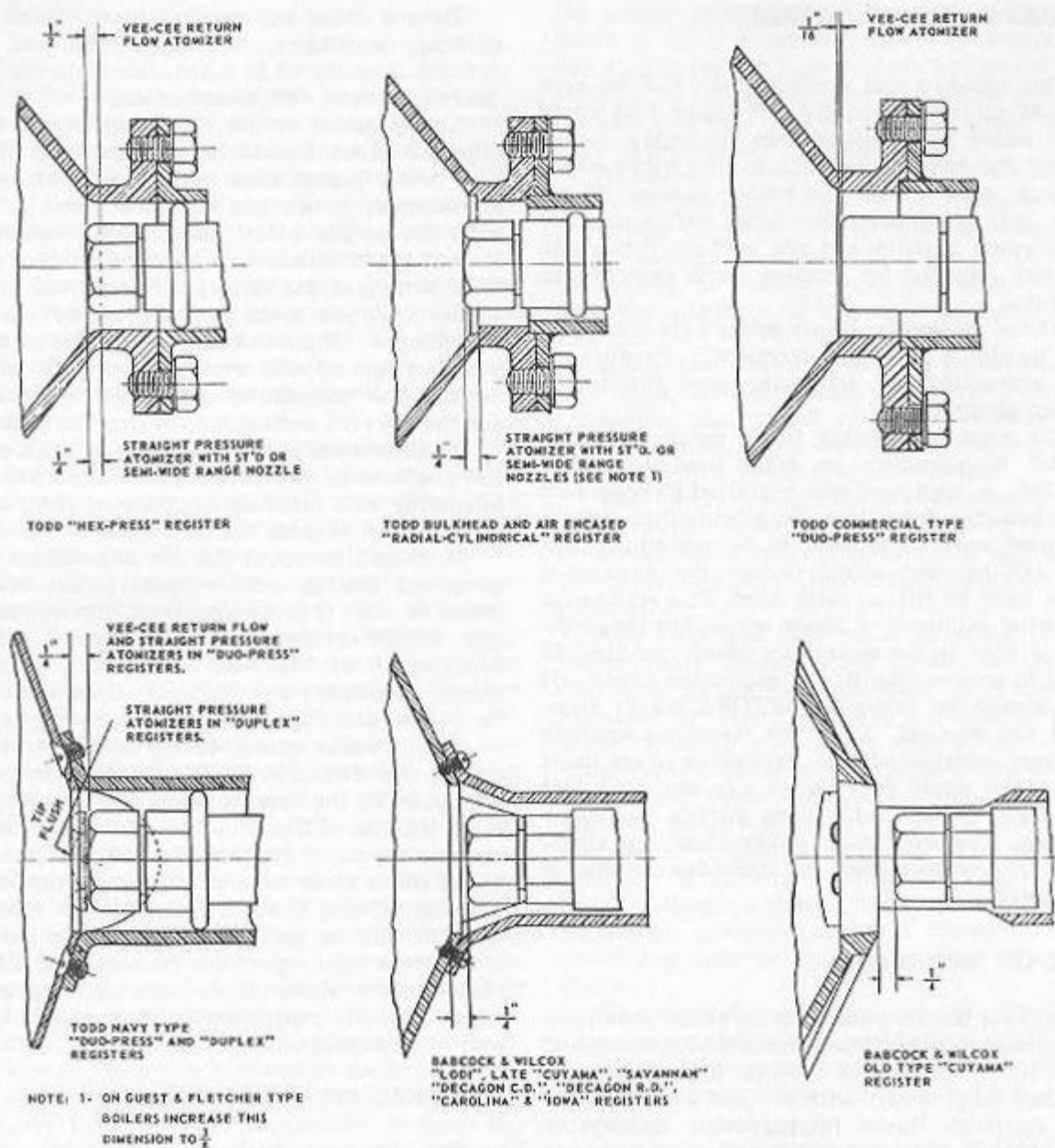


Figure 2-14.—Position of atomizer barrel in distance piece.

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in some boilers also include equipment for injecting chemicals for boiler water treatment.

After removing the fittings from the steam drum, thoroughly wirebrush and clean them. Check the dry pipe, the internal feed line, and the surface blow line to be sure that all the holes are free and clear of obstructions. In addition, inspect the inside of the feed line for oil accumulations.

Before reinstalling the fittings, wirebrush, clean, and hose down the steam drum. It should be clean and free of any oil or other accumulation.

When replacing the fittings in the steam drum, all the bolts should be drawn tight. The desuperheater flanges must be thoroughly cleaned before the desuperheater is fitted into place and bolted. New gaskets must be installed. The flanges must

be drawn up evenly and tightly to prevent any leakage from the flanged joints.

Additional information concerning internal fittings can be obtained from either the Bureau of Ships Technical Manual (chapter 9510) or the manufacturer's technical manual for the specific boiler.

TUBES

Regular and careful inspection of boiler tubes provides the information required to determine the need for tube renewal, to determine the effectiveness of boiler water treatment and other maintenance procedures, to diagnose boiler operating troubles, to analyze boiler casualties, and in general to give an overall picture of the condition of the ship's boilers.

Inspection Requirements

At each regular scheduled shipyard overhaul, two generating tubes and one superheater tube must be removed from each boiler for examination. Each tube thus removed must be split, permanently identified as to the boiler from which it was taken, the tube number, and the location of the tube in the boiler. The tubes are examined by the activity that removes them and are then returned to the ship with a report of corrective action recommended, if any. The tubes must then be retained aboard ship until they have been examined by a Board of Inspection and Survey. The corrective action recommended by the repairing activity and any corrective action taken by the ship must be recorded in the machinery history so that this information will be available to the Board of Inspection and Survey.

If tubes are removed between overhauls, samples of generating tubes and superheater tubes may be saved for inspection by the Board of Inspection and Survey so that additional tubes will not need to be removed at the time of the overhaul. Note, however, that tubes which have failed in service or which have been damaged cannot be used in this way for inspection by the Board.

Superheater tubes removed for inspection must be replaced. Generating tubes removed for inspection need not be replaced if (1) there are not more than 10 tubes plugged as a result of inspection requirements, and (2) the tubes were removed from the last two rows of the

tube bank. Tubes removed from furnace walls or from fireside rows must be replaced.

Economizer tubes are not ordinarily removed for inspection unless it is suspected that the economizer is not in good condition. The requirement that a superheater tube be removed for inspection is waived in the case of (1) boilers having the walk-in type of superheater, and (2) boilers in which the removal and replacement of individual superheater tubes cannot be accomplished without cutting bulkheads.

Sample tubes removed for inspection should be representative of the other tubes in the row from which they are cut. For example, a recently renewed tube should NOT be selected as a sample. In order to obtain proper samples, the tubes must be cut out in accordance with the procedures prescribed by the Naval Ship Systems Command.

When there is reason to suspect serious or widespread tube damage, or when the condition of the tubes cannot be clearly determined on the basis of a few sample tubes, an "exploring block" of tubes should be cut. The exploring block should be not more than 10 tubes wide, and it must be deep enough to include the tubes in the center row of the tube bank. A superheater tube and an economizer element must also be removed for inspection when the exploring block is cut.

The need for cutting an exploring block (together with the required superheater tube and economizer element) is determined initially by the engineer officer. A repair activity reviews the facts and makes whatever inspections are required as a basis for recommendations to the type commander. With the information thus supplied, the type commander decides upon the extent of the repairs desired, taking into account the operational commitments of the ship and other factors.

Tube failures in other than the A and B rows generally occur in the outer half of the tube nest as a result of external corrosion just above the water drum. When such failures have occurred, either in operation or under hydrostatic test, or when the examination of tubes in the exploring block shows that the tube thickness is less than half the original thickness, complete renewal must be made of all tubes from the center row to the outer row (inclusive) over a fore-and-aft length of the tube bank sufficient to completely cover the affected area. This renewal must be made regardless of the condition of the tubes that were not included in the exploring block.

The existence of slight, scattered pitting does not necessarily require the complete retubing of the boiler, even if the thickness of the tubes at some of the pits is less than 50 percent of the original tube thickness. When pitting is observed, tubes should be split and examined to see whether the pitting is (1) moderately heavy, and (2) general throughout the boiler.

Internal pitting resulting from improper treatment of boiler water is most likely to occur in tubes that receive the most heat (screen tubes, fire row tubes) and in areas which are particularly subject to oxygen pitting. In general, oxygen pitting tends to occur most commonly in downcomers, in superheaters, and at the steam drum ends of generating tubes. If active oxygen pits (that is, pits which are still scabbed over, rather than clean) are found when the boiler is inspected, or if oxygen pitting is suspected because of the past operating history of the boiler, one or two tubes should be removed from the areas in which oxygen pitting is most likely to be found.

The tubes thus removed should be split and examined. If 25 percent of the pits are deeper than 50 percent of the tube wall thickness, and if at least a few of the pits are deeper than 65 percent of the tube wall thickness, a sample of about 20 tubes from the screen and last rows of the generating bank should be cut. These tubes should be split and examined and their condition should be evaluated on the same basis as before. If 25 percent of the pits are deeper than 50 percent of the wall thickness, and if at least a few are deeper than 65 percent, the oxygen pitting is considered to be general throughout the boiler and moderately heavy. With these findings, complete tube renewal should certainly be considered. However, it is possible that complete tube renewal may be postponed in some cases if (1) the boiler can be successfully cleaned by a chemical cleaning, (2) the boiler can successfully withstand a 125-percent hydrostatic test, and (3) future boiler water treatment, use of blowdown, and laying-up procedures can be expected to be in strict accordance with the Naval Ship Systems Command requirements.

Inspection of boilers sometimes shows an unexpected condition in which adjacent boiler tubes are warped in such a way that they touch each other. When this condition exists, the tubes are said to be married. Tube marriages may result either from overheating of the tubes or from stresses developed in the tubes during installation. For this latter reason, newly

erected boilers and boilers that have been retubed should always be inspected for tube alignment after the initial period of steaming.

When inspection reveals one or more tube marriages, the decision as to whether or not the married tubes should be renewed should be based on the following considerations:

1. If the tube marriage occurs in screen tubes 1 1/2 inches or larger, or if the furnace side wall or rear wall tubes are bowed, tube replacement is usually required.

2. If 1-inch or 1 1/4-inch tubes in the main bank of generating tubes are married, replacement is usually not required if the tube joints are tight under hydrostatic test.

3. Inspect the external surfaces of the tubes. If they show blistering or other signs of overheating, the tubes should be renewed.

4. Inspect the watersides. Where tube marriages exist, a poor watersides condition may indicate hard scale or oil within the affected tubes. If hard scale or oil does exist, the married tubes should be replaced and all appropriate steps should be taken to remove the scale or oil from the rest of the boiler. If the condition of the tubes is uncertain, or if a large number of tube marriages have occurred, remove one or more sample tubes, split them, and examine them carefully.

5. Tube marriages may cause gas laning, which may in turn cause local overheating of the inner casing, the bottom part of the economizer, and other parts. Inspect the boiler carefully for signs of local overheating that might have been caused by gas laning resulting from the tube marriages. If local overheating is found, the married tubes should be renewed.

6. On single-furnace boilers, a lane more than 1 1/2 inches wide may allow overheating of the superheater and of the superheater supports. If a large lane (1 1/2 tubes wide or wider) exists near the superheater outlet header end of the boiler, the married tubes that cause such a large lane should be renewed.

In addition, when tubes are inspected, the finned tubes (if installed) should be checked. Finned tubes are installed in the LC row instead of studded and packed tubes on some double-furnace boilers. A few cases of warping and cracking of the finned tubes have been reported. Check the tubes, the fins, and the welds which join the fins to the tubes. Report any warping, cracking, or other damage that you find.

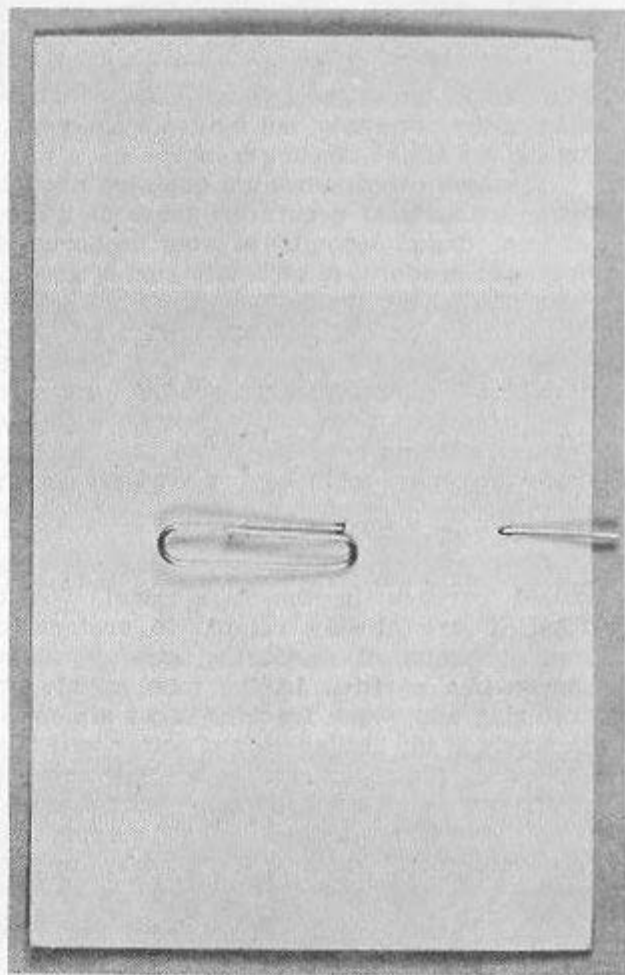
Identifying Causes Of Tube Failure

In order to identify the cause of tube failure by visual inspection, it is essential to know something about the various ways in which tubes rupture, warp, blister, and otherwise show damage. Tube failures must be reported on a standard form, using standard terminology. The sections which follow deal with the inspection techniques required for determining the causes of tube failure and with the various ways in which boiler tube damage is classified and identified.

INSPECTION TECHNIQUES AND EQUIPMENT.—The inspection techniques required for determining the cause of tube failure must naturally vary according to the nature of the problem. For example, a rupture in a fire row tube can usually be described adequately on the basis of simple visual observation; but the cause of damage to a tube that is deep in the tube bank cannot usually be determined without removing the intervening tubes. When a blistered tube suggests a waterside deposit, the nature and extent of the deposit can be determined only by removing and splitting the tube so that the waterside may be examined.

Relatively simple equipment is required for the field inspection of damaged or fouled pressure parts. Equipment for this purpose should include (1) devices for measuring tube diameters, depth of pits, and thickness of deposits; (2) instruments for separating deposits and corrosion products—a sharp knife, a chisel, a steel scribe, or a vise to crack deposits loose from the tube samples; (3) an approved type of portable light; (4) a supply of clean bottles for collecting samples of deposits; and (5) a mirror for viewing relatively inaccessible places.

Many of these items of equipment can be improvised if necessary. For example, a simple gage for measuring the depth of waterside pits may be made by pushing a straight pin or a paper clip through a 3 x 5 inch card so that the point of the pin or clip projects beyond the card, at right angles to the card. Such an improvised depth gage is shown in figure 2-15. A section of string can be wrapped around a deformed tube and then laid along a ruler to obtain a measure of tube enlargement or tube thinning. Of course, special tools such as calipers, depth gages, and scale thickness indicators give more accurate results and should be used if they are



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Figure 2-15.—Improved depth gage.

available; but the improvised tools, if used with care, can also give good results.

CLASSIFICATION OF BOILER TUBE DAMAGE.—Boiler tube damage is considered in this section, under four major classifications: (1) fireside cavities and scars, (2) waterside cavities and scars, (3) tube deformities and fractures, and (4) tube deposits.

CAVITIES AND SCARS ON THE TUBE FIRESIDES often indicate the reasons for tube failure. The term **CIRCUMFERENTIAL GROOVE** is used to describe the metal loss that occurs in bands or stripes around the circumference of a tube. Fireside grooving of this type often occurs at the header ends of horizontal tubes such as superheater tubes. The most common cause of this damage is leakage from tube seats higher

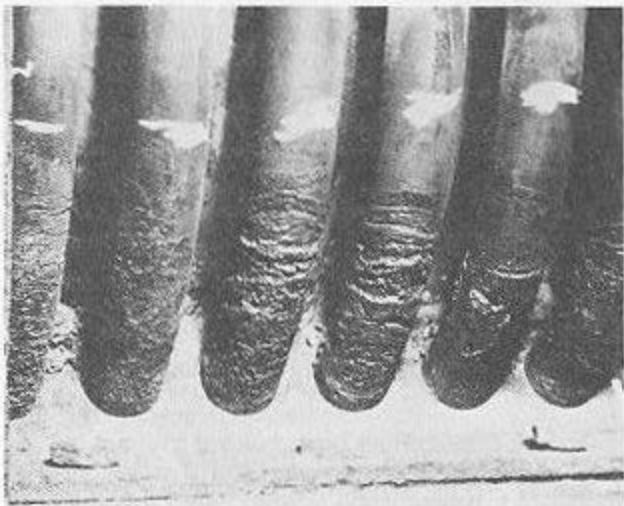
up in the tube bank. The grooving occurs as the water runs down the header and onto the tube ends, or as it drips directly onto the tubes. This kind of damage is greater on the top of the tube than on the underside, but the groove may extend around the entire circumference.

Fireside circumferential grooving may also occur on vertical generating tubes as a result of thin, damp deposits of soot on horizontal drums or headers. In fact, this kind of grooving can occur in any part of the boiler where leakage provides a sufficient supply of water. Large quantities of water trapped between the water drum and the boiler casing—as, for example, from a serious economizer leak—can produce general fireside grooving around the bottom of the rear generating tubes. An example of this general fireside grooving is shown in figure 2-16.

CRATERS are deep, irregular, straight-walled cavities in the tube metal. WATER TRACKS are closely related to craters; the tracks consist of wandering, straight-walled, canyon-like cavities in the tube metal. Both cratering and water tracking occur almost exclusively at the header ends of water wall tubes and division wall tubes that are surrounded by refractory; they are caused by water becoming trapped between the tube metal and the surrounding refractory. Water washing of boiler firesides, without proper drying out, is a frequent cause of cratering and water tracking; however, any leak higher up in the boiler can also cause this type of damage. The size of the leak and the angle of the tube upon which the water leaks determine to a large extent whether the resulting damage will be circumferential grooving, cratering, or water tracking. Both cratering and water tracking are shown in figure 2-17.

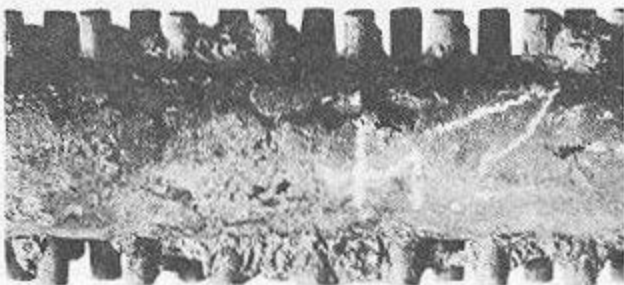
GENERAL FIRESIDE THINNING consists of a uniform loss of metal over a relatively large area on the outside of the tube. Soot corrosion is the most common cause of general fireside thinning. The parts that are particularly subject to this kind of damage are superheater tube ends between the headers and the seal plates; water drum ends of generating tubes; and return bends in economizer tubes. General fireside thinning of a generating tube is shown in figure 2-18.

A rather unusual type of general fireside metal loss sometimes results from the combination of extremely high tube temperatures and the burning of fuel oil that contains vanadium compounds. The vanadium compounds carried



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Figure 2-16.—General fireside circumferential grooving.



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Figure 2-17.—Fireside cratering and water tracking.



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Figure 2-18.—General fireside thinning of generating tube.

in the flame can cause rapid oxidation of metal at high temperatures. This type of damage is unusual in water-cooled parts of the boiler, since

critical temperatures are not usually attained. Figure 2-19 shows a stainless steel superheater tube that has suffered this type of general thinning as a result of fuel ash damage.

FIRESIDE BURNING occurs when the rate of heat transfer through the tube wall is so reduced that the metal is overheated. Waterside deposits can cause fireside burning, but most serious fireside burning occurs when a tube becomes steam bound or dry. Figure 2-20 shows the coarse, brittle appearance of tube metal that has suffered fireside burning.

STEAM GOUGING occurs when steam jets out of a hole in an adjacent tube. Steam gouging can be identified by the extremely smooth surface of the cavity, together with the irregular shape of the cavity. As may be seen in figure 2-21, a steam gouge looks as though the metal had been blasted away and the cavity polished.

TOOL MARKS such as chisel cuts or hammer scars can usually be identified without too much trouble. As shown in figure 2-22, tool marks do not resemble corrosion effects in any way.

Some **WATERSIDE CAVITIES AND SCARS** that may be recognized by visual examination are discussed here.

LOCALIZED PITTING is the term used to describe scattered pits on the watersides. These pits are usually—though not always—caused by the presence of dissolved oxygen.

WATERSIDE GROOVES are similar to localized pits in some ways, but they are longer and broader than the pits. Waterside grooves tend to occur in the relatively hot bends of the tubes near the water drum; they may also occur on the external surfaces of desuperheater tubes. Some waterside grooves are clean, but most contain islands of heavy corrosion scabs. A typical example of waterside grooving is shown in figure 2-23.



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Figure 2-19.—General fireside thinning of stainless steel superheater tube (result of fuel ash damage).



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Figure 2-20.—Fireside burning.



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Figure 2-21.—Fireside steam gouge.



98.143

Figure 2-22.—Fireside tool marks.



98.144

Figure 2-23.—Waterside grooving in a generating tube.

CORROSION FATIGUE FISSURES are deep-walled, canyon-like voids. They have the appearance of being corroded, rather than fractured,

and they may be filled with corrosion products. These fissures occur in metal that has been fatigued by repeated stressing, thus making it more subject to corrosion than it would otherwise be.

GENERAL WATERSIDE THINNING can occur if the boiler water alkalinity is too low over a long period of time, if the boiler water alkalinity is too high, or if acid residues are not completely removed from a boiler that has been chemically cleaned. The greatest loss of metal from general waterside thinning tends to occur along the side of the tube that is toward the flame. The entire length of the tube from steam drum to water drum may be affected. Figure 2-24 shows general waterside thinning.

WATERSIDE BURNING may occur if the temperature exceeds about 750° F, in plain carbon steel tubes, or about 1000° F, in most alloy superheater tubes. The effect of waterside burning is the oxidation of the tube metal to a shiny, black, magnetic iron oxide known as high temperature oxide.

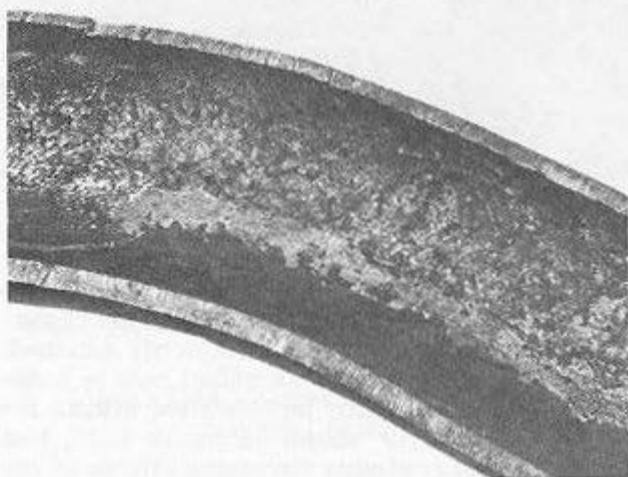
WATERSIDE ABRASION is the term used to describe waterside cavities that result from purely mechanical causes rather than from corrosion. For example, tube brushes or cutters may cause abrasion spots at sharp bends in economizer, superheater, and generating tubes. The surface markings of such abrasions indicate clearly that they result from mechanical abrasion rather than from corrosion.

DIE MARKS appear as remarkably straight and uniform longitudinal scratches or folds on the watersides of the tube. They are the result of faulty fabrication. Die marks, shown in figure 2-25, may extend for the full length of the tube. Localized corrosion occurs quite often along the die mark.

TUBE DEFORMITIES AND FRACTURES cover abnormal bends, blisters, bulges, cracks, warps, sags, and other breaks or distortions. Like the cavities and scars previously discussed, tube deformities and fractures are fairly easy to distinguish by visual observation.

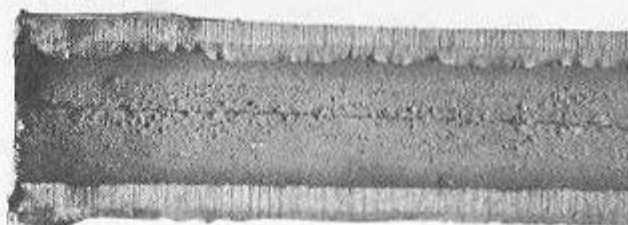
The **THIN-LIPPED RUPTURE**, shown in figure 2-26, is a fairly common tube deformity. The rupture resembles a burst bubble; the open lips are uniformly tapered to sharp knife-like edges, with no evidence of cracking or irregular tearing of the metal. True thin-lipped ruptures occur in economizer tubes, in generating tubes, and—to a much lesser extent—in superheater tubes. Ruptures of this type indicate that the flow of steam or water was not adequate to absorb the

heat to which the tube was exposed; consequently the tube metal softened and flowed and then burst. Thin-lipped ruptures may be caused by a sudden drop in water level or by tube stoppage.



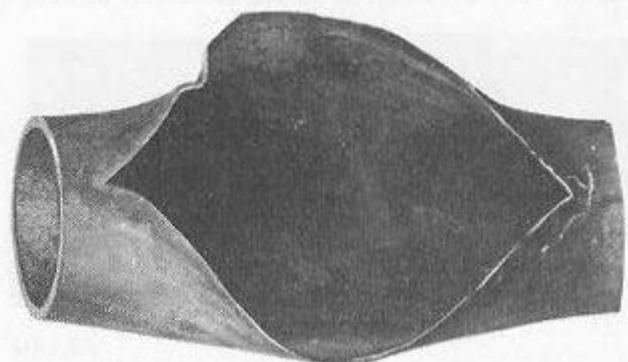
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Figure 2-24.—General waterside thinning.



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Figure 2-25.—Die marks on waterside of tube.



98.147

Figure 2-26.—Thin-lipped rupture.

Serious **THICK-LIPPED RUPTURES** resemble the thin-lipped ruptures except that the edges are thick and ragged rather than tapered and knife-like. Thick-lipped ruptures that occur in mild steel generating tubes indicate milder and more prolonged overheating than that which leads to thin-lipped ruptures. Abnormal firing rates, momentary low water, flame impingement, gas laning, and many other causes can produce mild but prolonged overheating which can eventually lead to thick-lipped ruptures. A typical thick-lipped rupture in a generating tube is shown in figure 2-27.

Thick-lipped ruptures are the most common type of rupture in superheater tubes; sudden intense overheating or mild and prolonged overheating tends to produce this type of rupture in alloy steels. The superheater tube shown in figure 2-28 literally blew to pieces when the thermally stressed metal finally yielded under superheater pressure.

PERFORATION is the term used to describe any opening in a tube (other than a crack) that is NOT associated with tube enlargement. The most common kind of perforation is probably the pinhole leak. In many cases, the first evidence of tube failure is a pinhole leak.

THERMAL CRACKS, sometimes called **CREEP CRACKS**, result from prolonged, mild overheating or repeated short-time overheating. Cracks of this type are found most often in alloy superheater tubes, but they can occur in mild steel tubes as well. The tube is not usually enlarged when a thermal crack exists; the cracked wall has normal thickness, and the break has a dark crystalline appearance. A typical example is shown in figure 2-29.

Certain chromium superheater tubes that contain molybdenum and titanium sometimes develop very long, straight, seamlike longitudinal cracks as a result of very slight cold working or hot working. Such failures can occur in service because of original defects, even though the boiler has been operating under normal conditions and has not been overheated. A crack of this type in a chromium superheater tube is shown in figure 2-30.

TUBE ENLARGEMENT of the type shown in figure 2-31 is relatively common in superheater tubes but rare in generating tubes. This uniform enlargement of a portion of the tube is caused by milder overheating than that which produces cracks or ruptures. If an enlarged tube is continued in service, it will almost certainly crack or break eventually.



Figure 2-27.—Thick-lipped rupture in generating tube.

98.148



Figure 2-28.—Thick-lipped rupture in superheater tube.

98.149

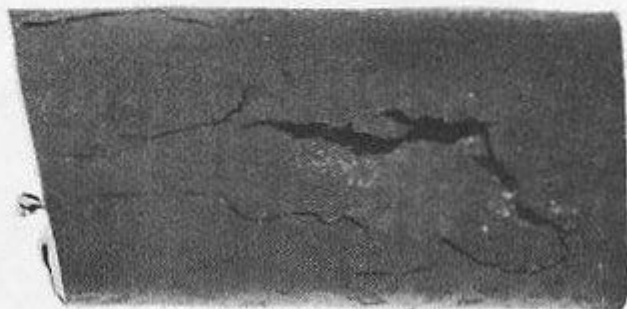


Figure 2-29.—Thermal crack (creep crack) in superheater tube.

98.150



Figure 2-30.—Thermal crack in chromium steel superheater tube.

98.151

HEAT BLISTERS differ from tube enlargements in that they affect only one side of the tube, usually the side toward the fireside. Blisters appear as egg-shaped lumps on the fireside. They indicate that the tube has been heated to the softening point and has blown out under boiler pressure. Heat blisters always indicate the presence of waterside deposits. If the deposit is brittle, as scale or baked sludge, blistering breaks the deposit and allows the boiler water to quench the hot metal before the tube bursts. Heat blisters are most commonly found on the fire row generating tubes; they are rarely found on superheater tubes or economizer tubes. A typical heat blister is shown in figure 2-32.

TUBE CORRUGATION is a peculiar type of heat blistering that occurs when the boiler water is contaminated with oil. Corrugation may consist of closely spaced small-diameter hemispherical bulges, as though the tube metal had been softened and then punched from the inside with a blunt instrument. It may also exist as a herringbone or chevron pattern on the tube wall nearest the flame, as shown in figure 2-33. It is not known exactly why oil contamination of the boiler water tends to cause this patterned corrugation.

SAGGING is the term applied to tubes that appear to have drooped downward toward the furnace under their own weight. This type of



Figure 2-31.—Enlarged tube.

98.152



Figure 2-32.—Heat blister on fire row tube.

98.153

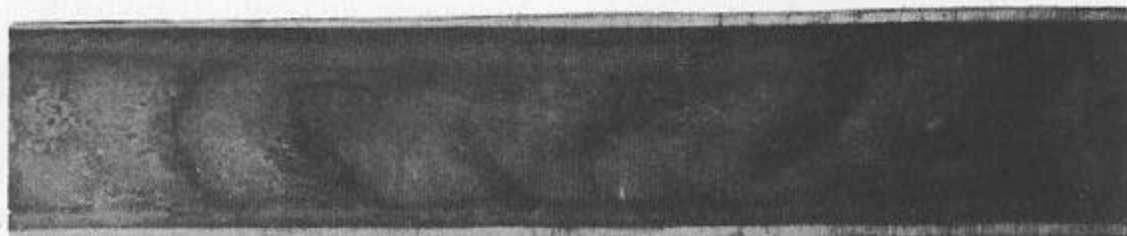


Figure 2-33.—Tube corrugation resulting from oil on watersides.

98.154

deformation results from semiplastic flow of the tube metal, caused by extremely mild overheating. A momentary condition of low water is probably the most common cause of sagging. If the boiler has been cooled slowly, and if the distortion is not so severe as to interfere with the designed flow of combustion gases, sagged tubes may still be continued in service.

WARPING is similar to sagging except that the distortion is haphazard rather than in one direction. Warping usually occurs as a result of sudden cooling of the tubes after they have been overheated. Cooling a boiler too rapidly after a low water casualty is a typical cause of warped tubes.

MELTING can occur as a result of a serious low water casualty. If the tube temperature becomes high enough, the tube metal actually melts and runs down into the furnace. A cluster of fused tubes that resulted from melting is shown in figure 2-34. Melting of aluminum economizer parts can cause tremendous damage to a boiler.

The molten aluminum from overheated economizer parts reacts so violently with the iron oxide coating on the steel tubes below that the heat of the chemical reaction may melt the steel tubes even though the furnace temperature is not high enough to melt them.

SWAGING is the term applied to the reduction of tube diameter by mechanical deformation. The effect is a recessed band or circumferential indentation around all or part of the tube circumference. Swaging is most likely to occur where a tube passes through a support plate or seal plate; thus it is more common in superheater tubes than in other kinds of boiler tubes. A swaged tube is shown in figure 2-35.

MECHANICAL FATIGUE CRACKS occasionally occur in boiler tubes from such purely mechanical processes as flexing. Cracks of this type can usually be identified by a clean, bright break through a major portion of the metal thickness. These cracks begin on the outside circumference of the tube.

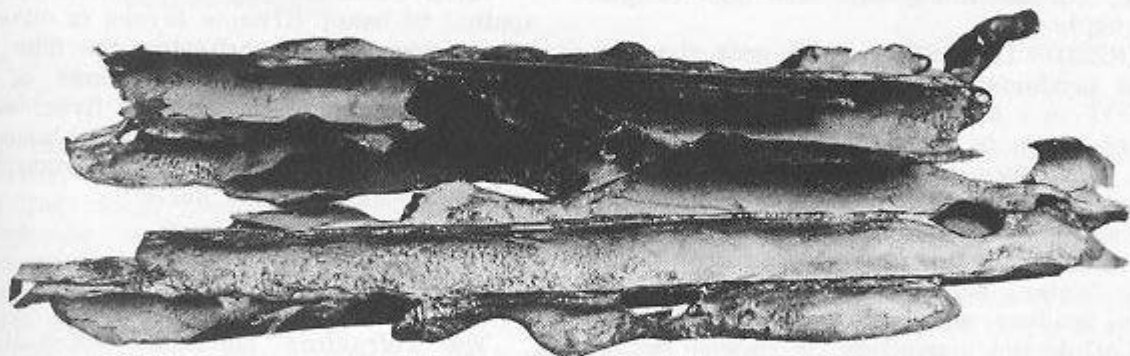


Figure 2-34.—Melted cluster of tubes.

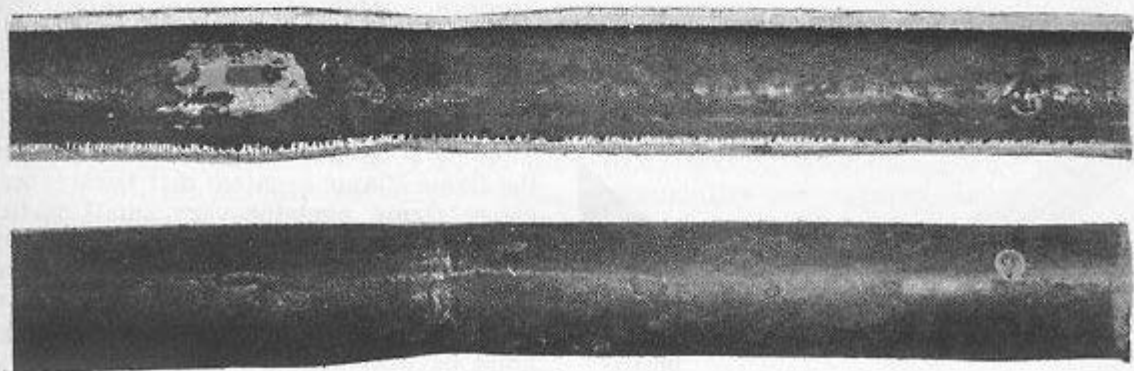


Figure 2-35.—Swaged superheater tube.

TUBE WALL LAMINATION is shown in figure 2-36. This lamination or layering occurs during the fabrication of the tube. It is the most common material defect found in boiler tubes.

FOLDED or UPSET TUBES are also the result of defective fabrication. A folded tube is shown in figure 2-37. This defect resembles a heat blister in appearance, but the folded tube shows no wall thinning and has a depression on the side of the tube opposite to the bulge.

STRETCHED or NECKED TUBES are also the result of defective fabrication. A stretched or necked tube is shown in figure 2-38.

FIRESIDE and WATERSIDE DEPOSITS can produce many of the scars and deformities just described. Basically, the reason why tube deposits cause tube failure is because they lead to localized overheating of the tube metal. The accurate identification of tube deposits is often a necessary part of determining the cause of tube failure.

WATERSIDE DEPOSITS include scale, sludge, corrosion deposits, and high-temperature oxide.

FIRESIDE DEPOSITS include soot, slag, corrosion products, and high-temperature oxide.

SOOT is a broad term used to cover all of the ash products (other than slag) that result from combustion. These ash products include carbon, sand, salts such as sodium sulfate, and other materials. Soot deposits are usually powdery or ashy on the tube surfaces near the top of the boiler, but tend to be packed solid on drums, headers, and the lower ends of the tubes.

SLAG is not a powdery or packed ash like soot; rather, it is a salt-like material that is fused to the tube surfaces. Slag is objectionable

on boiler tubes because it retards the transfer of heat to the tube metal and because it may cause gas channeling, with consequent local overheating of tube metal that is not covered by the slag. Most slags on boiler tubes are soluble enough so that they can be controlled by periodic washing of firesides. The main way to prevent slag is to avoid burning fuel oil that is contaminated with sea water.

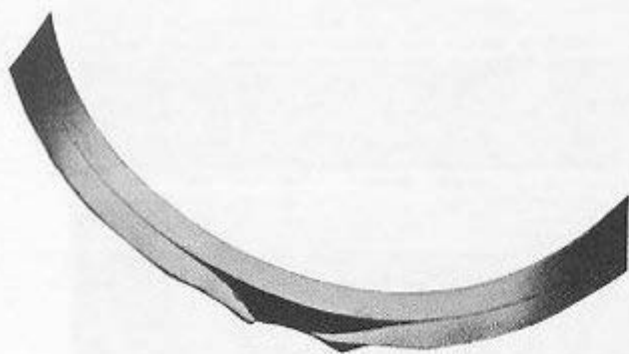
CORROSION DEPOSITS seldom form major fireside deposits. Occasionally, however, bulky deposits of ferrous sulfate may form as the result of the combination of soot and large amounts of water. These deposits have been known to travel away from their original location and adhere to remote rows of generating tubes. The deposits can usually be removed by water washing and mechanical cleaning. The source of the water leakage should be found and corrected. Also, the location of the original deposit should be found and the area should be carefully inspected for signs of corrosion.

HIGH-TEMPERATURE OXIDE is the term applied to heavy fireside layers of mixed iron oxides formed by overheating the tube metal. Low water is a frequent cause of high-temperature oxide on the tube firesides. The high-temperature oxide has a rather layered appearance; it resembles corrosion products, and is often wrongly called "scale."

REFRACTORIES

The refractory materials which line the boiler furnace retain heat for a long time, and so help to maintain the high furnace temperatures required for proper combustion. Refractories are also used to form baffles that direct the flow of combustion gases and that protect drums, headers, and tubes from excessive heat and flame impingement.

Refractories used in naval boilers are required to withstand severe service conditions and must therefore meet very high requirements. They must be able to resist the cutting action of the flame (flame erosion) that tends to occur because flame contains very small particles of solid matter. They must expand and contract uniformly, since unequal expansion sets up mechanical stresses in the refractories and unequal contraction causes cracks to develop. They must be resistant to thermal shock, caused by rapid changes of temperature, and as resistant as possible to the action of slag.



98.157

Figure 2-36.—Lamination of tube wall (fabrication defect).



Figure 2-37. —Tube fold (fabrication defect).

98.158



Figure 2-38.—Stretched or necked tube (fabrication defect).

98.159

Refractories used in naval boilers include firebrick, high-temperature insulating brick, insulating block, plastic firebrick, baffle mix (sometimes called castable mix), high-temperature refractory insulating castable, air-setting mortar, plastic chrome ore (PCO), and chrome castable refractory.

Additional information concerning the composition of refractories, securing devices, and installation of refractories can be obtained from either the Bureau of Ships Technical Manual (chapter 9510) or the manufacturer's technical manual for the specific installation.

Inspection and Repair

Under normal conditions, the boiler brickwork should last for a number of years without complete renewal, provided it is properly installed and is given adequate care after installation. When part of the furnace lining fails in any of its designed purposes, the boiler efficiency drops and there is danger of burning some metal part. Frequent inspections of refractories and casings, together with early repairs to any weak spots, can do much to prevent failure of the refractories and to postpone the need for complete renewal.

The frequency with which the refractories should be inspected depends upon the service conditions of the boiler. If the boiler is being steamed at high rates, or if rapid fluctuations are required, or if low grade or contaminated fuel is being used, deterioration of the refractories is likely to be rapid and inspections should be made as often as possible. If the boiler is being operated under relatively steady conditions, with good fuel oil, inspections may be made less frequently.

Before replacing or repairing brickwork, a great deal must be known about the condition of the entire refractory installation. On the basis of close inspection and careful measurements of wall and floor thicknesses, a decision will have to be made as to how much the refractories have been damaged in service, how much more deterioration must be expected before the next availability for repairs, and how well a good repair job will hold up under the expected conditions of service.

Causes of Refractory Deterioration

When the boiler is fired, the refractories undergo many physical and chemical changes.

Some refractories may not return to their original shape after they are heated, but may show a slight permanent expansion or contraction. Heat changes the mineral content of all refractories. As a rule, the change is slight and does not materially affect the quality of the refractory; in other cases, however, the change may be sufficient to cause failure of the furnace lining. Certain compounds in the furnace gases attack the refractories, in some cases causing considerable damage.

The two major causes of deterioration of the furnace lining are SLAGGING and SPALLING. Slag is formed when ash and other unburnable materials react with the brickwork. Although the ash content of fuel oil is low, there is always enough present to damage the refractories. The most dangerous slag-forming materials are vanadium salts and sodium chloride (the major salt in sea water).

If the slag that formed on the brickwork would remain in place, it would not cause any particular difficulty. Actually, however, the slag will not remain in place. Instead, it peels off or melts and runs off, taking some refractory with it and exposing a fresh layer of refractory to further slag attack.

The peeling of the refractory occurs basically because the layer of firebrick that has been penetrated by the slag has a different coefficient of expansion than the original firebrick. When temperature changes occur, therefore, a cleavage plane is formed and the slagged layer cracks and breaks off. The loss of firebrick through cracking and subsequent breaking or crumbling is known as SPALLING.

Spalling can also occur from temperature changes alone, without any slag being present. However, true thermal spalling is quite rare in modern naval boilers because the firebrick now used is of very high quality and is highly resistant to thermal spalling. Figure 2-39 shows a furnace wall in which the brick to the left of the expansion joint has been destroyed by true thermal spalling; to the right of the expansion joint, some slag penetration has occurred and some spalling from this cause has begun.

A particular type of slag results from using fuel oil that is contaminated with salt water. This slag, shown in figure 2-40, is very glassy in appearance. Glassy slag that melts and runs over the refractories is usually much more damaging than peeling slag.

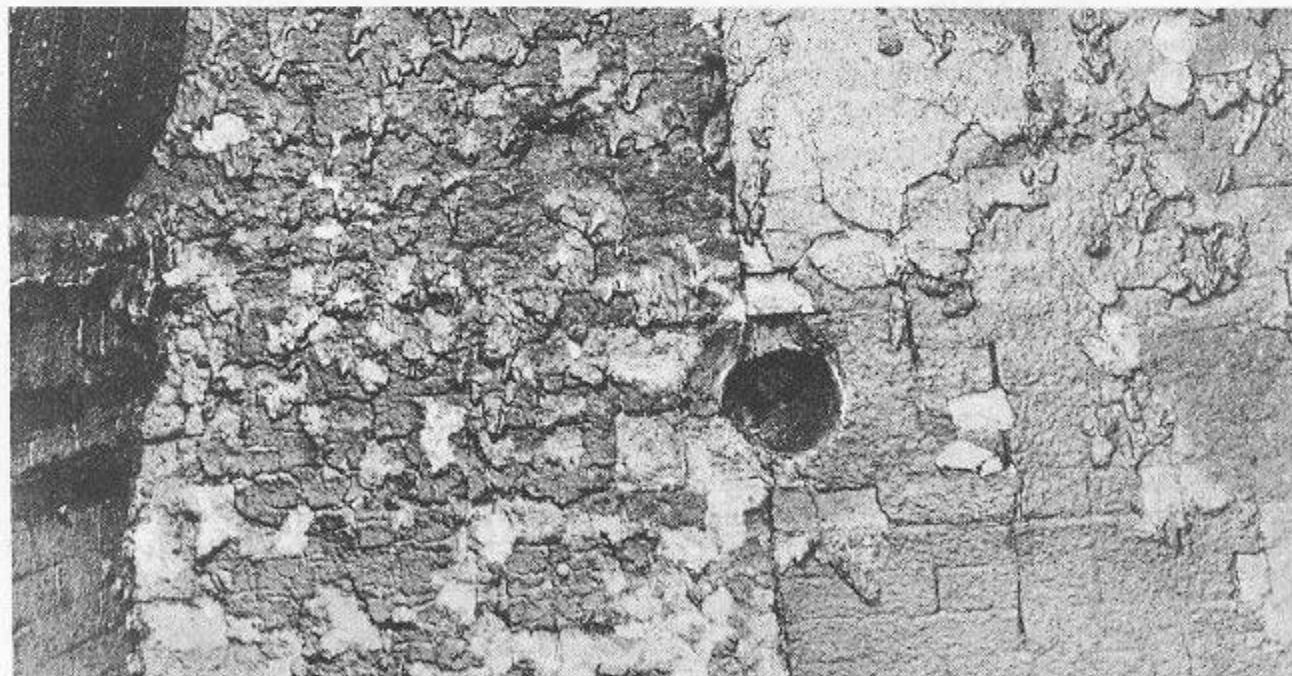


Figure 2-39.—Thermal spalling (left) and slag action (right).



Figure 2-40.—Glassy slag resulting from sea water contamination of fuel oil.

98.131

Another cause of furnace deterioration is **FIREBRICK SHRINKAGE**. True shrinkage—that is, permanent shrinkage—is relatively rare when approved firebrick is used. However, this defect does sometimes occur even in approved refractories. It is important to recognize true shrinkage, should it occur, because of the extremely dangerous condition it creates. When the firebrick shrinks, the hot-face dimensions of each brick become measurably smaller than the cold-face dimensions. Consequently, there is an open space around each brick and the entire wall or floor becomes very loose. Figure 2-41 shows the appearance of a wall and sloping deck in which true shrinkage of firebrick has occurred. A wall having this appearance is **DANGEROUS**, and should be completely renewed as soon as possible.

The regular expansion and contraction of refractories that occurs as the furnace is alternately heated and cooled is not permanent, and

therefore does not have as serious consequences as a true volume change. However, rapid changes of temperature cause unequal expansion or contraction and thus set up unequal stresses that may lead to serious failure of the refractories. Rapid raising of steam is probably more injurious to the refractories than to any other part of the boiler. Emergencies may arise which require the rapid raising or lowering of furnace temperatures; but it is important to remember that the refractories cannot stand this treatment very often. As a rule, raising the furnace temperature too rapidly is likely to cause the firebrick to break at the anchor bolts; lowering the furnace temperature too rapidly is likely to cause deep fractures in the firebrick.

Refractories are also damaged by any type of mechanical strain. Continued panting or vibration of a boiler may cause a weakened area of wall to be dislocated so that the bricks will fall out onto the furnace floor. Proper operation



Figure 2-41.—Wall and sloping deck, showing excessive shrinkage of firebrick.

98.132

of the boiler, with particular attention to the correct use of burners and forced draft blowers, will generally prevent panting or vibration.

Repairing Furnace Walls

Furnace walls should be repaired, rather than completely renewed, whenever feasible. Some walls that appear to be badly slagged and spalled may actually have many hundreds of hours of service left in them. Walls that are actually in good condition are often torn down and replaced merely because they "look bad." On the other hand, some walls look reasonably good and yet are dangerously thin as a result of slag and spalling.

The only way to really determine the condition of a furnace wall is to measure the wall thickness at the thinnest point. Usually this can be

done at an expansion joint. Sometimes, however, it will be necessary to remove a brick from the worst area and measure its thickness. A wall with firebrick $4\frac{1}{2}$ inches thick can lose no more than $1\frac{1}{2}$ inches of firebrick before there is danger of the casing becoming overheated.

When a wall is found to be dangerously thin, it must be replaced immediately. If inspection of a wall indicates that the wall might become dangerously thin before the next availability, the possibility of immediate replacement should be considered.

Note that slag must NEVER be removed from furnace walls unless the walls are to be rebricked immediately. It is impossible to remove slag without also removing brick.

When a wall is not to be rebricked immediately, all holes or damaged spots should be

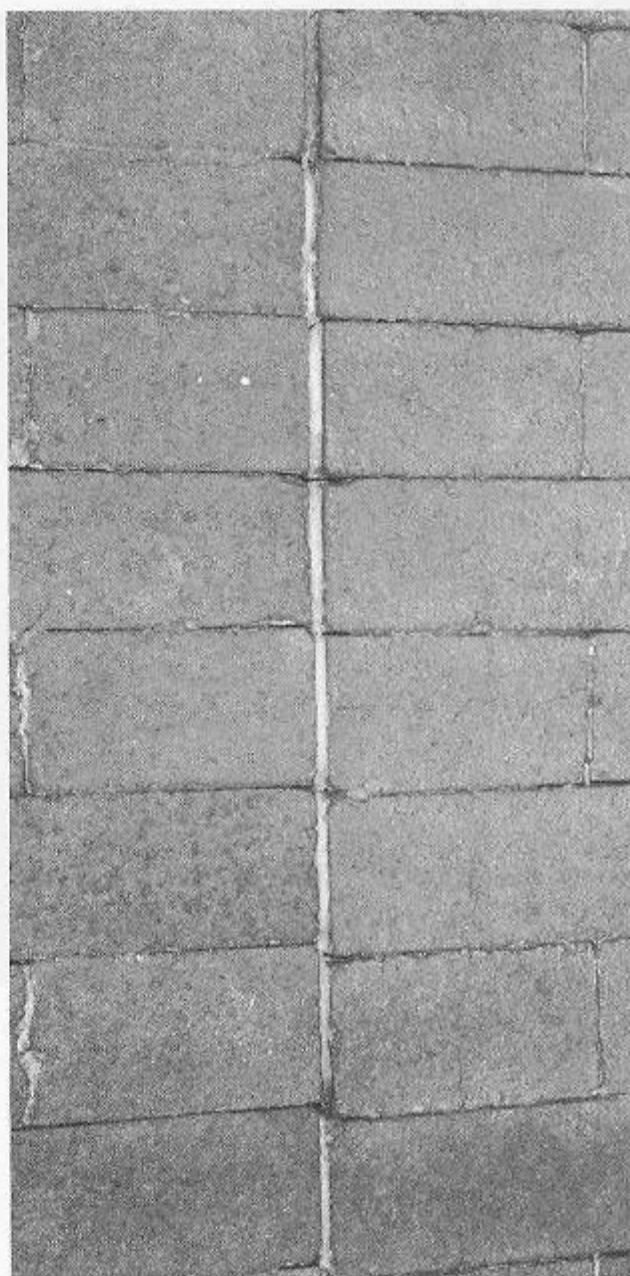
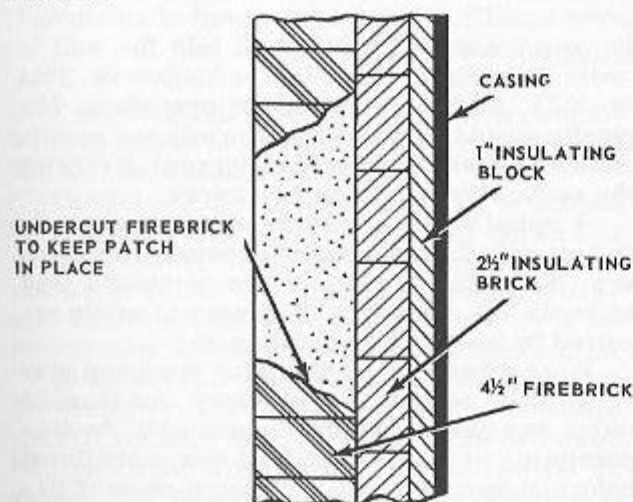
patched. Broken or loose brick should be replaced, or repaired with plastic refractory material. Figure 2-42 illustrates the proper method of patching with plastic refractory.

Repairing Furnace Floors

After a period of some years, the slag accumulation on the furnace floor will probably reach the point where it will be struck by flame and unburned oil from the burners. Loose slag may be swept out. Hard, fused slag is extremely difficult to remove without damaging the brickwork. If objectionable flame striking occurs when the slag is fused solid, the furnace floor must be renewed.

Care of Expansion Joints

Expansion joints should be inspected for signs of incomplete closure. It is important that the expansion joints be free of grog particles and mortar so that the joints CAN close properly when the boiler is fired. You can tell whether or not an expansion joint is closing completely when it is heated by inspecting it when it is cold. If the inside of the joint is light in color when the furnace is cold, the expansion joint is closing properly. Figure 2-43 shows an expansion joint that has closed properly when the furnace was hot; note the light color of the inside of the joint. If an expansion joint does not close properly when heated, the inside will be darkened and discolored.



98.133
Figure 2-43.—Expansion joint. Light color of joint indicates proper closure.

The same method can be used to tell whether or not cracks in the refractory are closing when the furnace is fired. If the cracks are dark, showing that they do not completely close, they should be filled with air-setting mortar.

Slag should be removed from expansion joints only if the removal may be accomplished without

38.196
Figure 2-42.—Undercutting firebrick to hold plastic patch in place.

breaking off the corners of the firebrick. Since the slag tends to cover only the surface, there is usually an open joint behind the slag to provide the necessary expansion space.

Loose particles often clog expansion joints and so prevent proper working of the brick when the furnace is fired. Always clean out as much material of this sort as possible without damaging the brickwork. With new installations, it is particularly important to keep the expansion joints open before they slag over.

Care of Copings, Fillets, and Baffles

The refractory materials used to protect drums and headers and used for fillets may fail in service either from slagging or from breaking up, depending upon the material that is used. Plastic fireclay tends to be eroded by slag; the chrome ore materials tend to crumble on the surface; castable refractories crack and sometimes spall on the surface. All copings, fillets, and baffles should be replaced or repaired, as required, as soon as the damage is evident.

Maintenance and Repair of Burner Fronts

Burner fronts require replacement more frequently than any other part of the furnace lining. It should be noted, however, that burner fronts are often replaced unnecessarily merely because they are somewhat cracked or slagged. Repairs or replacement should only be considered when cracks have loosened sections of the refractory, when slag or displaced refractory interferes with the flame, or when the cone angles differ from the specifications. It should be remembered, also, that it is not always necessary to replace the entire burner front when only a part of it is damaged; a good patch is relatively cheap, and can extend the service life of the front for several hundred hours. (NOTE: Plastic refractory is used for patching all types of burner fronts.)

The first firing of a new installation does more damage than any other single firing. Therefore, the first inspection is always an important one. The unfired burner front may appear to be in perfect condition while actually containing defects of material or workmanship that will show up immediately in the first firing.

Radial cracks of the type shown in figure 2-44 may be found on the first inspection. These cracks are not harmful. They are caused by

stresses resulting from the normal expansion and contraction of the refractory as it is heated and cooled. After the structural cracks occur, the stresses are relieved and there should be no further cracking of this type.

Cracks that eventually result in extensive damage form about 1 to 3 inches back from the furnace side of the installation. These cracks run approximately parallel to the surface, and are therefore called parallel cracks. Figure 2-45 shows parallel cracking of the burner cone. Parallel cracks usually appear at or slightly behind the leading edge of the bladed cone. They are not dangerous until they actually loosen pieces of the burner front.

Some combination of factors relating to installation and to boiler operation is probably responsible for parallel cracking. In general, it is known that the following conditions tend to cause parallel cracking: (1) low temperature during the initial firing; (2) rapid changes in steaming rates shortly after the initial firing; (3) sustained high operating temperatures; and (4) poor quality refractory or faulty installation.

After several hours of steaming, slabs of plastic about 1/2 to 1 inch thick may separate from the burner front surface and fall off. This defect is definitely caused by the fact that the surface layer is more densely rammed, during installation, than the remainder of the plastic. In service, the more dense section expands and contracts at a different rate than the less dense part; consequently, the surface layer soon cracks off. The dense ramming of the surface layer usually occurs as a result of an attempt to pound excess plastic back into the wall in order to bring it even with the brickwork. This is NOT correct installation procedure. The plastic should be pounded uniformly and evenly, and excess plastic should be scraped off to bring the surface even with the brickwork.

A radial crack is sometimes joined by a slanting crack in the narrow section between the burners. When this occurs, pieces of plastic tend to break off. This type of damage is easily repaired by means of a plastic patch.

When a castable burner front breaks up after very little service, it is likely that too much water was used in mixing the material. Another possibility is that the material was partially set before it was installed; a common cause of this trouble is that the castable, while in storage, reacts with moisture in the air and begins to set in the bag. This setting destroys some of the binder, and thus prevents the installation from

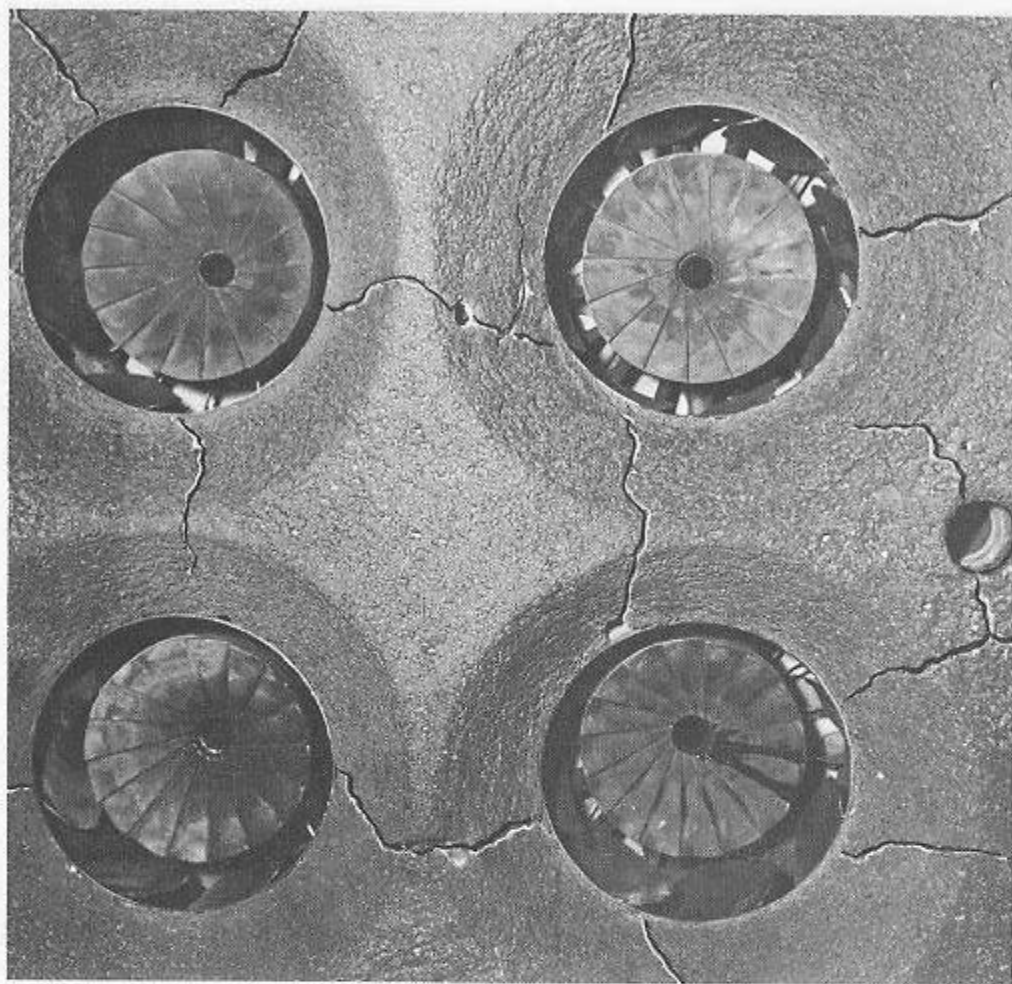


Figure 2-44.—Radial cracks in burner front.

98.134

ever reaching full strength. Castable should always be stored in a dry place. Any castable that has hardened should be discarded.

Castable, like other refractories, is subject to spalling. After several hours of service, a castable burner front may be found to be peeling off in 1/8-inch strips. The peeling material should not be removed unless it is in the burner cone and is interfering with combustion.

If the surface of a castable front is chalky or crumbly, find out how deep the condition goes. If no more than the surface can be rubbed off, the burner front has not been harmed. Do not remove the crumbly material. The condition is not serious unless the burner cone is affected or the casing shows signs of having been overheated; in such cases, of course, the burner front must be renewed.

Distorted flames, excessive carbon deposits, and other signs of poor combustion may indicate that the burner cone is out of shape. Although other factors may cause poor combustion, the burner cone should always be checked when any of these signs are noted. If the burner cone angle is off by as little as 3 degrees on either side, the interference with combustion will be noticeable. When a burner cone is distorted enough to interfere with the mixing of oil and air, the section that is not true must be cut out and replaced.

The extent of damage to a burner front should be the determining factor in the decision whether to repair the burner front or to replace it. As a general rule, it pays to replace the installation if more than 25 percent of the total surface is damaged. However, burner fronts should be



Figure 2-45.—Parallel cracks in burner front.

98.135

repaired rather than replaced if they are still protecting the casing and allowing proper mixing of air and oil. Even a large patch can be as permanent as the rest of the installation provided it is properly installed.

Plastic refractory should be used for patching both plastic and castable burner fronts. The patching material will not adhere to the refractory that has already set; therefore, it is always necessary to undercut the old material. Note, however, that undercutting alone will not hold a large patch. When a large patch is to be installed, a sufficient amount of old material will have to be cut out to allow the required number of anchor bolts or anchor strips to secure the new material.

A plastic patch will hold to the old material if the joining surfaces are thoroughly wet. Unless the new patch covers more than 10 square inches, it is not necessary to vent the material; however, it should be stippled in the usual manner. It is not necessary to bake out a patch.

While work is being done on a burner front, care should be taken to protect all open expansion joints in the floor. A tarpaulin or some other cover should be used to keep loose mate-

rial from getting into the open joints. When the work has been finished, the open joints should be carefully cleaned out and all loose particles removed.

MANHOLE AND HANDHOLE FITTINGS

At each regular boiler overhaul, all manhole and handhole fittings and the gasket seating surfaces on the drums and headers must be cleaned, inspected, and repaired or renewed if necessary. If the plates are warped, distorted, or otherwise damaged, they must be repaired or renewed.

Whenever manholes and handholes are opened new gaskets must be fitted. After a gasket has once been compressed, it cannot be reused but must be discarded. The correct size and type of gasket must be used. Makeup compound on the seating surfaces must not be used when installing the gaskets.

Before installing a new gasket, the two gasket seating surfaces (one on the drum or header and one on the plate) should be cleaned.

The cleaning must be very thorough. All corrosion products or other surface deposits and all adhering pieces of the old gasket must be removed. It is impossible to obtain a tight joint as long as any foreign matter remains on either seating surface or in the corners of the fitting. (Gaskets must be installed in accordance with procedures outlined in chapter 9510 (51) of the Bureau of Ships Technical Manual.)

Power-driven wire brushes are best for cleaning the seating surfaces. Scraper-type tools should be used only when wire brushes are not sufficient to clean the surface. Scraper-type tools must be used with great care if they are used at all, since they tend to remove too much metal from the seating surfaces.

If the gasket seating surfaces show extensive signs of pitting, it may be necessary to have these surfaces machined or reground. If the seating surface on a manhole or handhole plate is very badly pitted or damaged, it may be necessary to discard the plate and replace it with a new plate or with one that has previously been machined to blueprint specifications.

The clearance between the shoulder of a manhole plate and the manhole must not exceed $1/16$ inch when the plate is centered accurately. Figure 2-46 shows where the clearance is measured. If the clearance is found to be greater than $1/16$ inch, the plate should be built up by electric welding at the inner edge of the shoulder. Except in an emergency, this welding should be done at a naval shipyard so that the manhole plate may be stress relieved after it is welded and so that the welded surface may be remachined.

To ensure proper positioning of a manhole gasket, contract it on the long axis until the inner

edge of the gasket fits the shoulder snugly at the ends of the long axis of the manhole plate. The clearance between the gasket and the shoulder should be equalized at the top and bottom of the short axis. Do NOT allow the outer edge of the gasket to protrude at any point beyond the gasket seating surface in the drumhead. If an edge protrudes, the gasket may unravel when it is compressed by the tightening of the manhole cover. Discard any gasket that protrudes beyond the edge of the gasket seating surface.

To install a manhole or handhole plate, first center the fitting in the opening. Make sure that the shoulder does not bind on the edges of the opening. Then slip the yoke on and start the stud nut. Run the nut on the stud until it is hand-tight, and then give the nut one quarter of a turn with a wrench. Do NOT tighten the nut enough to compress the gasket.

When the boiler is given a hydrostatic test, the pressure of the water usually forces the manhole and handhole gaskets into place and thus ensures proper seating. The plates are first set up lightly. When the boiler is ready for testing, the pressure should be pumped up to within 50 psi of the hydrostatic test pressure, regardless of any leakage from the manhole or handhole plates. Leakage is likely to be general at first, but it will decrease as the pressure is increased. When the pressure is within 50 psi of the test pressure, most of the leakage will stop, although the nuts will still be loose.

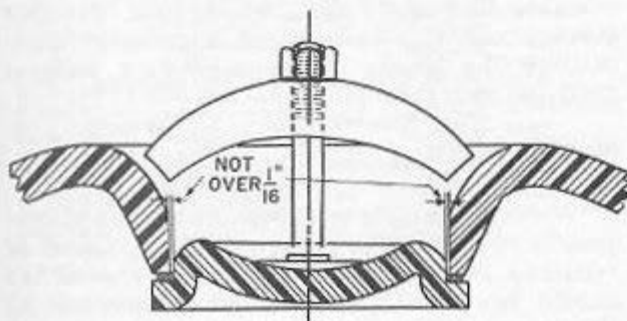
If some plates are leaking very badly, the trouble is probably caused by improper seating of the gaskets. As a rule, the gasket is caught on the outer edge, between the edge of the plate and the edge of the counterbore for the seat. A light blow with a hand hammer on the outside of the plate will usually relieve the tension on the gasket and allow it to seat properly.

After leaky gaskets have been adjusted, and while full test pressure is on the boiler, set up on all plates firmly. Use only the wrenches specified for this purpose.

Some economizer headers and a few superheater headers are fitted with handhole plugs instead of handhole plates. Detailed instructions for installing and removing the plug-type handhole fittings are given in appropriate manufacturers' technical manuals.

SOOT BLOWERS

Each time that a boiler is taken out of service, the soot blowers should be checked as



38.205
Figure 2-46.—Manhole plate clearance.

thoroughly as possible. A complete examination of the soot blowers should be made at least once a year.

Soot blower piping and connections should be examined at each major overhaul and at any other time when there is reason to suspect unsatisfactory conditions. In order to inspect soot blower piping, it will be necessary to remove some of the insulation and lagging. Be sure the piping is correctly reinsulated and relagged after the inspection. Note that insulation and lagging should NOT be used on soot blower steam piping that is located underneath floor plates. If such lines were insulated and lagged, corrosion would be likely to proceed, unnoticed and unchecked, with consequent danger of the line giving way.

Drain nipples or drain valves are provided at the low points in the supply piping. The drain nipple usually has a hole that is 1/8 inch in diameter. The drain valve may have either a hole drilled in the valve disk or a notch cut in the valve seat. All drain openings must be checked with a probe from time to time to make sure that they are open.

On most multinozzle soot blowers, there are three places that require the occasional addition or renewal of packing: (1) around the valve stem; (2) around the swivel tube at the point where the tube enters the gooseneck; and (3) around the swivel tube at the point where the tube enters the floating stuffing box. Split-ring packing is used in all these locations.

If leaks cannot be stopped by taking up on the packing gland, the addition of one or two packing rings may solve the problem. If leakage is severe, or if the old packing has been in service for a long time, it is best to remove all the old packing and replace it completely. Detailed instructions for replacing packing in soot blowers are usually given in the manufacturer's technical manual for the boiler.

The metal used in soot blower elements depends upon the gas temperatures to which the element will be exposed. Therefore the elements are NOT interchangeable even if the nozzles are identical in size and spacing. When soot blowers are disassembled for any reason, take particular care to see that each element is reinstalled in its proper unit.

Additional information on the maintenance and repair of soot blowers will be found in the manufacturer's technical manual for the boiler.

The proper pressure in the steam soot blower head which permits best results in cleaning is specified in the applicable boiler or soot

blower technical manuals or drawings. If no designated pressure can be found, the pressure should be approximately 300 psi. This pressure can be checked by temporarily installing a pressure gage at the connection provided on the head or at the element flange for this purpose. If it becomes necessary to adjust the pressure, applicable manuals or drawings should be consulted, as some soot blowers are pressure adjusted by means of an orifice in the companion flange, some by means of an adjustable orifice inside the head, and some by valve spring adjustment. Sufficient time must be allowed for gradual and thorough warmup of the steam lines before steam is admitted to the soot blowers. If this precaution is not observed, the piping may be subjected to thermal shock, thereby inducing excessive thermal stresses which, in turn, could result in failure of the piping.

BOILER SLIDING FEET

Boiler sliding feet must always be free to move. They must never be painted, and rust, scale, dirt, or other foreign matter must not be allowed to accumulate at the sliding feet. When sliding feet are cleaned and lubricated, an entry must be made in the engineering log. At each boiler cleaning period, the sliding feet must be examined to be sure that they are free to move. To check whether or not the sliding feet have been moving, the metal on the stationary base can be examined. If the sliding feet have been moving, there will be a small area of bright metal about 1/8 to 3/8 inch long on the base. If there is no area of bright metal, the sliding feet are not free to move. In this case, free the sliding feet and then lubricate them. Loosen the bolts and remove the grease fittings. Brush and scrape the area as thoroughly as possible to remove dirt, scale, rust, or other foreign matter. Then apply a penetrating oil through the grease fitting connection, using a 2000-psi hydraulic pump.

WATER GAGE GLASSES

Water gage glasses must be examined frequently and defective parts must be replaced or repaired as necessary. The frame assemblies should be dismantled at regular intervals so that the condition of the mica sheets may be determined. Broken or cracked mica sheets should be replaced immediately, since the line of a break

or a crack in the mica may easily be mistaken for the line of the water level.

The frames should be examined for leakage around the glasses. A leak between the glass and the gasket may produce a line that might be mistaken for a water level line. Also, continued seepage or leakage across the glass may produce a channel or groove that could be mistaken for the line of a water level. Persistent leakage will, in any case, tend to weaken the glass. If leakage between the gasket and the glass cannot be corrected by tightening the bolts, new gasket and new micas should be installed.

When assembling a water gage, first screw the bolts fingertight and then pull them up lightly with a wrench. When doing this, work from the center toward each end of the glass, alternately, so that the stress will be evenly distributed. After the assembled gage has been installed and the boiler is under steam, pull up the bolts securely. Again, start working at the center and work alternately toward each end. The bolts must be tightened several times again after the boiler has warmed them up. Also, they must be re-tightened from time to time.

The discussion so far applies to water gages generally, with particular reference to the standard water gages used on 600-psi boilers. The remainder of the discussion deals with some of the special considerations that apply to water gage glasses used on high pressure boilers.

The gaskets used in the assembly of water gages for high pressure boilers are not always of the same thickness, as may be seen in the cross-sectional view of a gage shown in figure 2-47. In this particular water gage, a gasket

1/32 inch thick is used between the body of the gage and the mica shield. Another gasket, called a cushion, located between the cover and the glass, is 1/16 inch thick.

Figure 2-48 shows several parts of the water gage assembly that is shown in cross section in figure 2-47. Notice the end spacers that are used to keep the glass centered in the body and to keep the glass from touching the metal body.

The sequence for tightening the bolts on high pressure water gages is basically the same as that previously described for the assembly of standard water gages. However, the manufacturer's instructions and drawing should be followed carefully. A special type of torque wrench (fig. 2-49) can be used on the high pressure water gages.

Spare parts for all water gages—both 600 psi and high pressure—must be stowed carefully. Do not permit them to come in contact with iron or steel. Do not allow the glasses to become scratched.

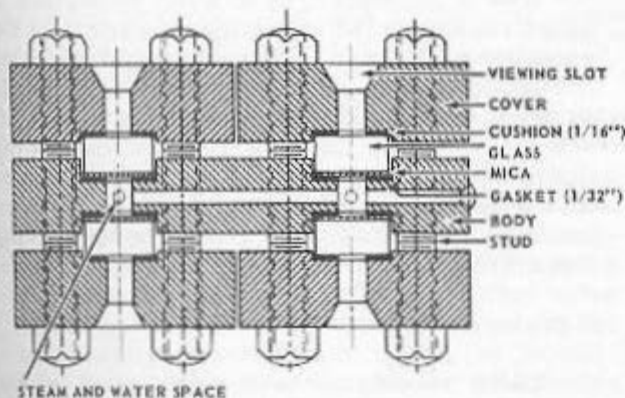
SAFETY VALVES

Naval boilers are fitted with steam drum safety valves and with superheater outlet safety valves. Several types of safety valves are in common use, but all are designed to open completely (pop) at a specified pressure and to remain open until a specified pressure drop (blow-down or blowback) has occurred. Safety valves must close tightly, without chattering, and must remain tightly closed after seating.

Steam Drum Safety Valves

The two types of steam drum safety valves discussed here are (1) the huddling chamber type, and (2) the nozzle reaction type.

A steam drum safety valve of the huddling chamber type is shown in figure 2-50. The initial lift or opening of the valve is caused by the static pressure of the steam in the drum acting upon the bottom of the feather. As soon as the valve begins to open, a projecting lip or ring of larger area is exposed for the steam pressure to act upon. The huddling chamber, which is formed by the position of the adjusting ring, fills with steam as the valve opens. The steam in the huddling chamber builds up a static pressure that acts upon the extra area provided by the projecting lip of the feather. The resulting increase in force overcomes the resistance of the spring, and the valve pops—that is, it opens



38.206

Figure 2-47.—Cross-sectional view of high pressure water gage glass.

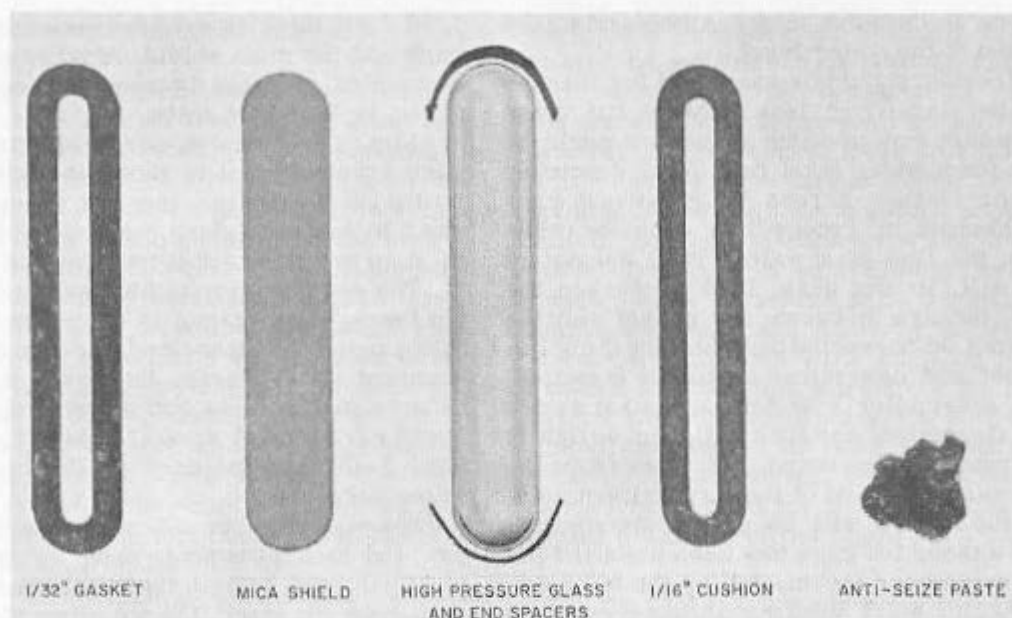


Figure 2-48.—Some parts of a high pressure water gage assembly.

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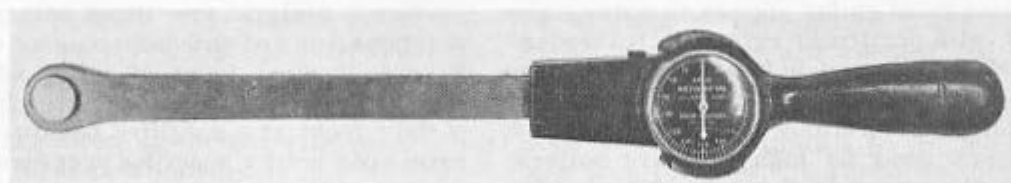


Figure 2-49.—Special torque wrench for tightening bolts on high pressure water gage assembly.

5.9

quickly and completely. Because of the larger area now presented for the steam pressure to act upon, the valve reseats at a lower pressure than that which caused it to lift initially. After the specified blowdown has occurred, the valve closes cleanly, with a slight snap.

The amount of tension on the spring determines the pressure at which the valve will pop. The position of the adjusting ring determines the shape of the huddling chamber and thereby determines the amount of blowdown that must occur before the valve will reseat.

A steam drum safety valve of the nozzle reaction type is shown in figure 2-51. The initial lift of this valve occurs when the static pressure of the steam in the drum acts upon the disk insert with force sufficient to overcome the tension of the spring. As the disk insert lifts, the escaping steam strikes the nozzle ring and changes

direction. The resulting force of reaction causes the disk to lift higher, up to about 60 percent of rated capacity. Full capacity is reached as the result of a secondary, progressively increasing lift which occurs as an upper adjusting ring is exposed. The ring deflects the steam downward, and the resulting force of reaction causes the disk to lift still higher. Blowdown adjustment in this type of valve is made by raising or lowering the adjusting ring and by raising or lowering the nozzle ring.

Superheater Safety Valves

Safety valves are always installed at the superheater outlet as well as on the steam drum. Superheater safety valves are sometimes set to lift at a lower pressure than that which lifts the steam drum safety valves, in order to ensure

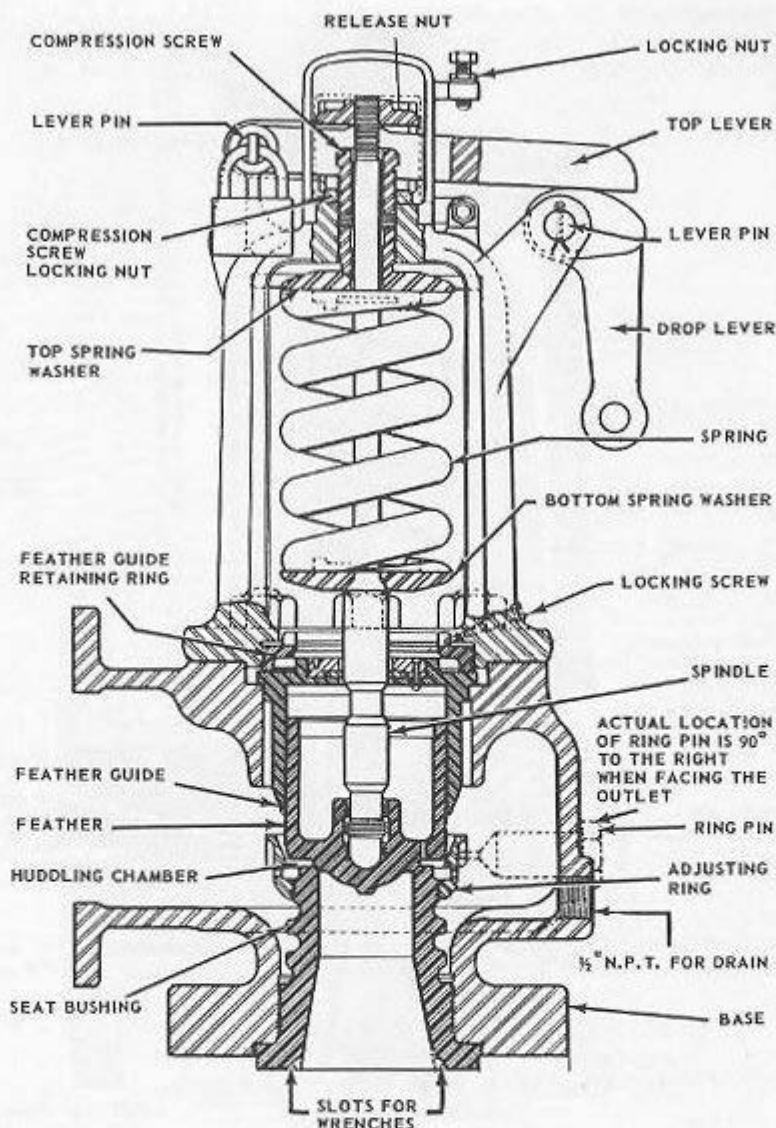


Figure 2-50.—Steam drum safety valve (huddling chamber type).

98.80

an adequate steam flow through the superheater when the steam drum safety valves are lifted. Three kinds of superheater safety valve arrangements are discussed here: (1) the pressure pilot-operated superheater outlet safety valve assembly, (2) the Crosby two-valve superheater outlet safety valve assembly, and (3) the Consolidated three-valve superheater outlet safety valve assembly.

Most double-furnace boilers are fitted with a **PRESSURE PILOT-OPERATED SUPERHEATER OUTLET SAFETY VALVE ASSEMBLY** of the

type shown in figure 2-52. This assembly consists of three connected valves: (1) a small spring-loaded safety valve installed on the steam drum; (2) an actuating valve installed on the steam drum; and (3) an actuated (or unloading) valve installed on the superheater. The stem of the drum valve is connected mechanically, by means of a lever, to the stem of the actuating valve. The actuating valve is connected by piping to the space above the disk in the superheater actuated (or unloading) valve. The unloading valve has no spring and relies solely on

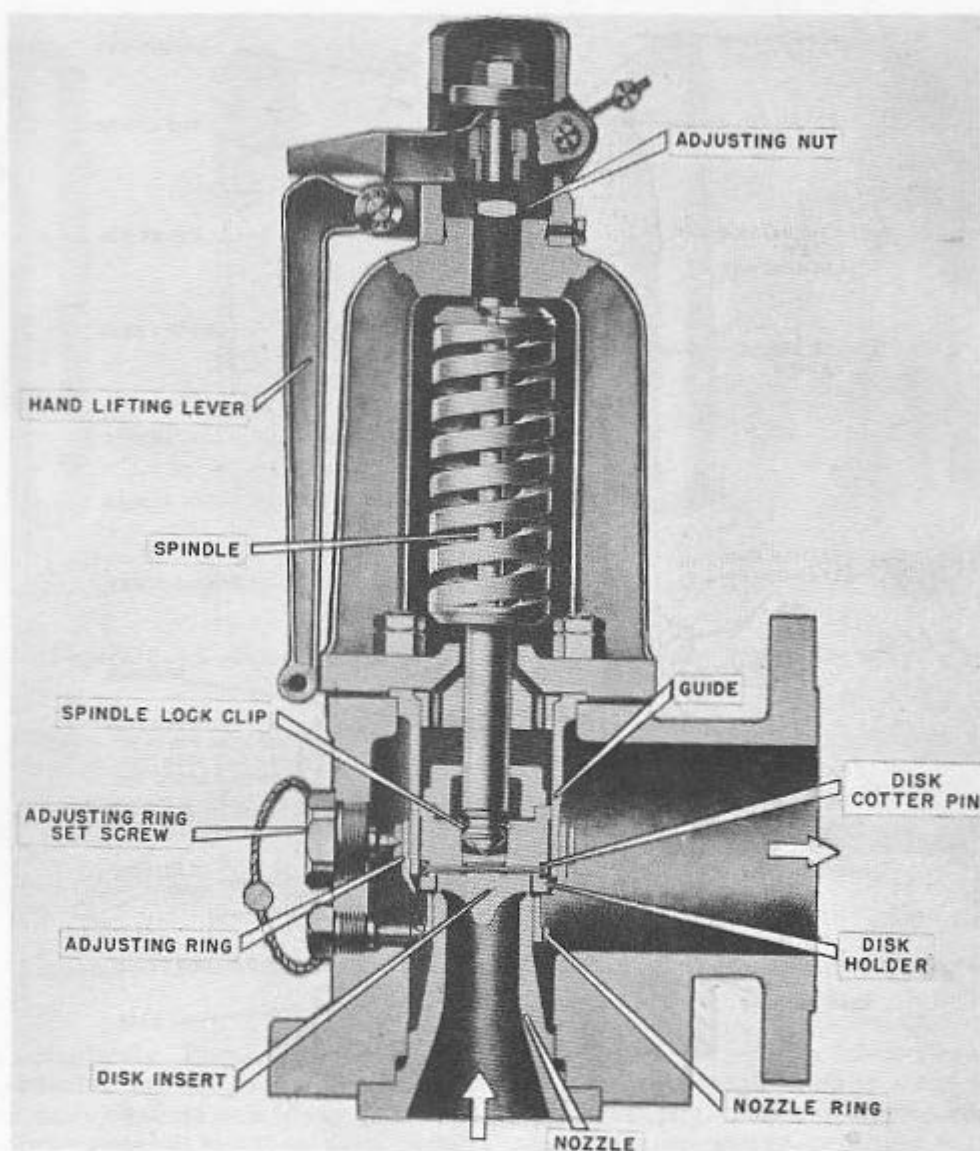


Figure 2-51.—Steam drum safety valve (nozzle reaction type).

29.219

pressure differential for its operation. Normally there is a static pressure above the disk of the unloading valve, since a small orifice (or in some designs a small clearance around the disk) allows some steam at superheater outlet pressure to enter the space above the disk.

When the drum valve is opened by steam drum pressure, the mechanical connection between the drum valve and the actuating valve causes the actuating valve to open also. With

the actuating valve open, steam flows from the space above the disk of the superheater unloading valve, through the actuating line, through the actuating valve, to the atmosphere. The sudden relief of pressure above the disk of the unloading valve causes that valve to open fully, so that steam is discharged from the unloading valve to atmosphere.

Many 1200-psi single-furnace boilers (and also some 600-psi single-furnace ones) are

equipped with Crosby TWO-VALVE SUPER-HEATER OUTLET SAFETY VALVE ASSEMBLIES of the type shown in figure 2-53. In an assembly of this type, both of the valves are

spring-loaded. The pilot valve on the steam drum and the superheater valve at the superheater outlet are connected by a pressure transmitting line that runs from the discharge side of

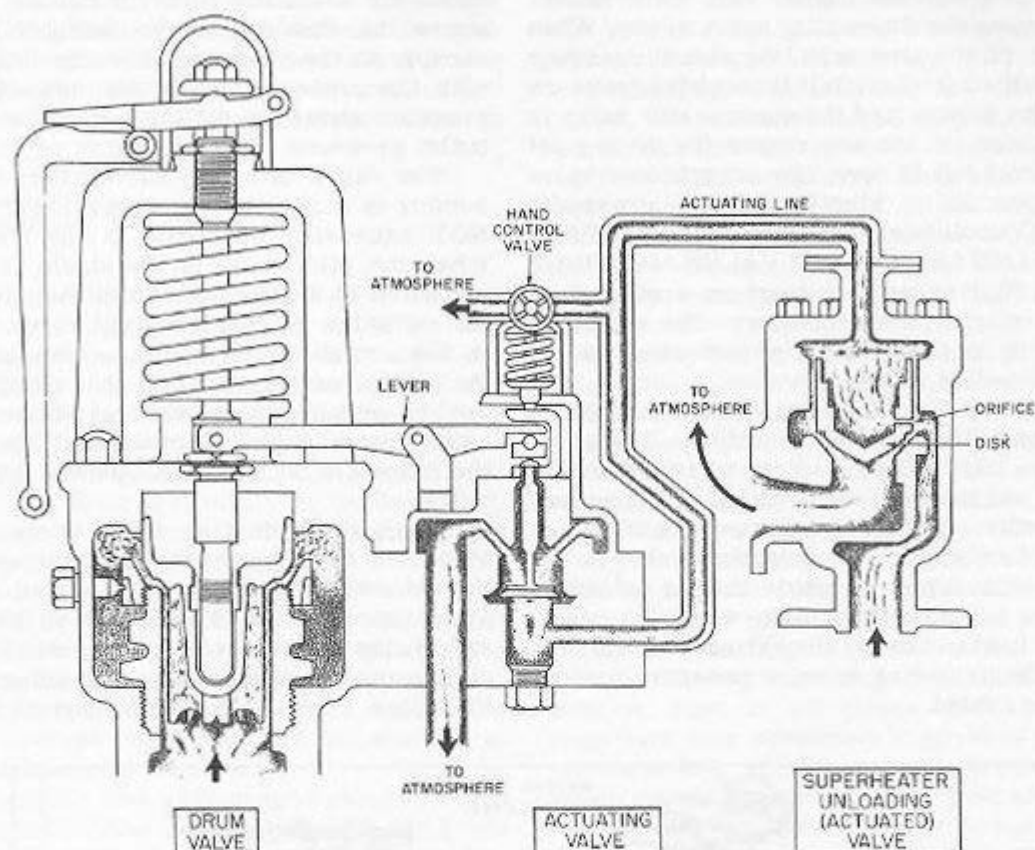


Figure 2-52.—Pressure pilot-operated superheater outlet safety valve assembly.

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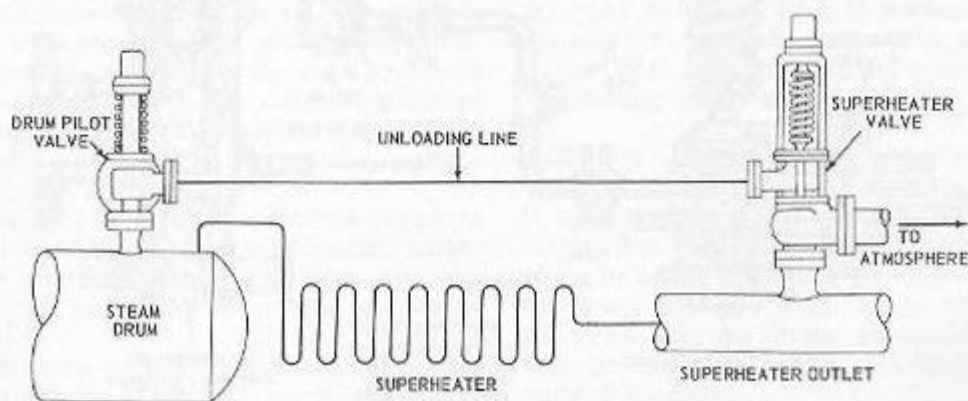


Figure 2-53.—Two-valve superheater outlet safety valve assembly (Crosby).

98.82

the drum pilot valve to the underside of the piston that is attached to the spindle of the superheater safety valve.

The superheater valve is set to pop at a pressure about 2 percent higher than the pressure which causes the drum pilot valve to pop. When the drum pilot valve pops, the steam pressure is transmitted immediately through the pressure line to the piston, and the superheater valve is thus actuated. If for any reason the drum pilot valve should fail to open, the superheater valve would open at a slightly higher pressure.

The Consolidated **THREE-VALVE SUPER-HEATER OUTLET SAFETY VALVE ASSEMBLY** shown in figure 2-54, is used on a number of 1200-psi single-furnace boilers. The assembly consists of a pilot valve, an actuating valve, and an unloading valve.

The spring-loaded pilot valve is mounted on the top centerline of the steam drum. The actuating valve and the unloading valve are assembled as a unit and mounted on the piping at the superheater outlet; they are connected to each other by a rocker arm. The actuating valve has a cylinder with a piston inside it. The unloading valve has a piston-type disk, without a stem, which is held in line by the cylinder in which it works. The unloading valve is pressure loaded, not spring loaded.

Steam from the superheater outlet enters the unloading valve cylinder and gathers around the valve disk above the seat. The steam bleeds through small ports to the space above the disk. When the actuating valve is closed, the steam above the disk of the unloading valve cannot escape, so the pressure above the disk equalizes with the pressure below the disk—that is, the pressure above the disk is equal to superheater outlet pressure.

The cause of safety valve lifting in this assembly is excessive pressure in the steam drum, NOT excessive pressure in the superheater. When the pilot valve on the steam drum opens, pressure is transmitted from the pilot valve to the cylinder of the actuating valve. Pressure in the actuating valve cylinder is applied under the piston, causing the spring to compress. The rocker arm moves upward at the end over the actuating valve and downward at the end over the unloading valve, thus opening the actuating valve.

When the actuating valve opens, pressure bleeds off to atmosphere. Since the space above the unloading valve disk is connected to the actuating valve, relief of pressure in the actuating valve also causes relief of pressure above the disk in the unloading valve. The unloading valve therefore opens, allowing steam to flow from

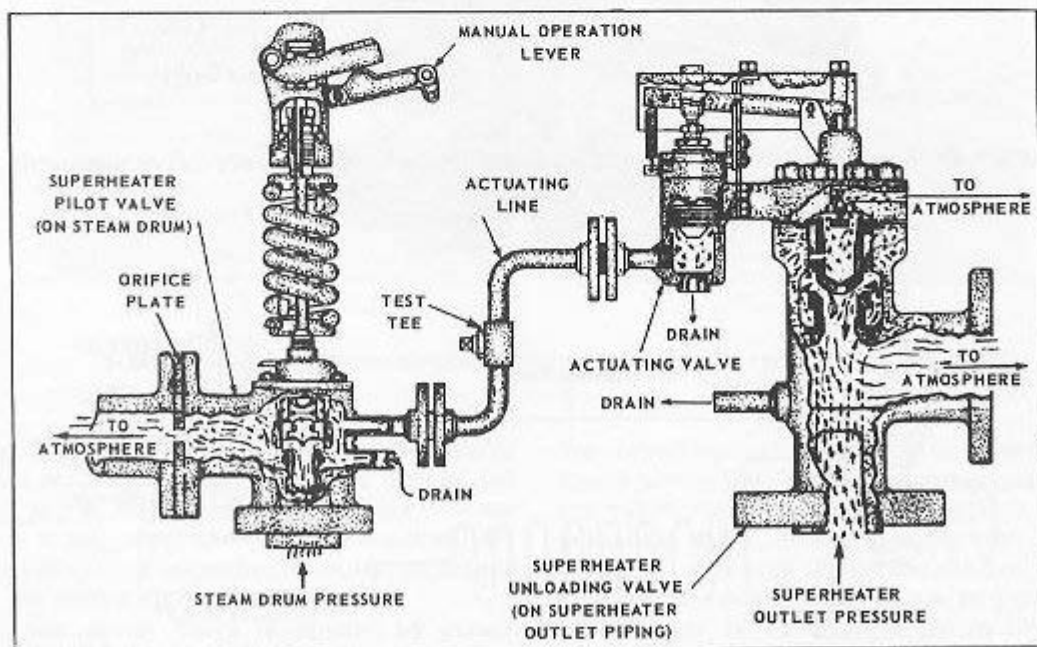


Figure 2-54.—Three-valve superheater outlet safety valve assembly (consolidated).

the superheater to atmosphere. When the pilot valve reseats, the actuating valve also reseats. As steam bleeds through the ports to the space above the disk in the unloading valve, pressure builds up and rapidly equals the pressure below the disk. The unloading valve closes. In summary, then, the superheater unloading valve always opens immediately after the steam drum pilot valve opens and closes immediately after the pilot valve closes.

Maintenance And Repair

Safety valves must be maintained in the best possible operating condition at all times. All tests, inspections, and adjustments must be made as required. However, unnecessary repairs or adjustments should not be made. As a general rule, leave safety valves strictly alone (except for the required tests and inspections) as long as their operation is satisfactory. Disturbance or alteration of the internal parts often causes unsatisfactory operation in valves were previously working all right.

After a period of service, it is likely that safety valves will simmer when they are within 1 1/2 to 2 percent of their popping pressure. Such simmering does not require corrective action, provided the valve does not simmer at the boiler operating pressure.

The popping and reseating pressures which are stamped on the valve name plate and given in the manufacturer's technical manual are specifically authorized by the Naval Ship Systems Command. If, after repeated efforts, the exact authorized popping pressures cannot be obtained, the following popping pressure tolerances are considered satisfactory as long as all valves on the boiler still pop in their proper sequence:

1. On boilers with a steam drum pressure of 325 psi or below (300 psi nominal standard safety valves or less) the desired tolerance is plus or minus 2 psi and the maximum tolerance is plus or minus 3 psi.

2. On boilers with a steam drum pressure of 326 to 710 psi (600 psi nominal standard safety valves) the desired tolerance is plus or minus 3 psi and the maximum tolerance is plus or minus 5 psi.

3. On boilers with a steam drum pressure of 711 to 1410 psi (1500 psi nominal standard safety valves) the desired tolerance is plus or minus 5 psi and the maximum tolerance is plus or minus 10 psi.

Safety valve settings must NEVER be increased or decreased without authorization from the Naval Ship Systems Command. Before authorization is given to increase safety valve settings, the boiler must be thoroughly inspected and hydrostatically tested for strength at 150 percent of designed pressure.

For continued satisfactory operation of safety valves, it is essential that all original dimensions be maintained very closely. Worn parts should be replaced when necessary. Grinding in of valve parts should be kept to a minimum, since any grinding involves the removal of metal and therefore changes the original dimensions. A safety valve may be ground in lightly once or twice without any appreciable effect on the clearances; but heavy or repeated grinding will change the dimensions and cause unsatisfactory operation of the valve.

In many cases, neither the equipment nor the technical skill required for a complete overhaul of safety valves is available on board ship. Whenever possible, safety valves in need of repair should be overhauled by a naval shipyard or by some other repair activity. Emergency repairs must sometimes be made, however, so it is important that a full allowance of boiler safety valve repair parts and tools be kept on hand at all times; and it is equally important that personnel concerned have some understanding of the correct procedures for repairing safety valves. When your ship's safety valves are to be overhauled by a repair activity, you will find it to your advantage to go and watch the experts working on the valves.

Additional information dealing with maintenance of safety valves can be obtained from either the Bureau of Ships Technical Manual (chapter 9510) or the manufacturer's technical manual for a specific valve. The sections which follow deal with information concerning testing and setting safety valves.

TESTING AND SETTING SAFETY VALVES.—

Before a safety valve is installed on a boiler, it must be given a hydrostatic test. The hydrostatic test pressure should be approximately equal to boiler operating pressure; it must NOT be great enough to cause the safety valve to lift. The purpose of the hydrostatic test is to test for leakage, not to test the popping pressure of the valve.

Boiler safety valves should be tested after each regular cleaning period or general overhaul of a boiler, before the boiler is put back

into service. More specifically, boiler safety valves must be tested after each 1800 hours of boiler operation and after every hydrostatic test. Each individual valve of each group must be lifted by steam and must be reset if there is any discrepancy between the actual and the authorized popping and reseating pressures, and the maximum specified tolerances. Safety valves should also, of course, be tested at any other time when their operation indicates that testing is necessary.

IF THE SAFETY VALVES OF ANY BOILER CANNOT BE ADJUSTED TO LIFT PROPERLY, THE BOILER MUST NOT BE USED FOR STEAMING UNTIL THE FAULT HAS BEEN CORRECTED.

The pressure gage installed on each boiler should be used to set all safety valves installed on that boiler. The pressure gage should be carefully calibrated before any safety valve is tested, set, or reset. Pressure gages on all boilers should be calibrated to agree as closely as possible, particularly within 50 psi above and below boiler operating pressure.

In order to test and set a safety valve, it is necessary to gag all other safety valves on the boiler. The gag screw should be made **HAND-TIGHT** only. Do **NOT** use excessive force in applying the gag, as this might bend the spindle or damage the seating surfaces of the feather and the seat bushing.

On the valve being tested, be sure that the lugs on the upper spring washer do not touch the bonnet.

To conduct the steam test, light off the boiler with one burner, following the boiler lighting-off procedures specified in the Bureau of Ships Technical Manual. Take whatever steps are necessary to ensure an adequate flow of steam through the superheater. After the pressure has risen somewhat, cut in one more burner with a larger size sprayer plate. Bring the boiler pressure up above operating pressure. When the boiler pressure is almost up to the safety valve popping pressure, secure the lighting-off burner. Continue to raise steam pressure, using the other burner, until the safety valve pops. Immediately secure the second burner. Note the pressure at which the safety valve popped. After blowdown has occurred, note the pressure at which the valve reseats. After a short interval, light off again and make a second test of the popping and reseating pressures of the safety valve. Between pops, drop the boiler pressure to just above boiler operating pressure.

Superheater outlet safety valves should **NOT** be popped more than once, as described previously, unless allowance is made for the effect of heat on the valve spring. If possible, allow a cool-down period of at least 1 hour between pops; or, if this is not feasible, remember that blowdown is shortened about 1/2 of 1 percent for each 100-degree rise in temperature.

To steam test a boiler for the purpose of testing safety valves, it is necessary to exceed the authorized operating pressure of the boiler. It is important to note that this is the **ONLY** situation in which the Naval Ship Systems Command authorizes raising the boiler pressure above the specified operating pressure.

When setting a safety valve, first set the popping point. Then, if necessary, make the blowdown adjustment. On all types of safety valves commonly used in the Navy, the popping point is set by adjustment of the compression screw. Blowdown adjustment is made in various ways, depending upon the type of valve.

In the huddling chamber safety valve, blowdown adjustment is made by raising or lowering the adjusting ring. This ring is threaded right-handed on the seat bushing. Lowering the adjusting ring decreases the amount of blowdown and raises the reseating pressure. Raising the adjusting ring increases the amount of blowdown and lowers the reseating pressure.

In the nozzle reaction type of safety valve, the upper adjusting ring is the principal means of blowdown adjustment. When adjusting this ring, remember that it is **ABOVE** the space through which the steam flows as the valve begins to lift. Therefore, raising the upper adjusting ring decreases the amount of blowdown. The nozzle ring also affects the amount of blowdown; however, the nozzle ring is factory set and seldom requires resetting in service. If it is necessary to adjust the nozzle ring, remember that raising the ring increases the nozzle effect and thus increases the blowdown. Lowering the nozzle ring reduces the nozzle effect and thus decreases the blowdown.

When adjusting the blowdown on any type of safety valve, be sure to keep an accurate count of the number of notches and the direction that each ring is moved. This will enable the ring to be returned to its original setting, in case of error, and thereby prevent gross maladjustment of the ring.

It is very important to follow the manufacturer's instructions when setting safety valves. A few special points should be noted in

connection with testing and setting the superheater valve of the Crosby two-valve superheater outlet safety valve assembly. The superheater valve is normally operated by the drum pilot valve. If the drum pilot valve fails to lift, the superheater valve is designed to function independently and to pop at approximately 2 percent above the drum pilot valve setting.

Since the operation of this superheater valve is affected by superheater outlet temperature, as well as pressure, particular care must be taken to maintain a constant superheater outlet temperature while the valve is being tested. The main object of testing the superheater valve is to make sure that it opens and closes sharply, even though there may be some variation in the opening and closing pressures. The valve should close from a relatively high lift without hanging at a low-lift position while the pressure drops. If the valve tends to drop down in lift gradually during the blowdown and to close from a very low lift, it is usually necessary to lower the adjusting ring to obtain sharp closure. If the reseating pressure is below the desired point and the closing lift is low, the nozzle ring should be lowered a notch at a time until the valve closes sharply within the desired blowdown range. It may be necessary to lower the adjusting ring at the same time, in order to obtain best performance.

To determine the popping pressure of the Crosby superheater valve when it is operated solely as a spring-loaded valve, without the drum pilot, it is necessary to gag the drum pilot. This type of test is necessary ONLY at the initial setting of the valve. All subsequent tests of the superheater valve should be made in combination with tests of the drum pilot valve; when the superheater valve is actuated by the drum pilot, the popping pressures of the two valves are identical.

ASSEMBLING THE LIFTING GEAR.—The lifting gear for a boiler safety valve should not be assembled until after the valve has been tested and set. When assembling the lifting gear, take particular care to make proper installation of the fork lever (or top lever) that is used for manual lifting of the valve. Many cases of incorrect installation of the fork lever have been reported; the most common error is installing the fork lever upside down. Incorrect positioning of the lever causes the valve spindle to be forced off center, and this is likely to cause valve leakage. Furthermore, inversion of the fork

lever will, in most safety valves, prevent full lift when the valve is actuated by hand. The correct position of the fork lever for each type of valve should be checked in the manufacturer's technical manual before the lifting gear is assembled.

INSPECTING AND TESTING THE LIFTING GEAR.—The hand gear for lifting safety valves must be examined carefully and operated, insofar as this is possible WITHOUT LIFTING THE SAFETY VALVES, before a boiler is lighted off. This inspection requirement should be included on boiler lighting-off sheets.

Every 3 months, the safety valves and the hand lifting gear must be tested by actually lifting the valves by hand when the steam pressure is within 100 psi of the reseating pressure. The valves must be lifted enough to give a good blow, so that scale will not lodge on the valve seats. It is important to see that each individual safety valve actually is lifted during this test.

Operating Troubles

The operating troubles most frequently encountered with boiler safety valves are chatter, simmer, leakage, and hang-up.

CHATTER.—Chatter may be indicated either by a metallic hammering sound or by a definite vibratory noise. The cause of chatter may be improper overlap distance, a bent spindle, improper clearances, or a blowdown ring that is too loose or shaky on its threads. If a valve chatters immediately after popping, the cause is probably insufficient steam flow or excessive back pressure. If a valve chatters just before reseating, the adjusting ring is probably set in a way that prevents full blowdown. Chatter must be stopped very quickly or the valve will be ruined.

SIMMER.—The first escape of steam before a safety valve pops is known as SIMMER. Simmering is allowable within 1 1/2 to 2 percent of the popping pressure, provided it does not occur at boiler operating pressure and provided the simmer is less than the blowdown. Greater simmer may indicate that the blowdown adjustment is incorrect. The blowdown ring may be set too low or the feather may not be lapped sufficiently.

LEAKAGE.—Leakage is usually indicated by a constant hissing at pressures below the blow-back point. Leakage may be caused by damaged seating surfaces; defective valve parts; the presence of scale or metal chips on the seating surfaces; binding of the lifting gear, the spindle, or other parts; or distortion caused by uneven stress on the flange bolts, improper installation of the exhaust pipe, or an imperfect bearing surface on the valve pad or support.

The first thing to try as a remedy for safety valve leakage is to lift the valve and give a generous blow. If the leakage was caused by scale or other foreign matter on the seating surfaces, the blow will probably remove the material and the valve will no longer leak. If the blow does not stop the leakage, gag the safety valve and determine the cause of the leak. Leakage in safety valves should not be allowed to continue unchecked, since it may indicate dangerous defects in the valve.

HANG-UP.—When a boiler safety valve will not reseat properly after it has popped and blown down, the cause may be either improper blowdown adjustment or some kind of mechanical interference. If the trouble cannot be corrected by changing the blowdown adjustment, the valve must be disassembled so that the cause of the trouble may be determined. The spindle should be checked first, as it is a fairly common cause of hang-up.

HYDROSTATIC TESTS

Boilers are tested hydrostatically for various purposes. It is important to understand in each case why a test is being made and to use—but NOT to exceed—the test pressure specified for that particular purpose. In general, most hydrostatic tests are made at one of three test pressures: boiler design pressure, 125 percent of design pressure, or 150 percent of design pressure. Other test pressures may be authorized for certain purposes. For example, a test pressure of 150 psi is required for the hydrostatic test given before a boiler undergoes chemical cleaning.

The hydrostatic test at design pressure is required upon the completion of each general overhaul, cleaning, or repair that affects the boiler or its parts, and at any other time when it is considered necessary to test the boiler for leakage. The purpose of the hydrostatic test

at design pressure is to prove the tightness of all valves, gaskets, flanged joints, rolled joints, welded joints, and boiler fittings.

The test at 125 percent of design pressure is required after the renewal of pressure parts, after chemical cleaning of the boiler, after minor welding repairs to manhole and handhole seats, and after repairs to tube sheets such as the correction of gouges and out-of-roundness. The "renewal of pressure parts" includes all tube renewals, rolled or welded, except downcomers and superheater support tubes.

The test at 150 percent of design pressure is required after welding repairs to headers and drums, including tube sheet cracks and nozzle repairs; after drain and vent nipple repairs; and after renewal or rewelding of superheater support tubes and downcomers. The hydrostatic test at 150 percent of design pressure is basically a test for strength. This test may be (but is not necessarily) required at the 5-year inspection and test for strength. The 5-year inspection and test is discussed later in this chapter.

Before making a hydrostatic test, rinse out the boiler with fresh water. Using at least 50-psi pressure, play the hose onto all surfaces of the steam drum, the tubes, the nipples, and the headers. Examine the boiler carefully for loose scale, dirt, and other deposits. Be SURE that no tools or other objects are left in the boiler.

Remake all joints, being sure that the gaskets and the seating surfaces are clean. Replace the handhole and manhole plates and close up the boiler.

Gag all safety valves. Boiler safety valves must NEVER, under any circumstances, be lifted by hydrostatic pressure. When gagging the safety valves, do not set up on the gags too tightly or you may bend the valve stems. As a rule, the gags should be set up only hand tight.

Close all connections on the boiler except to the air vents, the pressure gages, and the valves of the line through which water is to be pumped to the boiler. Be sure the steam stop valves are completely closed and that there will be no leakage of water through them.

After all preparations have been made, use the emergency feed pump to fill the boiler completely. After all air has been expelled from the boiler, close the air vents and build up the hydrostatic pressure required for the particular test you are making. A hand boiler test pump is furnished to many ships for use in building up the hydrostatic test pressure. If a hand test

pump is not available, build up the required test pressure by continuing to run the emergency feed pump after the boiler has been filled. In any case, the specified test pressure should not be exceeded. After the boiler is full, it takes very little additional pumping to build up quite a pressure.

To avoid complications arising from changes in pressure caused by changes in temperature, the water used should be at approximately the same temperature as the boiler and the fire-room. In any case, the temperature of the water must be at least 70° F.

While the hydrostatic pressure is being built up, the boiler should be very carefully checked for signs of strain or deformation. If there is any indication of permanent (or probably permanent) deformation, stop the hydrostatic test and make the necessary repairs. If it is not possible to make the repairs right away, give a second hydrostatic test, progressing slowly up to 20 psi less than the pressure at which the first test was stopped. If the boiler passes this second test successfully, the new working pressure of the boiler must be two-thirds of the test pressure reached on the second test, and all safety valves must be set accordingly.

Do not make any attempt to set up on leaky handhole or manhole plates until the pressure has been pumped up to within 50 psi of the test pressure. After all manhole and handhole leakage has been remedied, pump the pressure on up to test pressure. Check the pressure drop over a period of time. If all valves have been

blanked off, the maximum acceptable pressure drop is 1.5 percent of the test pressure over a period of 4 hours. If valves have been merely closed, instead of blanked off, the maximum acceptable pressure drop is 1.5 percent of the test pressure over a period of 1 hour.

A tube seat should not be considered tight unless it is bone dry at the test pressure. Any tube that cannot be made tight under hydrostatic test should be renewed or rerolled. A hydrostatic test at 1 1/4 times the boiler design pressure should be made after each renewal of any pressure parts and at any time when considered necessary by the commanding officer.

If there is an excessive pressure drop when there is only a slight leakage at tube joints, handholes, and manholes, the loss of pressure is almost certainly caused by leakage through valves and fittings. Valves and fittings should be overhauled and made tight.

At 5-year intervals, each boiler must be inspected for integrity of welds and nozzle connections. Lagging must be removed from drums and headers sufficiently to expose the welded joints and the nozzle connections. The welds and nozzle connections must be inspected visually from both inside and outside. If there is any doubt about the welds, they should be inspected by magnetic particle inspection or dye penetrant inspection. If either the visual examination or the magnetic particle or dye penetrant inspection indicates any questionable areas, a hydrostatic test for strength at 150 percent of boiler design pressure must be applied.

CHAPTER 3

FUEL OIL EQUIPMENT

This chapter deals with the equipment commonly used for pumping, measuring, heating, straining, burning, and otherwise handling or controlling fuel oil on steam-driven surface ships. Fuel oil characteristics, stowage, handling, and maintenance of equipment are also covered in this chapter.

FUEL OIL SERVICE EQUIPMENT

Before discussing the individual units of fuel oil equipment in detail, an overall view of the flow of fuel oil can be obtained by tracing the path of the oil from the time it leaves the storage tanks to the time it is mixed with air and burned in the boiler furnace. The arrangement shown schematically in figure 3-1 is typically found on ships having double-furnace boilers with straight-through-flow atomizers. The same general arrangement of fuel oil equipment is used on most ships, except that additional units—fuel oil coolers, valves operated by the automatic combustion control system, and thermostatic control devices—are used on some of the newer ships.

The path of fuel oil can be traced by following figure 3-1. From a storage tank, the oil passes through a manifold to the fuel oil service tank. The fuel oil booster and transfer pump can take suction from the manifold or discharge to it. The primary function of the fuel oil booster and transfer pump is to transfer fuel oil from storage tanks to service tanks.

The fuel oil service pump is used to pump oil from a service tank to the boiler. If the fuel oil service pump cannot take suction directly from a service tank, the fuel oil fill and transfer pump can be used as a booster pump, discharging oil directly to the suction side of the fuel oil service pump.

With the fuel oil service pump in operation, the fuel oil flows through the remote-operated quick-closing valve; the fuel oil meter, or the

meter bypass; the fuel oil heater, or the heater bypass; the fuel oil strainers; the main fuel oil valve (sometimes called the master valve) to the boiler; and the emergency quick-closing valve. The fuel oil then enters two burner manifolds—one on the saturated side, one on the superheater side.

The pressure of the oil going to the burner manifolds is controlled by a pressure-regulating valve (micrometer valve) on each burner manifold. From each burner manifold, the fuel oil passes through a separate burner root valve to each burner line.

The fuel oil enters the burner through an atomizer valve. The oil mixes with the air supplied by the forced draft blowers, and is burned in the boiler furnaces.

The fuel oil equipment described in the following sections includes pumps, valves, meters, heaters, strainers, burners, and other items needed to deliver fuel oil to the furnace at the required pressures and temperatures and to burn the oil in the furnace. Most of this equipment is either a part of the fuel oil service system or else very closely related to it.

FUEL OIL SERVICE PUMPS

Fuel oil service pumps take suction from the service tanks through independent tailpipes, cutout valves or manifolds, suction mains, and pump connections. The suction arrangements for fuel oil service pumps allow rapid changes of pump suction from one service tank (or from one tank group manifold) to another. The pump suction piping is arranged to keep to a minimum any contamination that might result from one service pump taking suction from a service tank that is contaminated with water. The tank stripping system is connected through stop-check valves to the service suction mains, so that these mains can be cleared of oil that is contaminated with water. The service suction

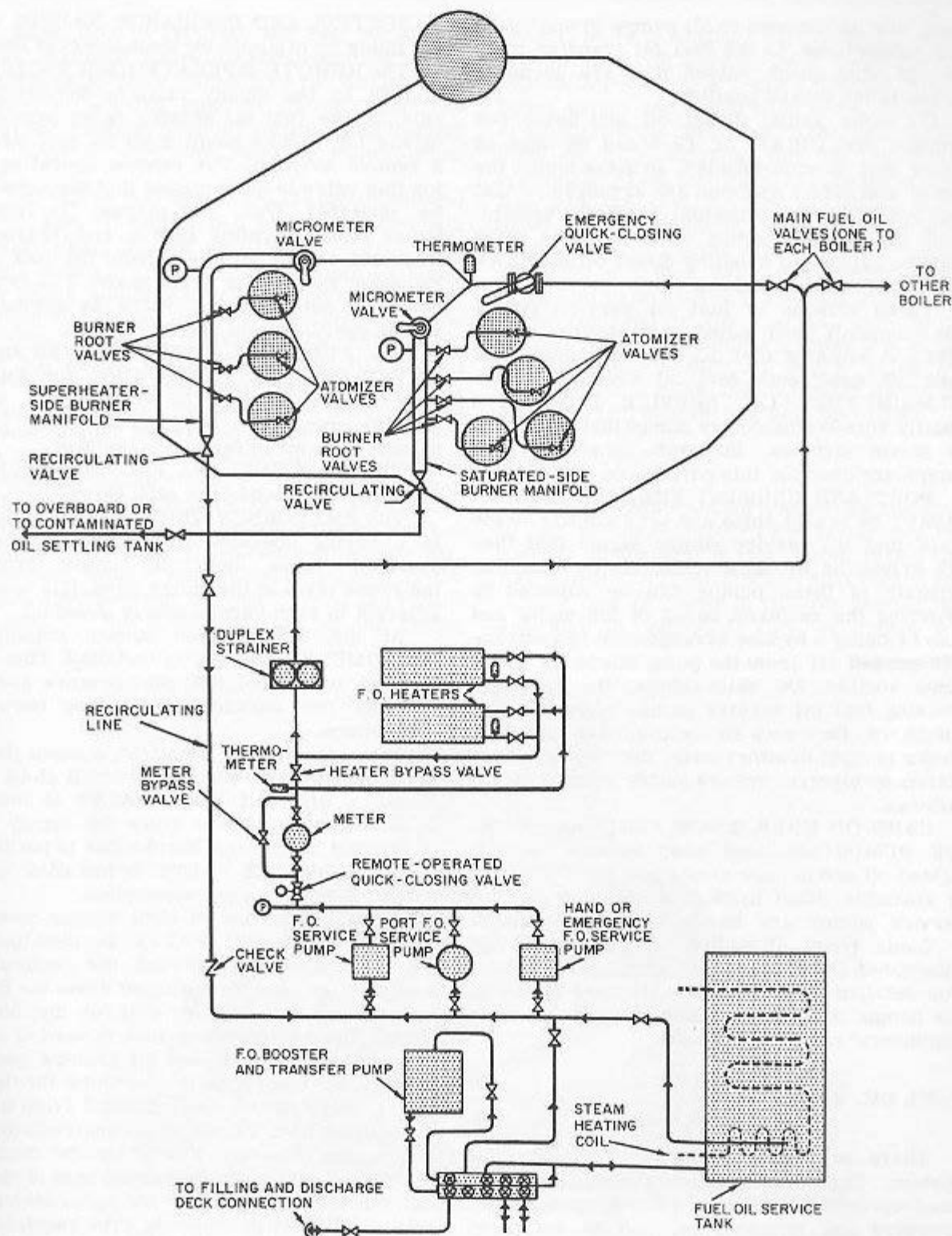


Figure 3-1.—Path of fuel oil on ship with double-furnace boilers.

main that is common to all pumps in one space has connections to the fuel oil transfer main through stop-check valves that are normally locked in the closed position.

On some ships, diesel oil and heavy end aviation fuel (HEAF) or JP-5 can be used as boiler fuel in emergencies. In these ships, the diesel and HEAF systems are arranged so that they can discharge to the fuel oil service system. Fuel oil service pumps used on these ships must be capable of handling diesel oil and HEAF as well as regular fuel oil.

Three classes of fuel oil service pumps are commonly used: main fuel oil service pumps, port and cruising fuel oil service pumps, and hand or emergency fuel oil service pumps.

MAIN FUEL OIL SERVICE PUMPS are usually screw-type rotary pumps that are driven by steam turbines. However, other types of pumps are used for this purpose on some ships.

PORT AND CRUISING FUEL OIL SERVICE PUMPS on recent ships are very similar to the main fuel oil service pumps except that they are driven by two-speed electric motors. The capacity of these pumps can be adjusted by selecting the required speed of the motor and also by using a bypass arrangement to recirculate unused oil from the pump discharge to the pump suction. On older ships, the port and cruising fuel oil service pumps may be rotary pumps or they may be axial-piston variable-stroke pumps; in either case, they are normally driven by electric motors rather than by steam turbines.

HAND OR EMERGENCY FUEL OIL SERVICE PUMPS are used when boilers must be lighted off and neither steam nor electric power is available. Most hand or emergency fuel oil service pumps are herringbone gear pumps.

Basic types of pumps are described and illustrated in chapter 9 of this training course. For detailed information on the fuel oil service pumps on your own ship, consult the manufacturers' technical manuals.

FUEL OIL VALVES

There are several valves in the fuel oil system. These valves allow the system to be lined up so that oil, under proper conditions of pressure and temperature, can be delivered to and burned in the boiler furnace. Many of the most important valves in the fuel oil service system are shown in figure 3-1.

SUCTION AND DISCHARGE VALVES allow the lining up of pumps for the delivery of fuel oil.

The **REMOTE-OPERATED QUICK-CLOSING VALVE** in the supply main on the discharge side of the fuel oil service pump provides a means for rapidly shutting off the fuel oil from a remote location. The remote operating gear for this valve is so arranged that the valve may be operated from two places: (1) from the boiler front operating station, and (2) from the fireroom escape trunk or from the deck above and near the access to the space. The remote-operated quick-closing valve is normally a spring operated gate valve.

The **FUEL OIL METER VALVES** and the **METER BYPASS VALVE** allow the fuel oil meter to be used or to be bypassed, as the situation requires. The fuel oil meter is bypassed when oil is being recirculated.

The **MAIN FUEL OIL VALVE** to each boiler is normally a globe-type stop valve.

The **EMERGENCY QUICK-CLOSING VALVE** is a spring operated gate valve that can be operated from both the upper level and the lower level at the boiler front. It is installed adjacent to each burner supply manifold.

At the top of each burner manifold, a **MICROMETER VALVE** is installed. This valve is used to control fuel oil pressure and thus controls the amount of oil being burned in the furnace.

From the burner manifold, a small flexible line goes to each burner. A small globe valve called a **BURNER ROOT VALVE** is installed in each burner line to allow the supply of oil to be shut off to any burner that is not in use.

An **ATOMIZER VALVE** is installed on each burner at the atomizer connection.

At the lower end of each burner manifold, a **RECIRCULATING VALVE** is installed. By means of these valves and the recirculating line, fuel oil can be returned from the burner manifold to the suction side of the fuel oil pump. The recirculating line is used to circulate oil through the fuel oil heaters and thus bring it up to proper temperature for lighting off. A clearing line branches off from the recirculating line. Valves in the recirculating line and in the clearing line allow the discharge of fuel oil either to the suction side of the fuel oil service pump or to the contaminated oil settling tank (or overboard). (The requirements established by the Oil Pollution Acts must be observed when oil is pumped overboard.) A **CHECK VALVE** in the recirculating line prevents

the back flow of oil from the fuel oil suction main. A check valve is also installed at the connection of the clearing line and the contaminated oil settling tank, to prevent back flow from the contaminated oil settling tank through the clearing line and into the recirculating line.

The valves just mentioned are typically found in the fuel oil system of a boiler equipped with straight-through-flow atomizers. Several additional valves are required in the fuel oil system of a boiler equipped with return-flow atomizers. Instead of a burner manifold, a supply header and a return header are installed at the boiler front. The valves on the supply side of the fuel oil system usually include a remote-operated quick-closing valve; fuel oil meter and meter bypass valves; fuel oil heater and heater bypass valves; and emergency quick-closing valve (or a solenoid valve); a micrometer valve; and a burner supply root valve to each burner. On the burner itself, there is a valve that corresponds to the atomizer valve used for a straight-through-flow atomizer. A burner return root valve is located in the return line between the burner and the return header. On the discharge side of the return

header, there is usually a gate valve; a pressure-regulating valve; a second set of meter and meter bypass valves, for a second fuel oil meter; a relief valve; and a plug cock which can be used to discharge the return oil to the fuel oil suction main or to a clearing line that leads to the contaminated oil settling tank. The recirculating line and the clearing line are fitted with the usual valves, including check valves to prevent back flow of oil. Some return-flow installations are also provided with valves that allow the return oil to be routed to a fuel oil cooler before being returned to the fuel oil service pump suction. Where automatic combustion controls are installed, a fuel oil supply valve and a fuel oil return valve, both operated by the automatic control system are also provided.

FUEL OIL METERS

Most meters used for measuring the amount of fuel oil discharged to the boiler are of the positive-displacement type, often called DISK-TYPE or NUTATING-PISTON METERS. A meter of this type is shown in cutaway view in figure 3-2 and in exploded view in figure 3-3.

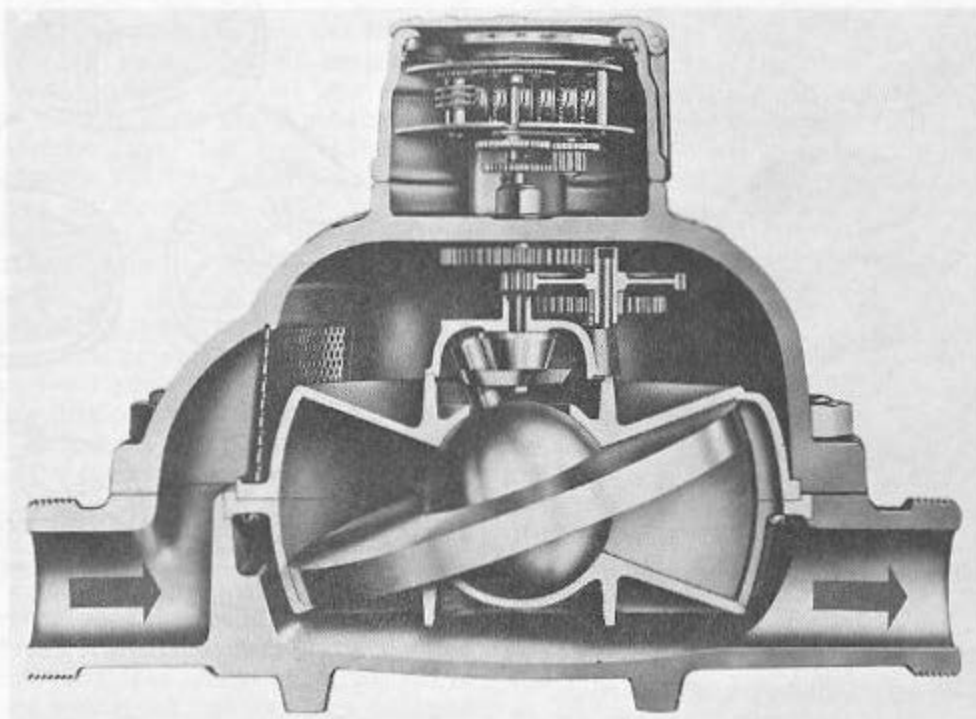
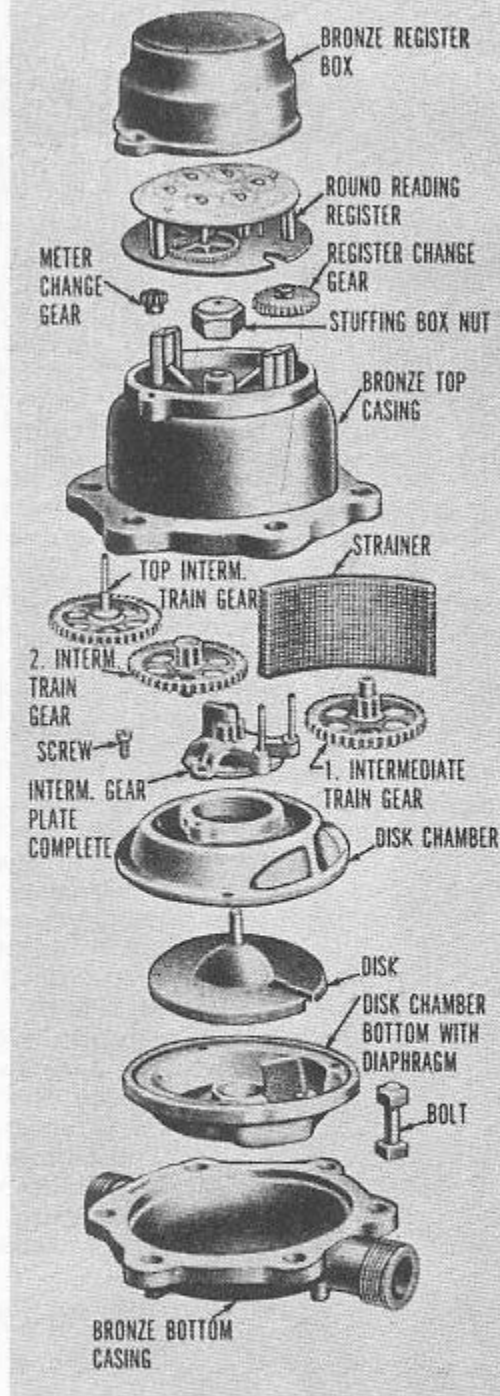


Figure 3-2.—Cutaway view of disk-type fuel oil meter.



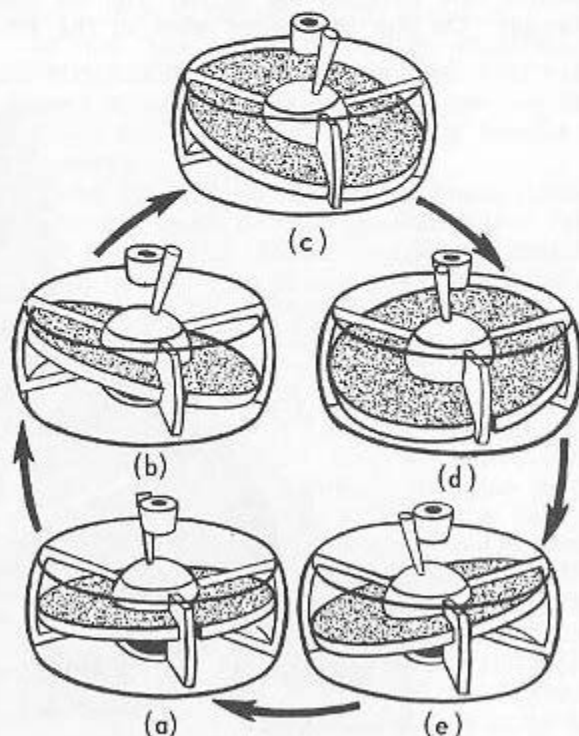
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Figure 3-3.—Exploded view of disk-type fuel oil meter.

The flow of oil through the meter causes the disk (or piston) to move with a peculiar motion which imparts a rotary motion to the pin that projects from the upper spherical surface. The rotary movement of the pin rotates the gears, and the gears actuate a counting device at the top of the meter.

Understanding the motion of the disk is the key to understanding the operating principles of the fuel oil meter. The disk moves with a motion that is called a NUTATING motion. A nutating motion might also be described as a ROCKING AROUND motion, similar to the motion of a spun coin just before it settles flat on its side. The disk in the fuel oil meter cannot settle on its side like a spun coin, since the disk is nutating or rocking around on a lower spherical bearing surface.

The disk cannot rotate because it is held in place by a fixed diaphragm that runs vertically through a slot in the disk. However, the nutational motion of the disk imparts a rotary motion to the pin that projects from the upper spherical surface. Figure 3-4 illustrates the nutating



38.66X

Figure 3-4.—Diagram illustrating nutating motion of disk and rotary motion of pin in fuel oil meter.

motion of the disk that results from the flow of oil through the meter. By studying this diagram, it can be seen how the nutating motion of the disk gives a rotary motion to the pin so that the pin can rotate the gears. The gears, in turn, actuate the counting device.

In order to get an accurate reading of the amount of oil discharged to the boiler, the meter must be bypassed when oil is being recirculated before the burners are lighted off. Therefore, fuel oil meters are always installed with a bypass arrangement.

When boilers are equipped with return-flow atomizers, supply and return fuel oil meters are installed. The difference between the two meter readings gives the amount of oil actually discharged to the boiler. (NOTE: Fuel oil readings should not be considered as replacing tank soundings.)

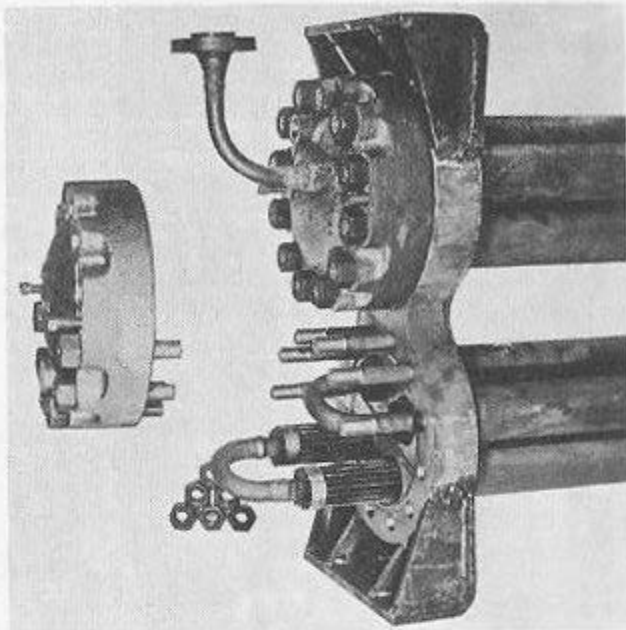
FUEL OIL HEATERS

Fuel oil heaters are installed in the oil supply line to the boiler, on the discharge side of the fuel oil service pump. The heaters heat the oil to the temperature required to produce the best viscosity for proper atomization. Steam at boiler pressure or at a reduced pressure is used as the heating agent in fuel oil heaters.

There are four types of fuel oil heaters approved for use in the fuel oil systems of naval ships. They are all heat exchangers of the shell-and-tube type, but they differ considerably in design. The Type A heater is arranged so that the oil circulates inside the tubes and the steam circulates outside the tubes. The Type B heater, generally referred to as the G-FIN HEATER, is an extended-surface unit in which each inner finned tube is encased in a separate outer tube or shell. The type C heater is an extended-surface unit in which each shell encloses more than one tube. The Type D heater is arranged so that the steam circulates inside the tubes and the oil circulates outside the tubes.

The only heater described here is the Type B or G-fin heater. This heater, which is shown in figures 3-5 and 3-6, is the type most commonly used on combatant ships.

In the G-fin type of heater, the oil flows through a series of shells, each of which contains a single finned tube. The shells are arranged in stacks and are connected together by a common tube sheet at one end. The end at which the shells are connected is called the REAR END or the



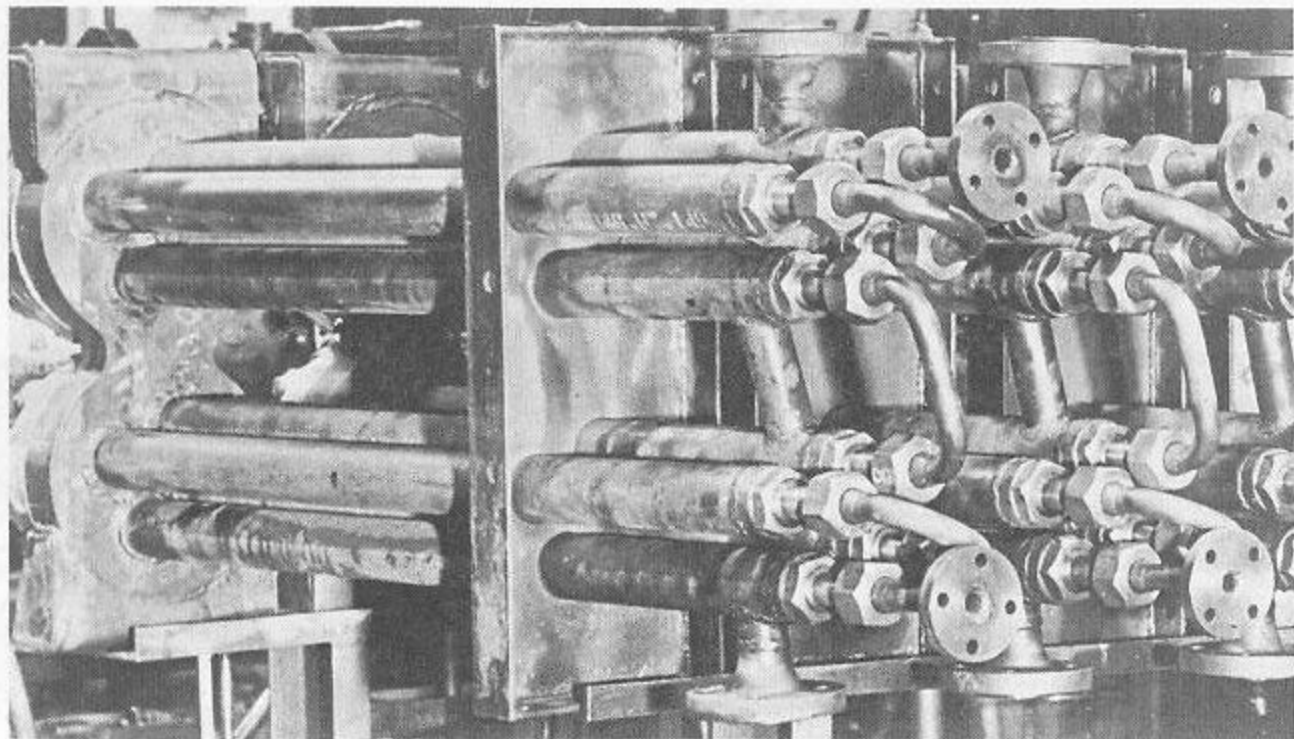
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Figure 3-5.—G-fin fuel oil heater (rear view).

FLOATING END (fig. 3-5). At the other end (fig. 3-6) the shells are connected together by tubes.

The steam flows through the inside of the finned tube. The oil flows inside the shell but outside the tube, along the straight longitudinal paths formed by the G-fins. The tube is not finned around the U-bend or opposite the shell connections, since fins in these locations would interfere with the flow of oil. The purpose of the fins is to increase the amount of heat-transfer surface; the exterior surface of each finned tube has more than eight times the area of the inside surface of the tube.

G-fin fuel oil heaters are installed in sections, each section usually consisting of four shell-and-tube assemblies. Each section can be operated separately. The number of heaters or heater sections used at any given time depends upon load conditions. As a general rule, it is more efficient to operate one heater or one heater section at full capacity than to operate two heaters or two heater sections at partial capacity.

Drain lines and fittings are installed to allow the steam side of the heater to be kept drained at all times. Steam traps are fitted in the drain lines. Other fittings and connections found on G-fin fuel oil heaters include steam and oil



38.68

Figure 3-6.—G-fin fuel oil heater (front view).

valves, vents, steam strainers, relief valves (which discharge into sight-flow funnels and then into spill tanks), connections for pressure gages and thermometers, and oil drain connections.

On many ships, the temperature of the fuel oil leaving a heater is controlled by making small adjustments in the position of the steam throttle valve to the heater. A small steam bypass around the steam throttle valve allows small changes to be made in fuel oil temperature under light load conditions. G-fin fuel oil heaters installed on some newer ships are equipped with regulating valves that automatically regulate the admission of steam to the heaters and so automatically control the fuel oil temperature. These regulating valves are controlled by the temperature of the fuel oil in the discharge from the heater bank.

Water must not be allowed to accumulate on the steam side of a fuel oil heater, as it would reduce the heating capacity of the unit. In idle heaters, water accumulation tends to cause corrosion.

Special precautions must be taken to prevent leakage of oil into the steam side of heaters. Heater drains must be inspected hourly for the

presence of oil. If oil is found in the drains, the defective heater must be secured and the drains run to the bilges. If only one heater is in use when oil leakage is discovered, a second heater must be cut in before the leaking one is secured.

It is important to control heater temperature at all times. Heating the fuel oil to too high a temperature causes the oil to break down and deposit carbon on the finned tubes, thus fouling the heater.

In operating fuel oil heaters, remember that steam must not be admitted to the heater unless oil is flowing through. When cutting in a heater, get the flow of oil started before cutting in the steam. When securing a heater, cut out the steam before stopping the flow of oil. In testing of fuel oil heaters always refer to chapter 9550 (55) of the Bureau of Ships Technical Manual.

FUEL OIL STRAINERS

Strainers are installed in the fuel oil service system to catch particles of foreign matter that might otherwise interfere with atomizer operation. On some older ships, basket-type strainers were installed on the suction side of

the fuel oil service pump. These suction strainers are no longer required by Navy specification. Instead, strainers are installed between the fuel oil heaters and the burner manifold. After the oil has been heated, it is very fluid and readily gives up any foreign particles contained in it.

Duplex strainers of the basket type are usually used in fuel oil service systems. The strainers are installed in such a way that the oil flows from the center of the basket to the outside, leaving dirt and sediment in the basket. Duplex strainers are installed with a valve arrangement that allows for the removal of one basket for cleaning while the other basket remains in service. At least two clean baskets should be kept near the strainer so that baskets can be changed and cleaned when necessary.

A duplex pressure gage, installed by means of a three-way plug cock arrangement, indicates the pressure on each side of the basket in use. If the pressure is noticeably higher on the inlet side than on the outlet side, the basket probably needs to be cleaned. Even if there is no special indication that the basket in use needs to be cleaned, the baskets should be shifted and cleaned once a day as a matter of routine.

The general operating procedure for duplex strainers is as follows:

1. Prior to shifting to the clean side, inspect this side to ensure that the basket cover is properly positioned and secured tightly, and the vent and the drain are shut.
2. Shift the oil flow to the clean side by slowly moving the shift handle its full limit of travel. If a leak becomes evident, shift back to the previously used strainer compartment, and lock the shift handle in this position.
3. After shifting, inspect the strainer for leaks.
4. Ensure that the strainer compartment, which is to be disassembled to be opened, is not under pressure; this may be accomplished by slowly opening the drain valve.
5. Crack the vent valve of the compartment to be opened.
6. Remove the cover.
7. Before lifting out the basket, drain the compartment until the oil level is below the basket support flange. This will prevent any unstrained oil from reaching the strained oil.
8. Clean, inspect, and reassemble the side of the strainer that was in use. Ensure that the compartment gasket is sound and correctly placed.
9. After cleaning and reassembling, inspect the unit visually to ensure that the cover has

been replaced properly and secured tightly. Check the unit for leaks by a trial shift to the compartment just cleaned. Fill the compartment with oil and air vented from the compartment by opening the vent valve and cracking the switching valve very slightly. Hold a rag (or other means) at the vent in order to prevent oil from spraying into the room. After oil shows at the vent, continue venting until all air is out of the compartment, then close the vent. Then move the shift handle slowly to its full limit of travel and inspect for leaks. Be prepared to shift back if a leak is evident. Upon successful operation of the unit, shift the switching valve back to the other side and, again, lock firmly.

In strainers utilizing a valve plug for changing the direction of oil flow, the valve plug must be unseated by operating the jack lever before it can be rotated. The valve plug must never be raised any higher than necessary to permit turning it with full arm force. The valve plug must be tightened down, or seated, as soon as shifting is complete.

As far as specific operating procedures are concerned, a definite step-by-step procedure for shifting strainers should be established. This should include the general procedures mentioned previously and additional procedures compatible with the specific installation and service for which the unit is installed. These procedures should be posted in the immediate vicinity of each strainer installed in the system.

FUEL OIL BURNERS

Practically all fuel oil burners used on naval boilers are mounted on the boiler front. Special openings called BURNER CONE OPENINGS are provided in the furnace front for the burners.

The two main parts of a fuel oil burner are the atomizer assembly and the air register assembly. In addition, various valves, fittings, and connections are required. The following sections deal with atomizers, which divide the fuel oil into very fine particles; air registers, which permit combustion air to enter the furnace in such a way that it mixes thoroughly with the finely divided oil; and burner safety devices, which prevent spillage of oil when an atomizer assembly is removed from the burner while the burner root valve is still open.

Atomizers

Three main kinds of atomizers are now in use on naval boilers. Straight-through-flow

atomizers are used on most boilers. Return-flow atomizers are used on many of the newer ships, particularly those equipped with automatic combustion controls. Steam-assist atomizers are used on boilers in a few new ships.

STRAIGHT THROUGH-FLOW ATOMIZERS.

—In a straight-through-flow atomizer, all oil pumped to the atomizer is burned in the boiler furnace. The fuel oil is forced through the atomizer barrel at a pressure between 125 and 300 psi. With this type of atomizer in use, the firing rate is controlled by changing the number of burners in use, the fuel oil pressure, and the size of the sprayer plates.

The fuel oil goes through the nozzle, which directs the oil to the grooves of the sprayer plate. These grooves are shaped so as to give the oil a high rotational velocity as it discharges into a small cylindrical whirling chamber in the center of the sprayer plate. The whirling chamber is coned out at the end and has an orifice at the apex of the cone. As the oil leaves the chamber by way of the orifice, it is broken up into very fine particles which form a cone-shaped foglike spray. A strong blast of air, which has been given a whirling motion in its passage through the diffuser and the stationary air flaps of the burner register, catches the oil fog and mixes with it. The mixture of air and oil enters the furnace and combustion takes place.

A fuel oil burner with a straight-through-flow type of atomizer is shown in cross section in figure 3-7. Figure 3-8 shows how burners of this type look when installed at the boiler front.

A straight-through-flow atomizer assembly consists of a goose neck, a burner barrel (also called an atomizer barrel), a nozzle, a sprayer plate, and a tip. These parts are shown in figure 3-9. Figure 3-10 shows two views of a nozzle and sprayer plate. The nozzle is threaded on the inside so that it can be screwed onto the end of the barrel. The grooved or slotted face of the sprayer plate fits against the front face of the nozzle. The tip (not shown in figure 3-10) screws onto the externally threaded part of the nozzle and thus holds the sprayer plate tightly and evenly against the nozzle.

The two types of nozzles now in general use are the STANDARD NOZZLE and the SEMI-WIDE-RANGE NOZZLE. These two types of nozzles are shown in cross section in figure 3-11. The standard nozzle has four oil holes; the semiwide-range nozzle has six. When the present

supply of semiwide-range nozzles is exhausted, only standard nozzles will be issued.

The sprayer plates most commonly used are called STANDARD SPRAYER PLATES (fig. 3-12). Standard sprayer plates may be either flat-faced or dished and rounded, and they may have three, four, or six oil grooves. Standard sprayer plates with four grooves are most common.

Another type of sprayer plate is known as the STANDARD HIGH-CAPACITY SPRAYER PLATE. At the present time these plates are used on only a few ships. The diameter of the whirling chamber is larger in a high-capacity sprayer plate than in a standard sprayer plate. All high-capacity sprayer plates are dished and rounded. Most of them have six grooves, but a few of the very large sizes have eight grooves.

Sprayer plates and nozzles are used in several combinations. The STANDARD ATOMIZER ASSEMBLY consists of a standard sprayer plate and a standard nozzle. The SEMI-WIDE-RANGE ATOMIZER ASSEMBLY consists of a standard sprayer plate and a semiwide-range nozzle. The HIGH-CAPACITY ATOMIZER ASSEMBLY consists of a high-capacity sprayer plate and a standard nozzle. High-capacity sprayer plates must NOT be used with semiwide-range nozzles.

The size of sprayer plates used in straight-through-flow atomizer assemblies is indicated by four numbers which are stencilled on the face of the sprayer plate. The first two digits indicate the bore of the orifice (standard drill size). The second two digits are the quotient (with decimal point left out) of the combined cross-sectional area of the sprayer plate grooves divided by the area of the orifice. In addition to these numbers, the sprayer plates may also bear a manufacturer's designation. For example, let's take a sprayer plate size 3808 and see how it would be identified by different manufacturers:

38T08 Todd Combustion Equipment, Inc.

P.C.R.S. 3808 . . Philadelphia Naval Shipyard (C.R.S. stands for CORROSION-RESISTING STEEL.)

3808. Babcock & Wilcox Co. (No identifying letter.)

The same letters are used to identify nozzles and tips—that is, "T" for Todd; "P.C.R.S." for Philadelphia Naval Shipyard; and no identifying letter for Babcock & Wilcox Co.

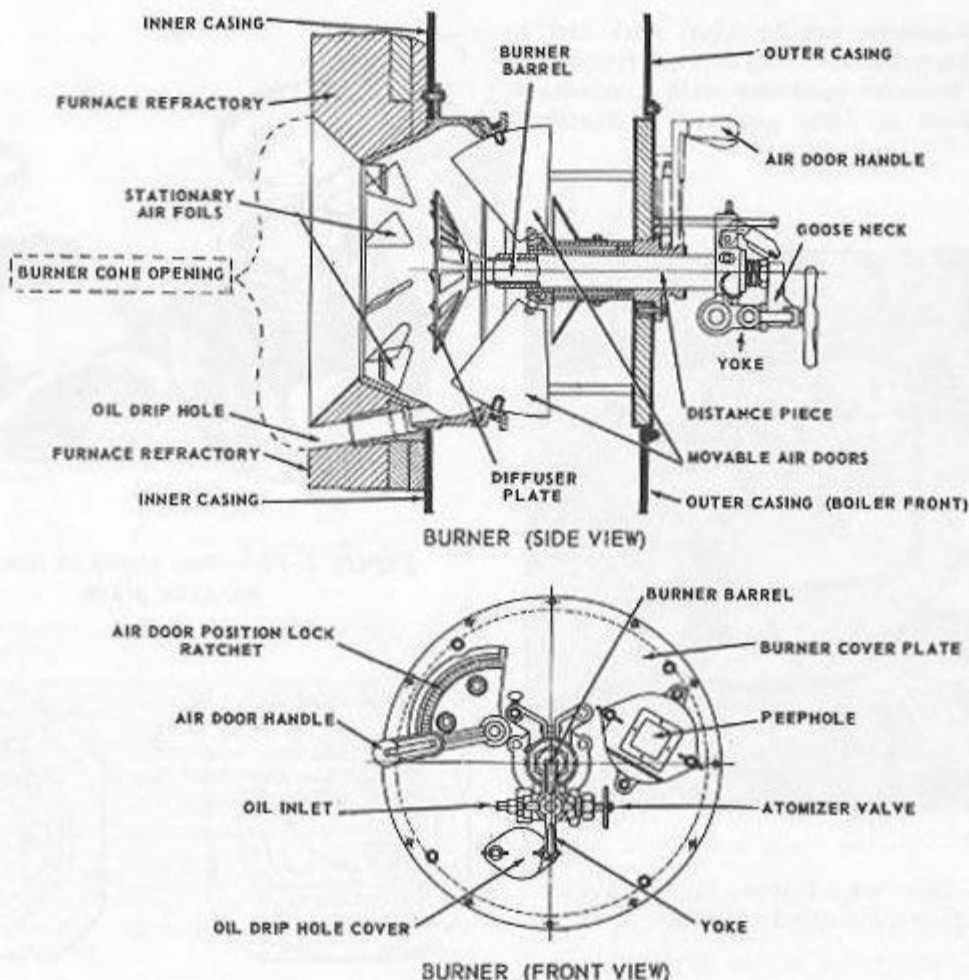


Figure 3-7.—Cross-sectional view of Babcock & Wilcox Carolina-type fuel oil burner with straight-through-flow atomizer. 38.69

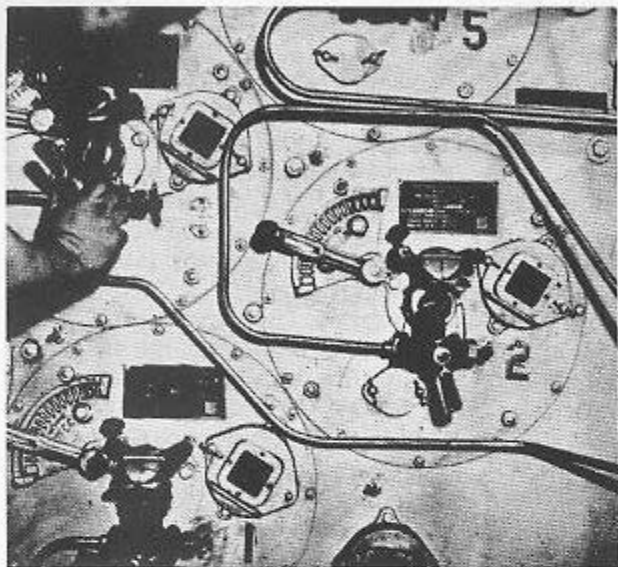
Some sprayer plates are also further identified by a letter or letters that follow the number. For example D (as, 3808-D) indicates that the sprayer plate is dished and rounded. The letters HC (as, 1609-HC) indicate that the plate is a high-capacity sprayer plate.

To ensure proper atomization of the oil, all atomizer parts must be kept clean and in good condition. Even the slightest change in the dimensions of atomizer parts can seriously affect atomization. Even a tiny scratch or a speck of carbon on or in a sprayer plate will cause the spray to be uneven. Most damage to sprayer plates is caused by careless handling and inadequate cleaning. Procedures for cleaning sprayer plates and other atomizer parts

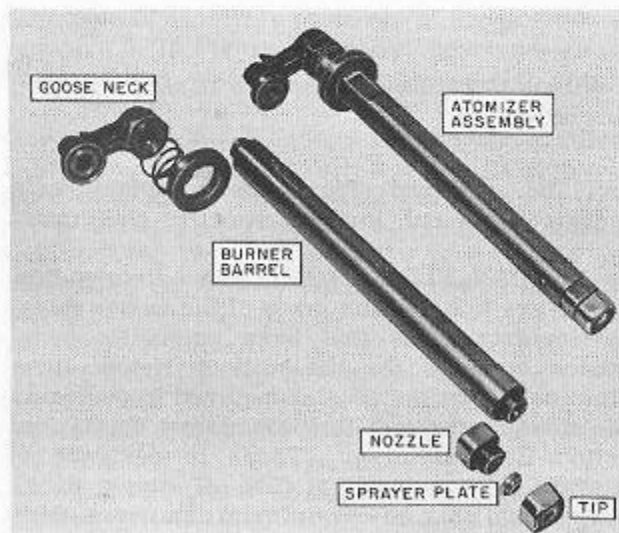
can be obtained from the manufacturer's technical manual for the specific equipment.

RETURN-FLOW ATOMIZERS.—Return-flow atomizers are used on many of the newer ships, particularly those that have automatic combustion controls for the boilers. Return-flow atomizers are not as standardized in design as the straight-through-flow atomizers. One type of return-flow atomizer (Todd) is designed to operate with a constant fuel oil supply pressure of 300 psig and a minimum return pressure of 25 psig; this type of atomizer is usually called a VARIABLE-CAPACITY (or VEE-CEE) atomizer. Another return-flow atomizer (Babcock & Wilcox) operates with a variable fuel

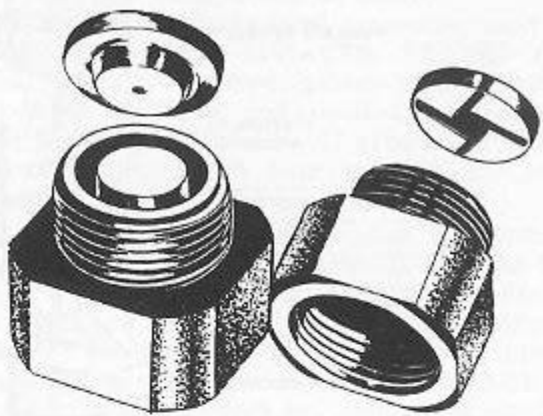
oil supply pressure (up to 1000 psi) and a variable return pressure. Still another type (also Babcock and Wilcox) operates with a constant supply pressure of 1000 psi and a variable



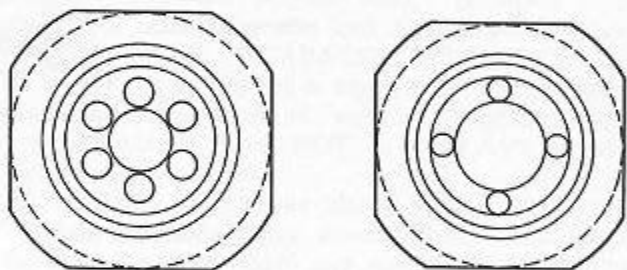
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Figure 3-8.—Babcock & Wilcox Carolina-type fuel oil burners installed on boiler front.



38.71
Figure 3-9.—Parts of a straight-through-flow atomizer assembly.



38.72X
Figure 3-10.—Two views of nozzle and sprayer plate.



38.73
Figure 3-11.—Semiwide-range and standard atomizer nozzles.

return pressure. Since several types of return-flow atomizers are in use, always check the manufacturer's technical manual for detailed information on the return-flow atomizers used in any particular installation.

The return-flow atomizer shown in figure 3-13 and described here operates with a constant fuel oil supply pressure. The amount of oil burned in the furnace is controlled by regulating the oil return pressure. The supply oil enters through the tube-like opening down the middle of the atomizer barrel and passes through the sprayer plate. The tangential slots or grooves in the sprayer plate cause the oil to enter the whirling chamber with a rotary motion. As the oil reaches the return annulus, centrifugal force causes a certain amount of the oil to enter the return annulus. The amount of oil

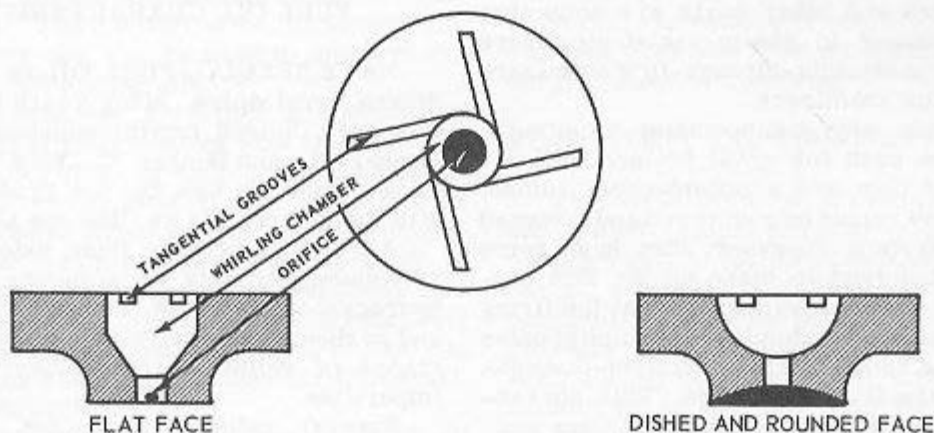
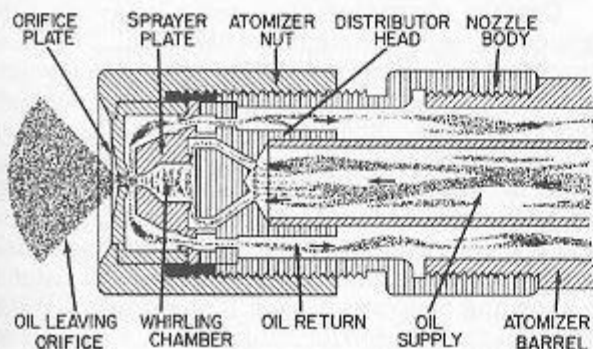


Figure 3-12.—Standard sprayer plates.

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Figure 3-13.—Return-flow atomizer.

thus returned is determined by the back pressure in the return line; the back pressure is in turn determined by the extent to which the return line control valve is open. The oil which is not returned emerges from the orifice in the form of a hollow, conical spray of atomized oil. The amount of oil burned is therefore the difference between the amount of oil supplied and the amount of oil returned.

Sprayer plates used with return-flow atomizers are marked with two pairs of numerals separated by a letter. The letter designates the design type. The two numerals appearing before the letter indicate the number of the drill used to make the orifice. The two numerals appearing after the letter indicate the ratio of the total cross-sectional area of the tangential slots to the area of the orifice; the decimal

point is omitted in this designation. For example, the marking 32Y20 on a sprayer plate would indicate:

- (1) that the orifice was made with a size 32 drill;
- (2) that the design type of the sprayer plate is identified as Y;
- (3) that 2.0 is the quotient of the total area of the tangential slots divided by the area of the orifice.

Orifice plate used with return-flow atomizers are also marked with numbers that indicate the drill size of the orifice. Sprayer plates and orifice plates used together **MUST** have the same size orifices. For example, a sprayer plate marked 32Y20 should be used only with an orifice plate marked 32.

STEAM-ASSIST ATOMIZER.—The straight-through-flow atomizers and the return-flow atomizers just described are both mechanical atomizers of the pressure type. The steam-assist atomizer, now in use on some new ships, operates on different principles. The fuel oil enters a steam-assist atomizer at a relatively low pressure and is very finely atomized by a jet of steam. Combustion air is supplied by forced draft blowers, just as it is in other installations.

A steam-assist atomizer has two supply lines coming into it, one for fuel oil and one for steam. These two lines make the atomizer look a good deal like a return-flow atomizer. However, the steam-assist atomizer does not return any fuel oil; instead, all oil supplied to the atomizer is burned in the boiler furnace.

Sprayer plates and other parts are somewhat differently shaped in steam-assist atomizers than they are in straight-through-flow atomizers and return-flow atomizers.

One reason why steam-assist atomizers have not been used for naval boilers until recently is that they use a considerable amount of steam which cannot be recovered and returned to the feed system. However, they have some advantages that tend to make up for this disadvantage. A major advantage is that the firing range of steam-assist atomizers is much greater than the firing range of either straight-through-flow or return-flow atomizers. This characteristic makes the steam-assist atomizer particularly useful for naval service, since it means that large changes of load can be made merely by varying the fuel oil supply pressure, without cutting burners in and out. The fuel oil supply pressure can be varied between 8 psi and 350 psi.

Air Registers

The main parts of an air register are (1) the movable air doors, (2) the diffuser, and (3) the stationary air foils. These parts are shown in figure 3-7. The movable air doors allow you to open and close the register. When the air doors are open, air rushes in and is given a whirling motion by the diffuser plate. The diffuser causes the air to mix evenly with the oil, and also prevents flame being blown back from the atomizer. The stationary air foils guide the major quantity of air and cause it to mix with the larger oil spray beyond the diffuser.

Burner Safety Devices

On all new construction, fuel oil burners are fitted with safety shutoff devices that close automatically when the atomizer assembly is removed from the burner. These safety shutoff devices prevent spillage of oil if an atomizer should be removed while the burner root valve is still open.

Safety shutoff devices are not found on burners on older ships. However, on these ships the threads on the atomizer valve stem are cut in such a way that the atomizer valve can be closed very rapidly, with less than a full turn of the valve handwheel.

FUEL OIL CHARACTERISTICS

NAVY SPECIAL FUEL OIL is used in steam driven naval ships. Many years ago, Navy fuel oils were divided into three classes—Bunker A, Bunker B, and Bunker C. This classification is no longer in use, but low grade fuel oil may still be referred to as "Bunker C oil."

All fuel oil comes from petroleum. Crude petroleum consists of a number of different hydrocarbons—that is, compounds of hydrogen and carbon. Crude petroleum quite often contains traces of sulfur, nitrogen, oxygen, and other impurities.

Several refining processes are used to change crude petroleum into fuel oil that is suitable for use in boiler furnaces. The nature of the crude petroleum and the refining processes that are used determine the characteristics of the fuel oil that is finally produced.

Certain characteristics must be known with respect to each consignment of fuel oil. The most important of these are viscosity, flash point, fire point, gravity, calorific value, ash content, water content, and sediment content. These characteristics are determined by various tests. Some of the tests are so complicated that they can be performed only in a fully equipped laboratory; but others are relatively simple and can be made on board ship. It is most helpful to know the purpose of each fuel oil test and the procedures for performing those tests made aboard ship.

Some naval ships are furnished with an oil testing outfit. This outfit includes a viscosimeter for determining the viscosity of oil; a flash tester for determining flash point; a hydrometer for determining gravity; and a centrifuge for determining the amount of water and sediment in oil.

VISCOSITY

The viscosity of a liquid is a measure of its resistance to flow. A liquid is said to have high viscosity if it flows sluggishly, like cold molasses. It is said to have low viscosity if it flows freely, like water. The viscosity of oil—and, indeed, of most liquids—is greatly affected by temperature.

The viscosity of fuel oil is usually expressed as the number of seconds required for a given amount of oil to flow through an orifice of a certain size, when the oil is at a specified temperature. Devices used to measure the rate

of flow are called VISCOSIMETERS or VISCOMETERS. The viscosimeter furnished for shipboard use can also be used to measure the viscosity of lubricating oils.

The viscosimeter furnished for shipboard use is a Saybolt viscosimeter with two orifices. The larger orifice is called the SAYBOLT FUROL orifice; the smaller one is called the SAYBOLT UNIVERSAL orifice. The Furol orifice is used for measuring the viscosity of relatively heavy oils; the Universal orifice is used for measuring the viscosity of relatively light oils. If the viscosity of an oil is likely to be more than 1000 seconds Saybolt Universal, use the Furol orifice.

A Saybolt viscosimeter consists of an oil tube; a constant-temperature oil bath which maintains the correct temperature of the sample in the tube; a 60-cc(cubic centimeter) graduated receiving flask; thermometers to measure the temperature of the oil sample and of the oil bath; and a timing device.

A Saybolt viscosimeter is shown in figure 3-14. Figure 3-15 shows details of the viscosimeter oil tube. The general procedure for using the Saybolt viscosimeter is discussed here briefly. Detailed instructions for using the device are given in chapter 9550(55), Bureau of Ships Technical Manual.

The oil to be tested is strained and poured into the oil tube. The tube is surrounded by the constant-temperature oil bath. When the oil sample is at the correct temperature, the cork is pulled from the lower end of the tube and the sample flows through the orifice and into the graduated receiving flask. The time(in seconds) required for the oil to fill the receiving flask to the 60-cc mark is noted.

The viscosity of the oil is expressed by indicating three things: first, the number of seconds required for 60-cc to flow into the receiving flask; second, the type of orifice used; and third, the temperature of the oil sample at the time the viscosity determination is made. For example, suppose that a sample of Navy Special fuel oil is heated to 122°F and that 132 seconds are required for 60-cc of the sample to flow through a Saybolt Universal orifice and into the receiving flask. The viscosity of this oil is said to be 132 seconds Saybolt Universal at 122°F. This is usually expressed in a shorter form as 132 SSU at 122°F.

Saybolt Furol viscosities are obtained at 122°F. Saybolt Universal viscosities for fuel oil are always obtained at 122°F. Various other

temperatures are used for obtaining Saybolt Universal viscosities of oils other than fuel oils. The temperatures must ALWAYS be included in the statement of viscosity.

FLASH POINT AND FIRE POINT

The flash point of a petroleum product is the lowest temperature at which it gives off enough vapor to form a flammable mixture with the air above the surface of the liquid. The fire point, also called the burning point, is the temperature at which enough vapor is given off to continue burning after ignition. The fire point is usually 10° to 70°F above the flash point.

Two general types of testers are used to determine flash points and fire points: open-cup testers and closed-cup testers. In both types, heat is applied to the oil and, at intervals, a small flame is passed over the surface of the oil. The temperature at which the oil flashes is the flash point; the temperature at which it continues to burn is the fire point.

The open-cup tester is always used for determining fire points, since a free supply of oxygen is required. The closed-cup method is used to determine flash points below 250°F; for example—NSFO, Diesel Fuel, and JP-5. The open-cup method is used to determine flash points above 250°F; for example, lubricating oils. In general, flash points obtained by the open-cup method tend to be about 10°F higher than those obtained by the closed-cup method.

Figures 3-16 and 3-17 illustrate the closed-cup apparatus that is used for determining flash points. The oil cup or container, which has a tight fitting lid, rests in a heating jacket. Stirring paddles, suspended in the oil cup, are operated by a flexible stirring shaft. While heat is applied to the sample in the oil cup, the paddles are operated to ensure uniformity of temperature throughout the sample. From time to time, a small flame is tilted into the cup. The temperature at which the vapor flashes with a very slight explosion is the flash point of the oil sample.

Each oil sample can be used for only one flash test. After one flash, some of the volatile vapors have been burned off and the volatility of the remaining oil is thereby reduced.

SPECIFIC GRAVITY AND API GRAVITY

The specific gravity of a substance is the ratio of the weight of the substance to the



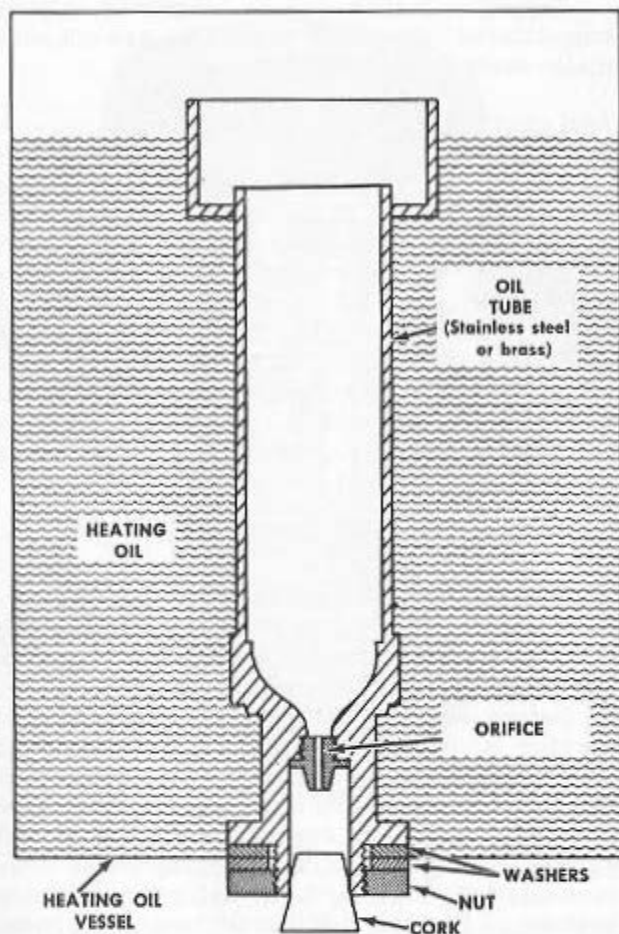
Figure 3-14.—Saybolt viscosimeter.

38.213

weight of the same volume of some standard substance, when both substances are under standard conditions of temperature and pressure. For solids and liquids, the standard substance used for comparison is pure water. In engineering, the standard conditions for both substances are 60°F and atmospheric pressure. Pure water at 60°F and atmospheric pressure is considered to have a specific gravity of 1.

A substance lighter than water has a specific gravity of less than 1. A substance heavier than water has a specific gravity of more than 1. If specific gravity is measured at some temperature other than 60°F, it is corrected to a value that will correspond with 60°F by the use of correction tables.

The gravity of petroleum products is usually expressed in degrees API, in accordance with



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Figure 3-15.—Details of viscosimeter tube.

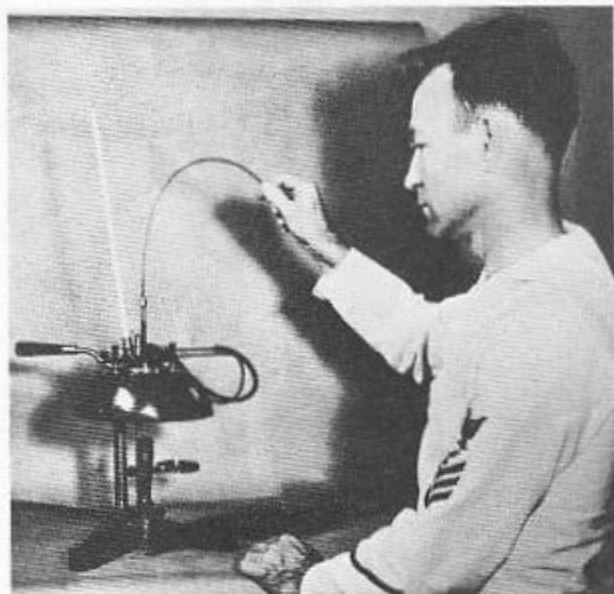
a scale developed by the American Petroleum Institute. The relationship between specific gravity is given by the formula,

$$\text{specific gravity} = \frac{141.5}{131.5 + \text{degrees API}}$$

API gravities are usually corrected to the standard temperature of 60°F by the use of correction tables.

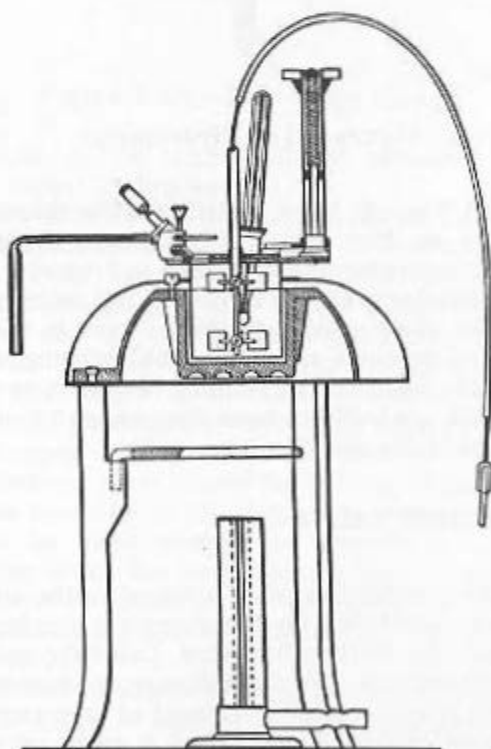
Hydrometers are used to measure both specific gravity and API gravity. The hydrometer that is normally used for testing fuel oil is graduated in degrees API.

A hydrometer is shown in figure 3-18. The instrument is immersed in a glass container of oil, in which it floats. The reading is taken from the graduated scale at the level of the



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Figure 3-16.—Closed-cup apparatus for determining flash point.



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Figure 3-17.—Diagrammatic view of closed-cup apparatus for determining flash point.



Figure 3-18.—Hydrometer.

38.217

liquid. The oil to be tested must be thoroughly stirred so that it will be uniform in density and temperature when the hydrometer and thermometer reading is made. The hydrometer and the glass container that is used to hold the oil must be clean and dry at the beginning of the test. The hydrometer reading must not be taken until all air bubbles have disappeared from the surface of the oil.

CALORIFIC VALUE

The calorific value of a fuel oil is the amount of heat produced by the complete combustion of a sample of specified size. Calorific value is sometimes expressed in calories and sometimes in Btu. A calorie is the amount of heat required to raise the temperature of 1 gram of water 1 degree Centigrade. A Btu is the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit. One Btu is equal to approximately 252 calories.

Calorific values can be measured only by complicated laboratory tests that are not normally made aboard ship.

ASH CONTENT

The amount of noncombustible material in a petroleum product is known as the ash content of the substance. To determine the ash content, a sample of oil is weighed in a small crucible and burned until all combustible material is gone. The residue left in the crucible is called ASH. The ASH CONTENT is determined by calculating the percentage of ash in the original sample. The determination of ash content is normally a laboratory procedure rather than a shipboard procedure.

WATER AND SEDIMENT

Fuel oil should be tested for water and sediment before it is taken aboard. Fuel oil in the tanks should be tested for water once each week and again before the oil is drawn for use.

Before fuel oil is transferred to a fuel oil service tank, and before a service tank is lined up for service pump suction, the tank from which the oil is to be drawn must be checked for the presence of water. Approximately 150 to 300 gallons of oil should be pumped to the contaminated oil settling tank, using the stripping system pump and the low suction connection. While this oil is being pumped, a sample, taken through the test connection on the discharge side of the stripping pump, should be examined for the presence of water.

In the sample, water may appear either in emulsion or in a clearly separable form, depending upon the temperature of the oil, the amount of mechanical agitation to which it has been subjected, and other factors. If water is present, stripping of the tank should be continued until test samples show that the oil is free of water.

When there is any doubt as to the presence of water in the oil, a sample of the oil should be tested in a centrifuge. A centrifuge is a machine which utilizes centrifugal force to separate water and sediment from the oil. Some centrifuges used aboard ship are electrically driven, like the one shown in figure 3-19. Others are driven by hand.

The oil to be tested is placed in graduated glass tubes of the type shown in figure 3-20. The tubes are placed in the centrifuge in an upright position, in metal tube carriers. The

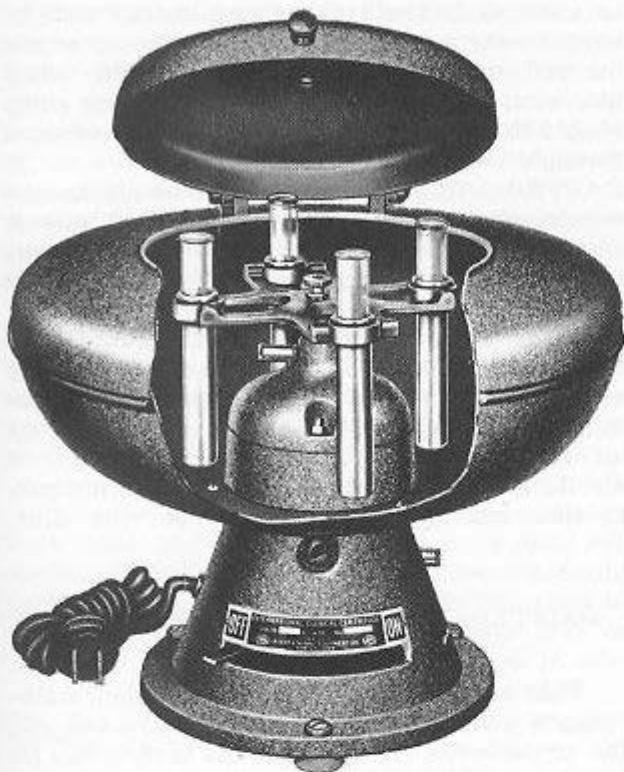


Figure 3-19.—Centrifuge.

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piece which carries the tubes in their tube carriers is rotated at about 1400 to 1500 rpm. Centrifugal force causes the bottom of the tubes to move outward, so that the tubes are in a horizontal plane. The water and sediment, being heavier than the oil, are forced to the outer tip (bottom) of the glass tubes. When the tubes are removed from the centrifuge after having been whirled for the specified length of time, the water and sediment will be at the bottom of the tubes. Since the tubes are graduated, a direct reading can be made of the volume of water and sediment from the marks on the tubes. Centrifuge tubes were formerly marked in cubic centimeters, but are now being marked in milliliters (ml). Full instructions for using a centrifuge are given in chapter 9550 (55), Bureau of Ships Technical Manual.

Samples of oil from tanks may be obtained either by means of the test connection on the discharge side of the stripping pump, as described before, or by means of devices called THIEF SAMPLERS. Two types of thief samplers are shown in figure 3-21. These samplers may

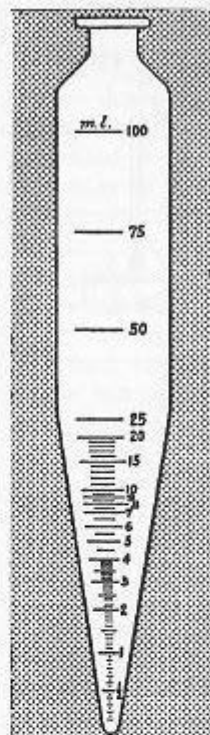


Figure 3-20.—Centrifuge tube.

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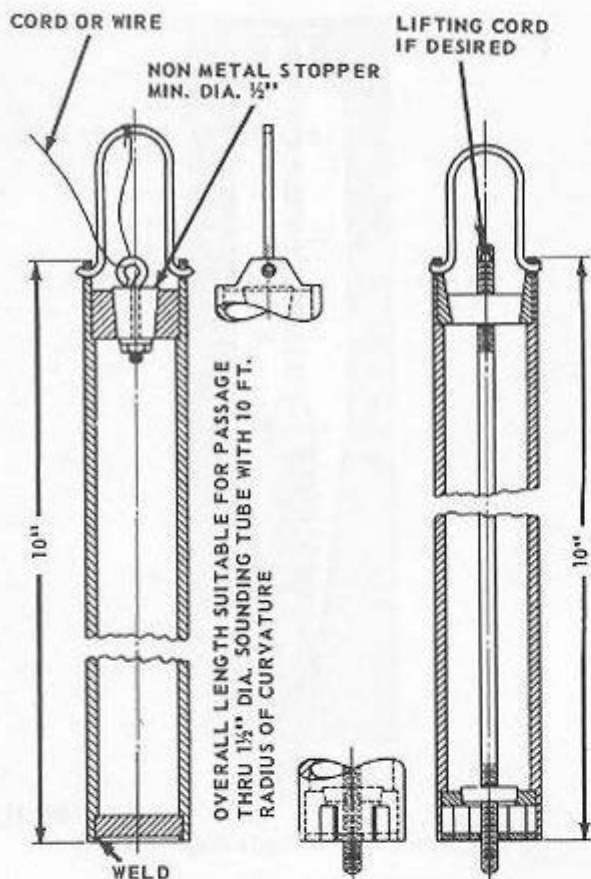
be made up on board ship or obtained from naval repair activities.

Both of the thief samplers shown in figure 3-21 may be used in standard 1 1/2-inch sounding tubes or in larger openings. The bottle-type sampler on the left side of the illustration is suitable for use where it is not necessary to obtain a sample from the very bottom of the tank. The weight of the bottle is carried on the stopper; a quick jerk of the cord or wire removes the stopper so that a sample may be taken at and desired level above the bottom of the tank.

The sampler on the right side of figure 3-21 should be used when it is necessary to take samples from the very bottom of the tank. If a pull cord is attached to the valve stem, this sampler may also be used to take samples at other levels.

All thief samplers should be made of non-ferrous metal to reduce the possibility of sparking.

Water contamination of fuel oil should be prevented. Water in the fuel oil is a serious engineering casualty that can lead to a series of other casualties. Sea water contamination is



38.220

Figure 3-21.—Thief samplers.

a particular problem because, in addition to interfering with the correct operation of the burners, it can cause extreme damage to refractories even if the amount of sea water is so slight that you cannot notice any effect at the burners. To prevent water contamination of the fuel oil—or, if that is impossible, to at least keep the contaminated oil from reaching the burners—it is necessary to:

1. Make the required tests of fuel oil when fueling ship.
 2. Sample and test fuel oil in storage, service and standby tanks as often as necessary.
 3. Keep the fuel oil systems (including valves, vents, tanks, and piping) in good condition.
 4. Follow correct procedures for separating water and oil in contaminated oil settling tanks.
- Oil and water mixtures in contaminated oil settling tanks should be allowed to settle as long as possible before separation of the liquids

is attempted. The tank heating coils should be used to warm the mixture so that the water and oil will separate more rapidly. When the water has settled to the bottom, the stripping pump should be used to discharge the water overboard through the low suction connection.

CAUTION: This water must not be discharged overboard near shore or in restricted waters. Even under the most favorable conditions, some traces of oil are almost sure to go overboard with the water.

After removing the water from the contaminated oil settling tank, a sample of the remaining oil should be taken and tested in the centrifuge to see if it is free of water. If the oil is found to be suitable for boiler use, it should be drawn through the high suction connection and discharged to a service tank.

MAINTENANCE OF FUEL OIL EQUIPMENT

This section deals with the inspection, maintenance and repair of fuel oil burners and with the procedures for cleaning and testing fuel oil heaters. Additional information on fuel oil burners and heaters, and other items of fuel oil equipment, may be obtained from either BuShips Technical Manual (chapter 9550) or the manufacturers technical manuals for the specific equipment.

FUEL OIL BURNERS

Fuel oil burners must be correctly installed, maintained in proper position and alignment, and kept clean and free of defects. Since atomizer parts were discussed earlier in the chapter, the following sections deal with some aspects of burner installation and maintenance that may be of particular importance aboard ship.

Installation and Care of Air Registers

The stationary air foils or bladed cones should be installed before the refractory or burner tile of the burner front is installed. The air foils fit over the ends of bolts that are fastened to the inner front plate. After the stationary air foils have been fitted over the ends of the bolts, the nuts should be tightened enough to hold the air foils firmly in place. The burner front forms should then be fastened in place and the refractory or burner tile installed.

It is essential that exact dimensions be maintained in setting up the refractory of the burner front. At this point, it should be emphasized again that the burner openings must be precisely concentric around the atomizer and that the slope of the burner cone opening must be precisely as specified in the plans. If the burner is not lined up properly with respect to the burner cone opening, flame impingement, damage to refractories, and poor combustion will probably result.

All parts of the air register—the air foils, the diffuser plate, and the air doors—should be checked at frequent intervals to make sure they are operating properly. In particular, new or newly assembled installations should always be checked before being put into operation.

All air surfaces of the register must be kept clean and free of oil, carbon, or dirt. Air doors, air foils, air scoops, and diffusers should be wiped off at frequent intervals. The slots in the diffuser plates must be entirely free of material that would impede the flow of air.

Positioning the Atomizer Barrel

The position of the atomizer barrel in the distance piece should be checked from time to time and adjusted if necessary by screwing the distance piece in or out until the proper relationship exists between the face of the atomizer tip nut and the diffuser plate. This setting of the distance piece, which varies for different types of burners, must not be changed without consulting the manufacturer's technical manual or the boiler plans.

Positioning the Burner Assembly

After the stationary air foils and the refractory burner cone have been installed, and after the atomizer barrel has been correctly adjusted in the distance piece, the entire burner assembly can be inserted through the opening in the outer casing. A piece called a SPOOL is fastened to the outside of the inner casing. As the burner assembly is inserted through the opening in the outer casing, it should be centered on the studs provided in the spool. After the burner assembly has been centered, it should be bolted firmly to the outer casing. The piping connections to the burner manifold can then be made up and the unit will be ready for operation.

Use of Gaskets

All gaskets used in a fuel oil burner assembly must be of the proper dimensions and material and must be installed exactly as specified in the manufacturer's technical manual. Failure to use the correct type or size of gasket or failure to position the gasket correctly is likely to cause fuel oil leakage and poor atomization.

Before burner gaskets are installed the seating surfaces should be cleaned carefully. The seating surfaces should be smooth and true, without nicks or other irregularities. If the seating surfaces are not perfectly true, it may be advisable to use high pressure packing instead of a regular gasket, as a temporary or emergency measure. However, the seating surfaces should be trued up and a proper gasket installed at the first opportunity.

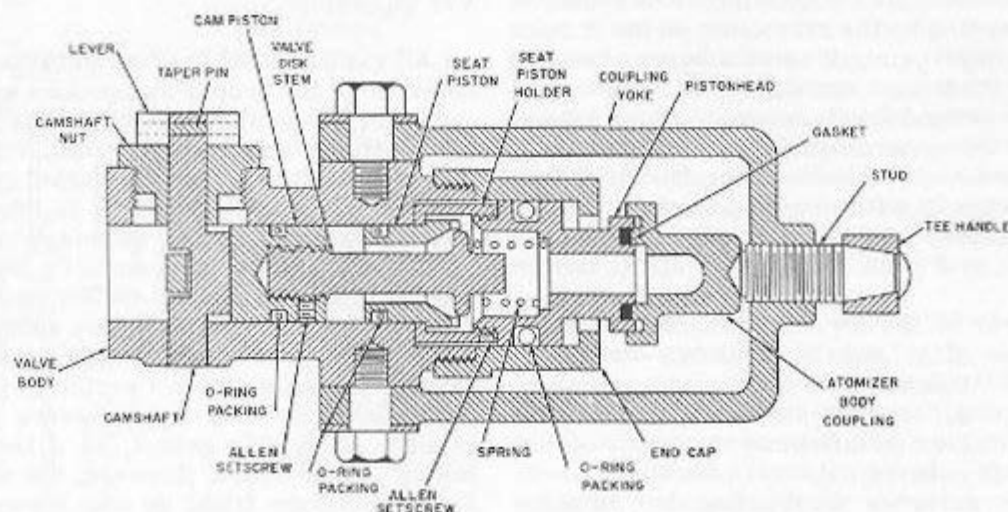
On burners that have safety shutoff valves or other automatic safety devices, the thickness of the gaskets is particularly important. Using a gasket that is too thick may prevent full opening of the safety check valve and thus reduce the pressure available for atomization of the oil. When selecting gaskets always use BuShips packing chart B-153 and refer to chapter 9950 (95) of the Bureau of Ships Technical Manual.

Maintenance of Burner Safety Devices

On all new construction, fuel oil burners are fitted with safety shutoff devices that close automatically when the atomizer assembly is removed from the burner. These safety shutoff devices prevent spillage of oil if an atomizer should be removed while the burner root valve is still open.

Maintenance of the burner safety devices is extremely important because defects in a safety device could easily interfere with combustion. The information on maintenance given here applies specifically to the Babcock & Wilcox burner safety shutoff valve shown in figure 3-22. For information on the maintenance of other types of burner safety devices, consult the manufacturer's technical manual.

DISASSEMBLING THE SAFETY SHUTOFF VALVE.—To disassemble the valve, first unscrew the end cap and remove it. The O-ring packing tends to hold the end cap firmly in place, so removal may be somewhat difficult. Next remove the camshaft nut and withdraw the



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Figure 3-22.—Safety shutoff valve for Babcock & Wilcox fuel oil burner.

camshaft and lever assembly. Remove the pistonhead, together with all parts that are fastened to the pistonhead.

No further disassembly is required in order to replace the O-ring packing. However, if it is necessary to replace other parts or if it is necessary to grind in the valve seat to the seat piston, the valve must be taken apart. To continue disassembling the valve, release the pistonhead by loosening the Allen setscrew. Unscrewing the pistonhead from the seat piston holder gives access to the spring. Loosen the Allen setscrew in the cam piston, and unscrew the cam piston from the valve disk stem. At this point the seat piston can be removed by bringing it through the seat piston holder. The valve is now completely disassembled and ready for any required repairs or replacements.

REASSEMBLING THE SAFETY SHUTOFF VALVE.—Burner safety devices must be very carefully reassembled so that all parts fit together as they should and all designed clearances are maintained. To reassemble the valve shown in figure 3-22, first insert the seat piston through the seat piston holder and insert the valve disk stem through the seat piston. Then position the valve spring over the valve disk stem, as shown in figure 3-22. Replace the pistonhead in the seat piston holder, making it up handtight. Then reset the Allen setscrew to lock this part of the assembly. Attach the cam piston, screwing it onto the valve disk stem until

only about three threads remain visible. Now insert the entire valve assembly into the valve body. Set the camshaft and lever assembly in place, threading the camshaft nut handtight on its seat.

To make the final adjustments, insert the blade of a screwdriver through the center of the pistonhead and engage the slot of the valve disk stem. With the lever in the closed position (vertical) hold the lever lightly and turn the screwdriver clockwise as far as it will go. Then back off one-eighth of a turn, to provide the necessary clearance at the cam. Release the lever, back off the camshaft nut, and remove the camshaft and lever assembly. Withdraw the pistonhead from the body and tighten the Allen setscrews to lock the cam piston in place on the valve disk stem.

Replace the entire valve assembly in the body, being sure that the open end of the cam piston faces upward. Replace the camshaft and lever assembly and take up the camshaft nut with a wrench. Replace the end cap, using a wrench. The valve is now reassembled and ready for operation.

FUEL OIL HEATERS

This section deals with information concerning testing, cleaning, repairing, reassembling, and reinstalling fuel oil heaters. The information which follows is generally applicable to all types of fuel oil heaters (discussed earlier in the

chapter) used aboard ship. For specific details, the manufacturer's technical manual should be consulted.

Testing Fuel Oil Heaters

The following tests are required for fuel oil heaters installed in the fuel oil service system:

1. Whenever a fireroom has not steamed for a period of more than a week, and in any case at least once each quarter, the entire system on the discharge side of the fuel oil service pump must be subjected to an oil pressure equal to the authorized setting of the fuel oil service pump discharge relief valve. This test, of course, includes the fuel oil heaters. While under test, the fuel oil heaters must be inspected for signs of leakage at all joints. The recirculation system is used during this test, and the oil is heated to a temperature corresponding to a viscosity of 200 seconds Saybolt Universal.

2. When any part of the fuel oil system has undergone repairs that might affect either the tightness or the strength of any part, the entire system including the fuel oil heaters must be subjected to an oil pressure equal to 150 percent of the designed operating pressure. In addition, the steam side of the heater (including the piping from the heater steam throttle valve to the drain discharge cutout valve) must be subjected to a hydrostatic test pressure equal to the designed steam operating pressure of the heater.

3. At least once each year, the steam side of all fuel oil heaters (including the piping from the throttle valve to the drain discharge valve) must be subjected to a hydrostatic test pressure equal to the designed steam operating pressure of the heater.

4. Every 5 years, the steam side of the fuel oil heaters must be subjected to a hydrostatic test pressure of 1 1/2 times the designed steam operating pressure of the heater.

Cleaning Fuel Oil Heaters

Most fouling on the oil side of fuel oil heaters is caused by overheating the oil. As a rule, fuel oil heaters should be cleaned each time the boiler is overhauled; if this is done, there should be little need to clean them at other times unless abnormal operating conditions cause excessive fouling.

Manual cleaning is approved ONLY for Type B and Type D heaters, and then only if it is done in strict accordance with the manufacturer's instructions. A chemical method of cleaning based on the recirculation of a water-diluted heavy duty degreasing compound is approved for all types of fuel oil heaters. The materials and equipment required for the chemical cleaning of fuel oil heaters are:

1. The cleaning agent. This is a heavy-duty degreasing compound conforming to specification MIL-C-20207C. This compound may be obtained from standard stock in 55-gallon drums and in 5-gallon cans.

2. A small, low-capacity pump. The fuel oil service pumps and other permanently installed shipboard pumps should NOT be used for this service, since the cleaning compound may attack certain kinds of packing. A spare water-circulating pump from some types of boat engines, connected to a small electric motor that operates at about 1750 rpm, makes a satisfactory pump for this use.

3. A steam coil or immersion heater for heating the cleaning solution.

4. A mixing tank or drum.

5. A pressure gage.

6. Piping and pipe fittings.

The general arrangement for recirculating the cleaning compound through a fuel oil heater is shown in figure 3-23. The procedure for cleaning should be in accordance with the Naval Ship Systems Command recommendations.

The following precautions should be observed when a fuel oil heater is being cleaned:

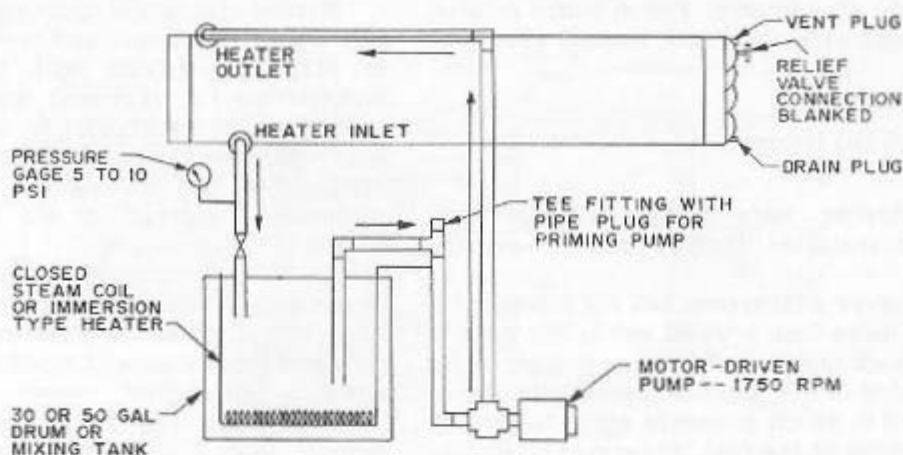
1. Never substitute any other chemical for the specified degreasing compound, unless permission is obtained from the Naval Ship Systems Command.

2. Do not use degreasing compound on aluminum or zinc surfaces.

3. Do not let the compound come in contact with skin or eyes. Wear protective equipment such as rubber gloves, rubber aprons, and goggles. If the compound does come in contact with skin, wash it off immediately with cold water.

4. The vapors of the degreasing compound are relatively nontoxic. However, the area should be kept well ventilated during the entire cleaning process.

5. Dispose of all oil-contaminated solutions in accordance with the provisions of the Oil Pollution Acts.



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Figure 3-23.—Arrangement for cleaning fuel oil heater by recirculation of degreasing compound.

Reinstalling Fuel Oil Heaters

Fuel oil heaters that have been disassembled for manual cleaning or for inspection following chemical cleaning must be very carefully reassembled. Before or during reassembly, all bearing surfaces of gasketed joints should be cleaned. Gasket materials should conform to the specifications given on the applicable drawings. Gaskets cut from sheet stock must be accurately laid out to ensure a proper fit. Bolted joints should be tightened evenly.

When heaters have been removed for cleaning, they should be hydrostatically tested on both the oil side and the steam side before they are reinstalled. This procedure will show up leaks which might not otherwise be noticed until the whole fuel oil system is placed under test.

When heaters are being reinstalled, any shims used in the original installation must be correctly placed so as to ensure proper alignment of the heater and the piping. In units that have slotted holes in the supports to permit expansion of the unit, the holddown bolts for these holes should be tightened only enough to make a snug fit. When reconnecting the steam and oil piping to a fuel oil heater, all flanges must be clean, gaskets must be in good condition and made of the specified material, and all bolted joints should be taken up evenly.

Before reinstalling a fuel oil heater, be SURE to remove any blanks that may have been used during the cleaning of the heater.

FUEL OIL STOWAGE AND HANDLING

Detailed information concerning fuel oil stowage and handling is given in chapter 9550(55), Bureau of Ships Technical Manual. The present discussion deals with some aspects of fuel oil stowage and handling.

FILLING FUEL OIL TANKS

The rated full capacity of a fuel oil tank is 95 percent of the total capacity, after allowance has been made for all obstructions and structures in the compartment. The remaining 5 percent of the space must remain free to allow for expansion of the oil. Care should be taken to see that oil tanks are never filled beyond the 95-percent level.

Fuel oil tank overflow systems are provided to reduce the danger of overstressing fuel oil tanks by subjecting them to excessive pressure. However, the overflow systems cannot completely eliminate this hazard unless certain operating precautions are observed. Precautions concerning the filling of tanks and the use of the tank overflow systems are given in the manufacturer's technical manual for the ship's piping systems.

Fuel oil storage tanks are fitted with air escapes. The air escapes have removable flash screens at the outlet. The flash screens must be inspected and cleaned at least once each quarter and replaced when necessary.

Automatic air escape valves and nonreturn valves that are accessible from outside the

tanks should be inspected and cleaned at least once a year, and more often if necessary. Automatic air escape valves and nonreturn valves that are accessible only from inside the tank should be inspected and cleaned whenever the tank is cleaned. Failure of these valves could cause serious tank damage by allowing excessive pressures to build up inside the tanks.

Liquid level indicating systems of the static head type are installed in many fuel oil tanks. Indicators for the level indicating system are either liquid manometers or differential pressure gages. Manometers have two scales. The right-hand scale is graduated in hundreds of gallons of the liquid using the average specific gravity of the liquid at 60°F. The left-hand scale is graduated to read in feet and inches of pressure head equal to the height of the liquid in the tank. Differential pressure gages have scales graduated in hundreds of gallons. Usually the 5 percent and the 95 percent full marks are prominently marked on the scale.

Tank capacity curves, generally available for each tank, indicate the capacity of the tank (in gallons), at each foot height of liquid level. The curves also show the location of the upper and lower datums (the location of the air bells above the bottom of the tank). The lower datum is below the 5 percent full, and the upper datum above the 95 percent full. Absolute empty or 100 percent full points cannot be indicated.

Static head liquid level indicating systems consist of air bells at the top and bottom of the tank, the indicator (usually a transparent column, liquid manometer), and piping connecting the air bells to the high and low pressure connections on the indicator. The indicating systems frequently are designed to allow low pressure air to flow through the piping from the indicator, through the air bell, into the tank; this prevents liquid from collecting in the system, causing erroneous readings.

BALLASTING AND DEBALLASTING

Most combatant ships are provided with water ballast compensation systems. These systems allow selected fuel oil tanks to be flooded with sea water in order to provide stability, torpedo protection, and protection from initial list in the event of underwater damage to the ship.

A specified sequence must be followed so that tanks and voids will be ballasted and

deballasted in proper sequence. When one fuel oil storage tank is almost empty, the fuel oil contained in it is pumped to another tank and the empty tank is then filled with sea water. The ballasting and deballasting plan specifies the sequence that will best maintain stability under various conditions.

Fuel oil tanks must be completely emptied of oil before sea water is admitted and completely emptied of sea water before they are refilled with fuel oil.

MAINTENANCE OF FUEL OIL TANKS

Fuel oil tanks are not painted on the inside but instead are protected from corrosion by the oil film on the inner surfaces. In order to maintain the protective oil film on all inner surfaces, the Naval Ship Systems Command requires that all fuel oil tanks be pumped full, to their overflow capacity, at least once each year.

Whenever a fuel oil tank is cleaned and made safe for personnel, a complete inspection of the tank must be made. At the same time, the heating coils must be tested and inspected. Fuel oil tanks and tank heating coils are inspected on schedules established by the Naval Ship Systems Command. All tests, inspections, cleaning, and repairs of fuel oil tanks, fuel oil tank heating coils, and fuel oil tank fittings must be entered on the applicable hull history card.

Aboard ships that are not fitted with water compensating-systems, at least one fuel-oil tank must be cleaned and inspected every 18 months. These inspections can usually be accomplished most expediently during the shipyard-overhaul period. The tank designated should be one in which the most extensive deterioration is expected.

Ships fitted with water-ballast compensating systems should clean and inspect at least ten percent of the tanks that have been flooded during the preceding 18-month period. No more than four tanks, however, need be inspected during any 18-month period.

Commanding officers must determine, from the results of these routine inspections, whether or not the inspection of additional tanks is necessary.

Cleaning fuel-oil tanks or entering these tanks for inspection, involves hazards to personnel and material if the prescribed safety precautions are not rigidly adhered to. The procedures for entering and cleaning fuel-oil

tanks are described, in detail, in chapter 9550 (55), of the Bureau of Ships Technical Manual.

A record of all inspections, cleaning, tests, and repairs, of fuel oil tanks and their fittings should be entered in the material history. An annual entry should also be made for each fuel-oil tank in the ship, indicating the date when the tank was last inspected.

RECEIVING FUEL OIL

Before receiving fuel oil, soundings or readings should be taken on all fuel oil storage tanks and all fuel oil service tanks. A statement showing the amount and location of all fuel oil on board must be submitted to the officer in charge of fueling.

Ballasted tanks must be deballasted and stripped as soon as possible after fueling is planned. All service tanks and as many storage tanks as possible should be topped off to the 95-percent level in order to reduce the number of tanks that must be filled while fueling.

When fuel oil is received from a naval source of supply such as a naval ship, a naval storage tank, or a naval fuel barge, the activity supplying the oil must furnish the commanding officer of the receiving ship with an analysis of the oil. If possible, an officer and the oil king of the receiving ship should witness soundings and the drawing of samples from the tanks of the supplying activity. The samples must be taken from the suction level of the tank from which the oil is to be drawn. One sample should be taken before loading is started; another should be taken after loading is completed. Both samples must be centrifuged to determine the percentage of sediment and water in the fuel oil.

When fueling is accomplished at sea, it may be impossible for the supplying ship to furnish a complete analysis of the oil and for the receiving ship to send representatives to witness the soundings and the sampling. In this case, the supplying vessel furnishes a statement of the API gravity and the sediment and water content of the oil. The receiving ship must then take samples during delivery and make tests to determine the percentage of sediment and water. The samples should be taken by dipper from the tank that is being filled, or drawn through connections in the delivery pipe line. Small samples should be taken and accumulated to make a total sample of at least 5 gallons. Smaller samples for tests are then taken from the total sample. All containers

used for taking and accumulating samples must be completely clean before being used.

As fuel is coming aboard, the oil king must keep a close watch on the levels in all tanks. He must keep the fueling officer informed concerning tank levels so that the pumping rate can be slowed when necessary.

After fueling has been completed, soundings and pneumatic readings must be taken to determine the amount of oil received. The amount received, the time at which the fueling operation began and the time at which it ended, and other details must be reported to the officer in charge of fueling. Computations of the amount discharged and received are exchanged between the delivering and receiving ships on completion of fueling via normal means of communications. Computations are compared and the results of the comparison are reported to the engineering log room and discrepancies (if any) noted.

SAFETY PRECAUTIONS

All petroleum products, including fuel oil, are dangerous if not properly handled. Fuel oil vapors are flammable and explosive, and they are dangerous if inhaled. Benzene (Benzol) should NOT be used below decks or in enclosed spaces because of the fire hazards involved in its use. Some of the most important precautions to be observed in connection with fuel oil and fuel oil equipment are as follows:

1. Do not allow anyone to smoke, when refueling.
2. Use only approved types of protected lights when working near fuel oil.
3. Do not allow oil to accumulate in bilges and voids. The vapor from even a small pool of oil could cause an explosion.
4. Never raise the temperature of fuel oil above 120° F in fuel oil tanks; or, if the tanks are next to a magazine, never allow the oil to become hot enough to raise the temperature of the magazine above 100° F or to maintain a temperature of more than 90° F in the magazine.
5. Never raise the temperature of fuel oil above the flash point in any part of the system except between the fuel oil heaters and the atomizers.
6. Never exceed the designed pressure in any part of a fuel oil system.
7. Do not allow smoking or the use of any open flame or any spark-producing object in

the immediate vicinity of vent pipes from fuel oil tanks.

8. Be sure that the wire screen protectors in the vent pipes are kept intact. Do not allow them to be painted.

9. REMEMBER THAT FUEL OIL FUMES ARE DANGEROUS IF INHALED. The effects range from eye irritation, headache, and dizziness to suffocation and unconsciousness. Any person suffering from inhalation of fuel oil fumes should be given first aid immediately. Remember, also, that a person who is suffering only mild effects from inhaling fuel oil fumes may be confused or drowsy enough to cause a serious accident.

10. Do not enter, and do not allow anyone else to enter, any fuel oil compartment which has not been declared SAFE FOR MEN by the gas-free engineer. Permission must always be obtained before any person is allowed to enter a fuel oil tank.

11. When your ship is in drydock, take every precaution to prevent oil draining from the ship into the dock.

12. Take every precaution to keep oil from spraying out into the furnace without being burned. Accumulations of oil on the furnace deck are very dangerous.

13. Be sure that all atomizer parts are clean, polished, and free from blemishes, scratches, and deposits before using them. Do not tamper with atomizer parts. Never make any changes in the dimensions of any sprayer plate or other atomizer part.

14. Never use steel wire or steel tools to clean atomizer parts.

15. Do not overtighten the atomizer tip when assembling an atomizer. Repeated overtightening of the tip will undercut the sprayer plate and result in oil leakage.

16. Keep the burner root valve FULLY OPEN when the burners are in operation and FULLY CLOSED when the burners are secured.

17. When burners are secured, remove the atomizers if feasible. During a standby period, when the ship is maneuvering, or when other conditions make it impracticable to remove the atomizers, withdraw the atomizers as far as possible.

18. Periodically, the burners should be checked to see that they are in good condition and that all settings and dimensions are exactly as specified.

19. Measures should be taken to ensure that all shielding around flanged joints and strainers be replaced after maintenance or repairs have been completed.

CHAPTER 4

BOILER WATER AND FEED WATER TESTS

The primary purpose of conducting tests of the water both in the feed system and the stowage tanks, and also in the boiler itself is to determine its characteristics so that necessary water treatment may be carried out. A clear understanding of the qualities desired in feed water and boiler water is essential to an understanding of the indicated test procedures. The major purpose of this chapter is to present the subject of water treating and testing in such a way that officer personnel can become thoroughly familiar with it.

BOILER WATER CONTAMINATION

Modern naval boilers cannot be operated safely and efficiently without careful control of boiler water quality. If boiler water conditions are not within allowable limits, the high operating pressures and temperatures of modern boilers will lead to rapid deterioration of the boiler metal, with the possibility of serious casualties to boiler pressure parts.

Maintaining boiler water in the required condition is therefore an extremely important job. In order to control the quality of boiler water, it is important to have both theoretical knowledge and practical skill—knowledge of boiler water problems and treatment, and skill in making boiler water tests.

However, before discussing boiler water problems, a knowledge of sources of contamination will be most helpful.

Sea water, the source of practically all fresh water used aboard ship, contains about 35,000 parts per million of sea salts. This is equivalent to roughly 70 pounds of sea salts per ton of water. When sea water is evaporated and the vapor is condensed in the distilling plant, the resulting distillate contains about 1.75 ppm of sea salts or roughly 70 pounds per 20,000 tons.

In other words, distillate is actually DILUTED sea water—sea water that is diluted to about 1/20,000 of its original concentration. It is not "pure water." In considering water problems and water treatment, one must remember that the basic impurity of sea water distillate would make water treatment necessary even if no other impurities entered the water from other sources.

The salts that are present in sea water—and, therefore, to a lesser extent in distillate—are chiefly compounds of sodium, calcium, and magnesium.

SEA WATER is most likely to enter the system at the following points:

1. Main and auxiliary condensers.
2. Distilling plant evaporators, condensers, and air ejectors.
3. Drain collecting tanks, open funnel drains, and drain lines that run through or terminate in the bilges.
4. Feed suction lines that run through bilges.
5. Reserve feed tanks (leaky seams or open sounding tubes).
6. Bottom blow valves on idle boilers.

FUEL OIL may enter the feed system and eventually be carried to the boiler. The most likely sources of fuel oil contamination are the fuel oil heaters and the fuel oil tank heating coils.

LUBRICATING OIL from the main lube oil system may enter the condensate system through the turbine gland seal system.

RUST PREVENTIVES or PRESERVATIVES used in new or activated ships may enter the condensate system or the feed system from a number of different sources.

DISSOLVED OXYGEN contamination results from defects in the deaerating feed tank, improper operation of the deaerating feed tank, air leakage into any part of the system, and—most commonly—failure to secure the boilers and lay them up in accordance with prescribed procedures.

CORROSION PRODUCTS may be picked up from piping, valves, and machinery at various points in the steam-water cycle. These corrosion products, like other contaminating materials, tend to be carried to the boiler.

WATER TREATMENT CHEMICALS must also be considered as contaminants of the boiler water. Although the chemicals are necessary, they do increase the amount of foreign matter in the boiler water.

MINERALS PRESENT IN SHORE WATER introduce an entirely new set of contaminating substances into the boiler water, if shore water is used as boiler feed. Even if shore water is distilled before use, it will still contain impurities that can NOT be counteracted by the standard methods of boiler water treatment. For this reason, shore water should never be used as boiler feed except in an extreme emergency. It should be noted, also, that steam obtained from shore will normally be contaminated in the same manner as distilled shore water. While recognizing the dangers of used shore water, shipboard personnel sometimes overlook the fact that the same dangers exist (though to a lesser degree) in using shore steam. If shore steam is routed to the drains, for example, trouble may later be encountered with the boiler water.

BOILER WATER PROBLEMS

Although there are many sources of boiler water contamination, the contaminating materials tend to produce three main problems when they are concentrated or accumulated in the boiler water. Thus, boiler water treatment must be aimed at controlling the results of boiler water problems: (1) waterside deposits, (2) waterside corrosion, and (3) carryover.

WATERSIDE DEPOSITS

Any waterside deposit interferes with heat transfer and thus causes overheating of the boiler metal. The general manner in which a waterside deposit causes overheating of a boiler tube is shown in figure 4-1. In a boiler operating at 600 psi, the temperature inside a generating tube is approximately 500°F and the temperature of the outside surface of the tube is about 100°F higher. Where a waterside deposit exists, however, the tube cannot transfer the heat as rapidly as it receives it. As shown in figure

4-1, the inside of the tube has reached a temperature of 800°F at the point where the waterside deposit is thickest; the outside of the tube at this point has reached a temperature of 950°F. What happens? The tube metal is overheated to such an extent that it becomes plastic and blows out, under boiler pressure, into a bubble or blister. The temperatures given in this example do not apply to all situations in which a boiler tube is overheated; the exact temperatures of the inside and the outside of a tube would, of course, depend upon the operating pressure of the boiler, the nature of the deposit, and other factors.

The term **WATERSIDE DEPOSITS** is used to include sludge, oil, scale, corrosion deposits, and high-temperature oxide. With the possible exception of oil, these deposits are not usually soluble enough to be removed by washing or boiling out the boiler.

Sludge

Sludge is a general term used to cover all sedimentary deposits of insoluble matter in the

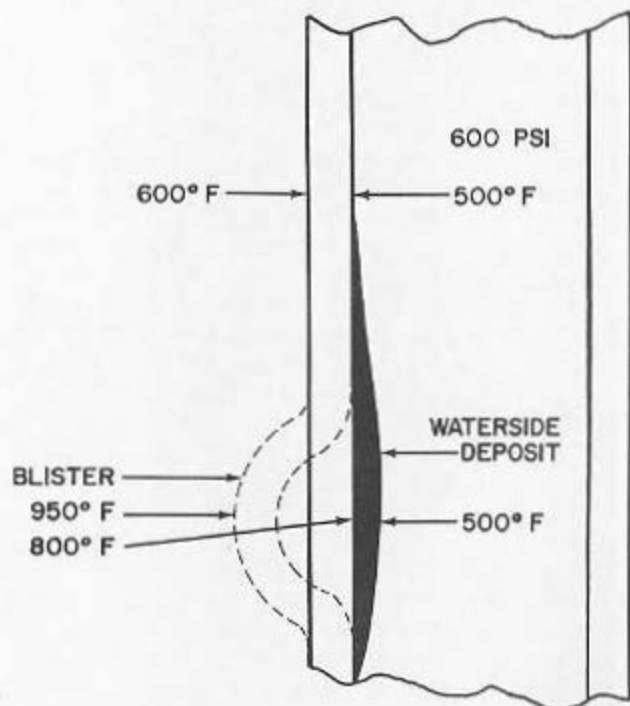


Figure 4-1.—Effects of waterside deposit on boiler tube.

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boiler water. In general, sludge consists of metal oxides (such as rust) and other corrosion products; reaction products of the chemicals used for boiler water treatment; and oil or grease.

Most sludges are originally soft and non-adherent. After remaining on the boiler surfaces for any length of time, however, sludges adhere firmly to the metal. In some cases, they can be as difficult to remove as scale (discussed later in this chapter).

Sludge simply settles out (or floats out) of the water and is deposited in layers on the inside of tubes and drums. Sludge deposits are not crystalline in structure; in this they differ from scale, which has a crystalline structure that may be seen under microscopic examination.

Most sludges are heavier than water, and therefore tend to collect in the lower drums and headers and in the lower ends of the tubes. Figure 4-2 shows a heavy deposit of sludge in a 2-inch fire row tube. Because of the high temperatures in the fire row tubes, sludge that accumulates in these tubes tends to become

baked. Baked sludge is extremely difficult to remove. The danger of baked sludge is indicated by the fact that approximately 25 percent of all boiler tube casualties are associated with such deposits.

It is far easier to PREVENT the accumulation of sludge than to try to remove sludge after it has baked onto tubes or drums. The proper use of blowdown is most effective in preventing excessive accumulations of sludge in the boiler water.

Oil

Oil is actually considered as a special kind of sludge. When oil gets into the boiler water, it tends to coat the watersides of the boiler uniformly. At high temperatures, it gradually carbonizes into a graphite-like sludge such as that shown on the boiler tube in figure 4-3.

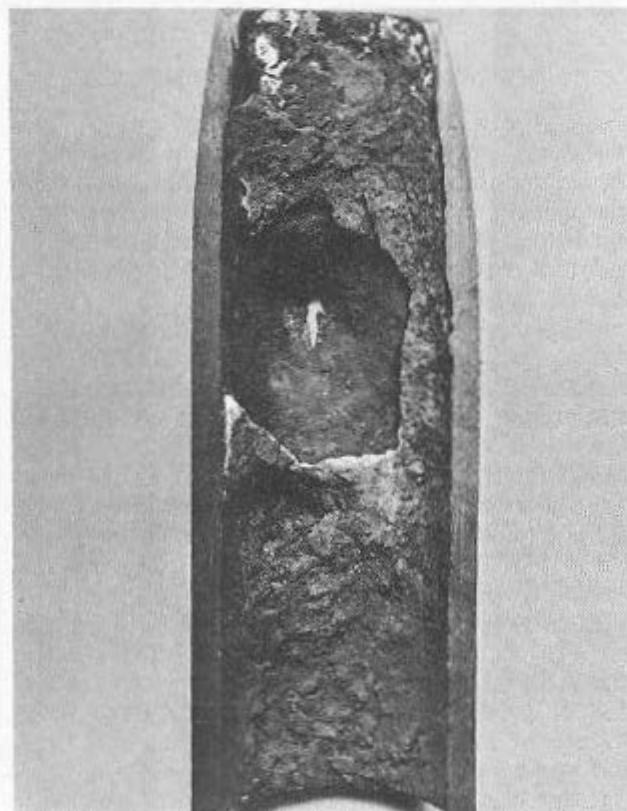
Under some conditions, oil in the boiler water may mix with other insoluble materials and roll into sludge balls such as those shown in figure 4-4. These balls cannot be detected except when the boiler is opened up for inspection or repair. On the whole, these sludge balls are not as troublesome as oil or grease alone would be, since they seem to collect the oil and thus prevent its deposit on waterside surfaces.

The early detection of oil or grease in the feed system is of the utmost importance. Drains from fuel oil heaters and from heating coils in lubricating oil tanks and fuel oil tanks should always be passed through inspection tanks before being discharged to the feed system. If oil or grease is detected in the drain inspection tanks, the drains must be diverted to the bilges until the source of contamination has been eliminated.

It is usually quite difficult to detect oil or grease in the boiler water. After oil or grease has been exposed to the extremely high temperatures in the boiler, any bubble or film of oil that appears in the gage glass is likely to be quite transparent and almost colorless. In addition, the oil may disappear temporarily when the gage glass is blown down, and may not reappear for some time. It is important, therefore, to take even the slightest indication of oil or grease as a serious matter. A very small drop of oil in a gage glass may indicate a large amount of oil in the boiler.

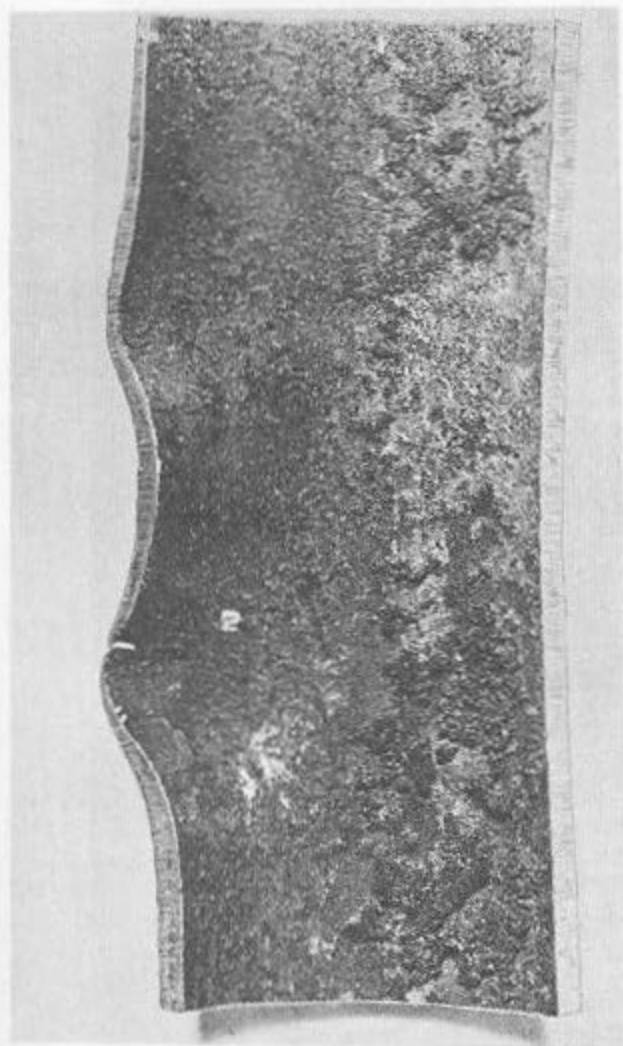
Scale

Although the word SCALE is used freely by shipboard personnel, true scale is actually rare



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Figure 4-2.—Baked sludge on boiler tube.

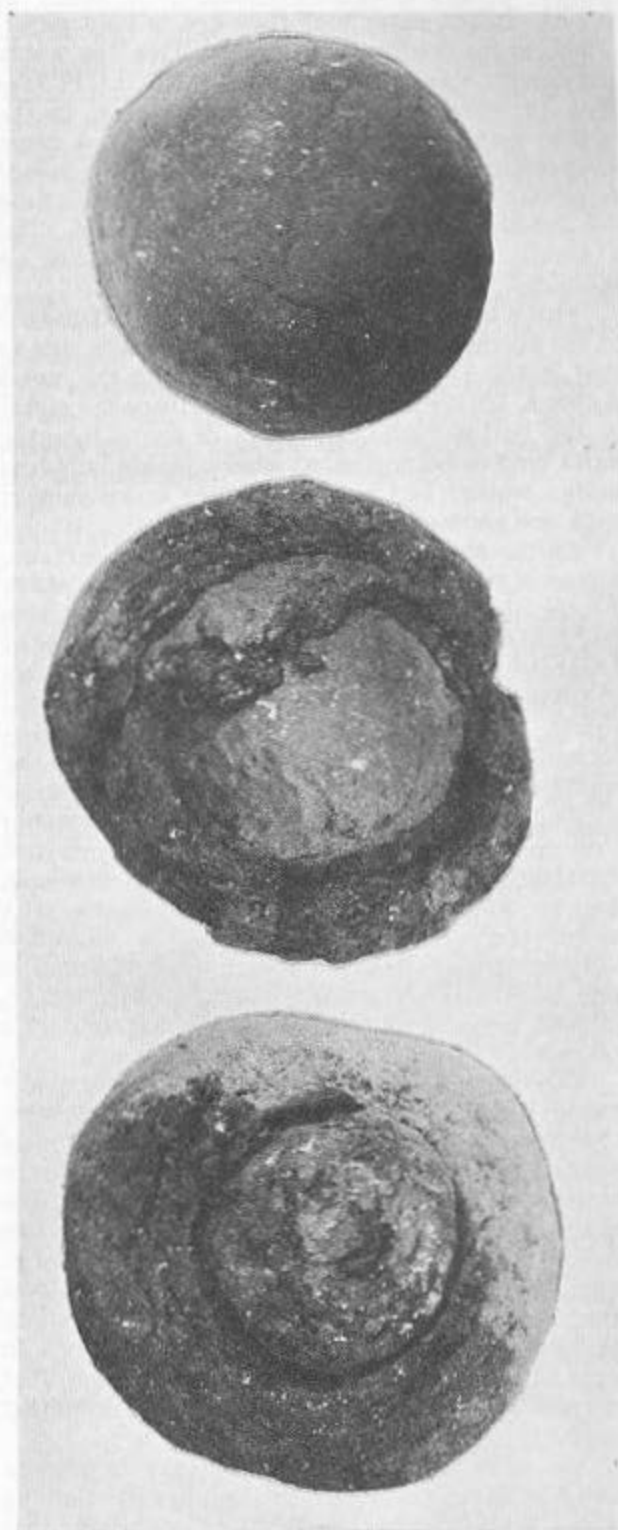


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Figure 4-3.—Carbonized oil on boiler tube.

in naval boilers. The discovery that scale has actually formed in a boiler should lead to an immediate investigation of the conditions that allowed its formation.

True scale is formed as the result of crystallization processes that occur because of temperature changes. In order to understand how scale may form in a boiler, the meaning of the solubility of salts in water must be clarified. Everyday experience leads us to believe that salts are more readily soluble in hot water than in cold water—that is, that hot water can hold more salts in solution than cold water. This is true for many salts. However, the salts that form scale in a boiler are LESS



38.134

Figure 4-4.—Sludge balls.

soluble in hot water than they are in cold water. Thus, in the cooler parts of the boiler, the water may contain scale-forming salts **IN SOLUTION**—that is, dissolved in the boiler water. In the hotter parts of the boiler, however, the same concentration of scale-forming salts will result in crystallization of the salts that cannot be held in solution at the higher temperature. The crystals that are thus formed are known as **SCALE**.

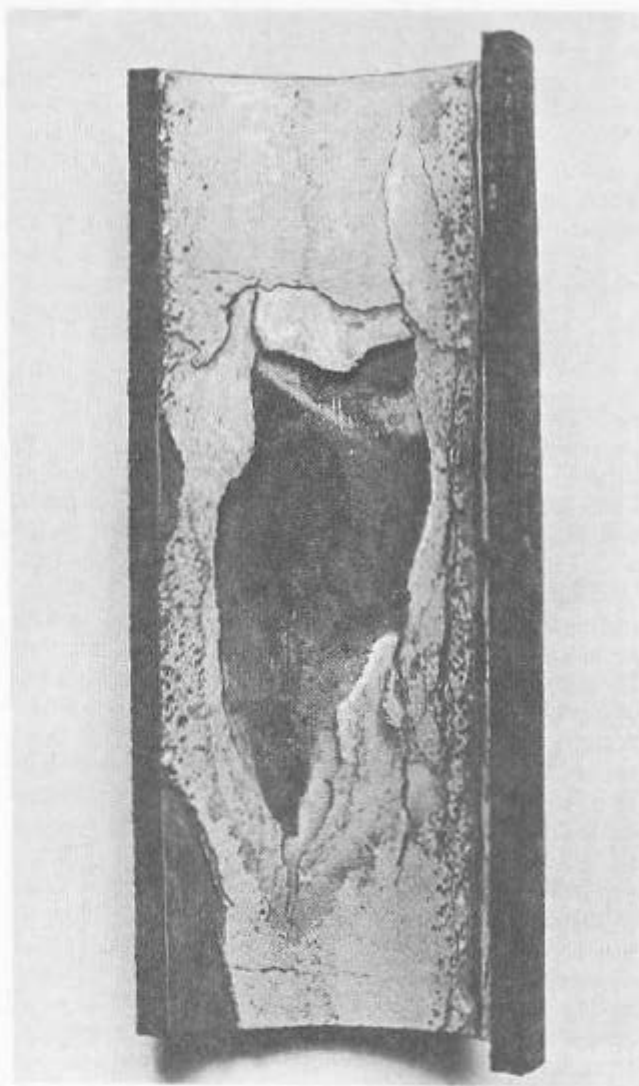
Since the scale-forming salts crystallize out of the hottest water and since the hottest water is that which is directly in contact with the metal surface, boiler scale forms directly on the metal of the boiler tubes. Crystals of scale-forming salts tend to be deposited where steam bubbles, boiler water, and a tube surface make contact with one another.

As the steam bubbles leave the metal surface, a ring of small scale crystals will be left to mark the location where the bubble was in contact with the boiler tube. As successive steam bubbles separate from the metal surface, the many rings of scale crystals become interlaced and the individual crystals increase in size. Most scale-forming salts crystallize at right angles to the metal surface—that is, normal to the tube wall.

Because scales are formed in the manner just described, they have a definite crystalline structure that may be seen under a microscope. Figure 4-5 shows scale as it appears on a boiler tube; note that the crystalline nature of the deposit is not visible in this picture. If this tube is viewed under a microscope, however, it will be noticed that the scale consists of a mass of crystals.

Compounds of calcium and magnesium are the principal scale formers in naval boilers. Calcium sulfate is probably the most dangerous scale-forming salt because it is soluble in boiler feed water but almost insoluble at the temperatures existing in the boiler tubes. In the absence of proper water treatment, therefore, practically all of the calcium sulfate that enters in the feed water must be deposited as scale in the boiler tubes. Calcium sulfate is so hard, and it sticks so tightly to the tubes, that it can scarcely be removed by mechanical cleaning.

As mentioned before, true scale is seldom found in naval boilers. However, the day that the water tests are not made could be the day that calcium sulfate scale would begin to form in a boiler. It's a lot easier to make boiler water tests and to keep up the proper boiler water



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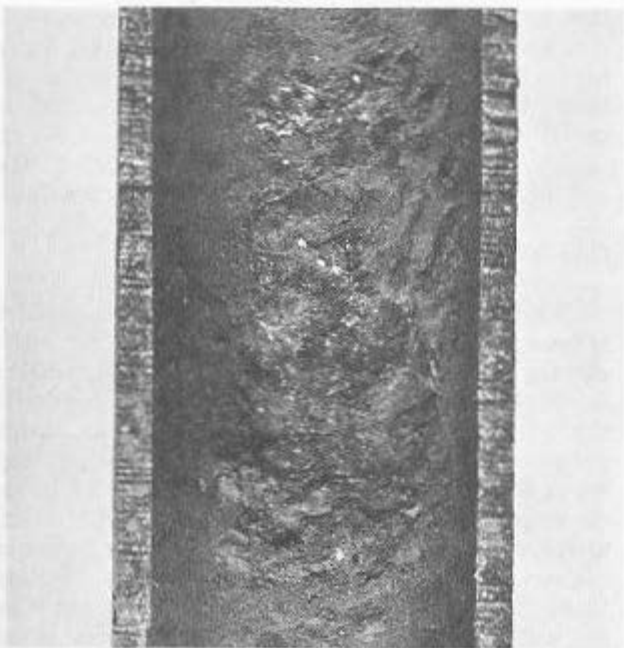
Figure 4-5.—Scale on boiler tube.

treatment than it is to remove scale or to try to explain why the scale was allowed to develop.

Corrosion Deposits and High-Temperature Oxide

Corrosion deposits, like scales, form directly in place on the boiler metal. Unlike scales, however, these deposits are the result of chemical reactions of the metal with the water; they are **NOT** the result of crystallization. A boiler tube with a typical corrosion deposit formed in place is shown in figure 4-6.

High-temperature oxide is a special type of corrosion product that results when hot metal

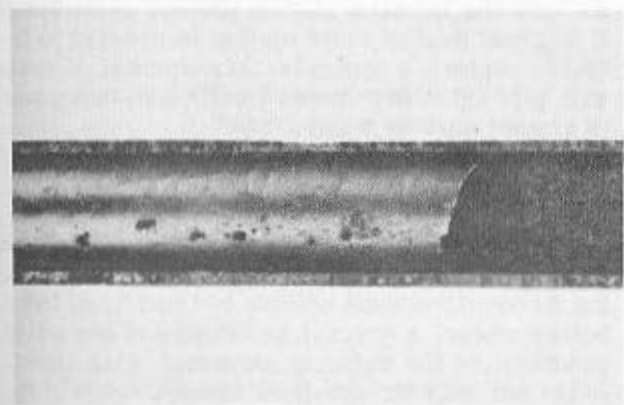


38.136
Figure 4-6.—Corrosion deposit on boiler tube.

reacts with air or water. This oxide is sometimes called "mill scale" because it gives the boiler metal an appearance similar to that of the surface of newly rolled steel. High-temperature oxide on a boiler tube is shown in figure 4-7.

WATERSIDE CORROSION

The term WATERSIDE CORROSION is used to include both localized pitting and general corrosion. Most, if not all, waterside corrosion



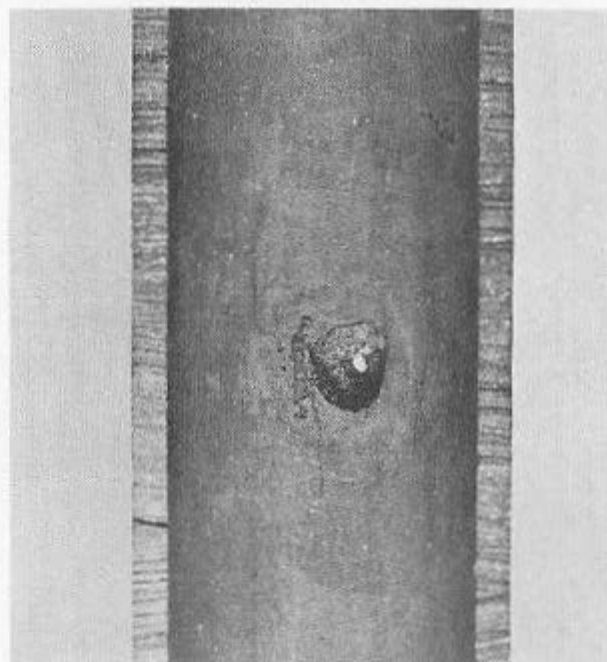
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Figure 4-7.—High-temperature oxide on boiler tube.

is probably electrochemical in nature. There are always some slight variations (both chemical and physical) in the surface of any boiler metal. These small chemical and physical variations in the metal surface cause slight differences in electric potential between one area of a tube and another area. Some areas are ANODES (positive terminals) and others are CATHODES (negative terminals). Iron from the boiler tube tends to go into solution more rapidly in the anode areas than at other points on the boiler tube.

This electrolytic action cannot be completely prevented in any boiler. However, it can be kept to a minimum by maintaining the boiler water at the proper alkalinity and by keeping the dissolved oxygen content of the boiler water as low as possible.

Localized Pitting

The presence of dissolved oxygen in the boiler water contributes greatly to the type of corrosion in which electrolytic action makes pits or holes of the type shown in figure 4-8. These pits actually indicate the anodic areas in which iron from the boiler tube has gone into solution in the boiler water. Under certain circumstances, some of the metal may be deposited over the pit, forming a sort of scab of



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Figure 4-8.—Oxygen pit in boiler tube.

the type shown in figure 4-9. It is possible for a boiler tube to have some of these oxygen pits without showing any other signs of corrosion.

General Corrosion

General corrosion occurs when conditions favor the formation of many small anodes and cathodes on the surface of the boiler metal. As corrosion proceeds, the anodes and cathodes constantly change position. Therefore, there is a general loss of metal over the entire surface. Low alkalinity (or low pH) allows this type of general corrosion to proceed unchecked.

If the boiler water is excessively alkaline (or if the pH value is too high), general corrosion may also occur. When alkalinity is very high, strong caustic concentrations develop in

the hottest parts of the boiler. These caustic concentrations dissolve the protective oxide layer from the surface of the boiler metal and thus permit continuous chemical reaction to occur between the metal and the boiler water.

General corrosion may also occur if the chloride content of the boiler water is too high.

CARRYOVER

Failure to control the quality of boiler water frequently results in carryover. Under some circumstances, very small particles of moisture (almost like a fine mist) are carried over with the steam. Under other circumstances, large gulps or slugs of water are carried over. The term PRIMING is generally used to describe the carryover of large quantities of water. Both kinds of carryover are dangerous and both can cause severe damage to superheaters, steam lines, turbines, and valves. Whatever moisture or water is carried over carries with it the solid matter that is dissolved or suspended in the water. This solid matter tends to be deposited on turbine blades and in superheater tubes and valves. Figure 4-10 shows a superheater tube in which solid matter has been deposited as a result of carryover. Priming, or the carryover of large slugs of water, is especially dangerous because it can do such severe damage to machinery; for example, priming can actually rip turbine blades from their wheels.

One cause of carryover is foaming of the boiler water. Foaming occurs when the water contains too much dissolved or suspended solid matter. The solids tend to stabilize the bubbles so that the bubbles pile up instead of bursting. If a great deal of solid matter is present in the boiler water, a considerable amount of foam will pile up. Under these conditions, carryover is almost sure to occur.

BOILER WATER TESTS

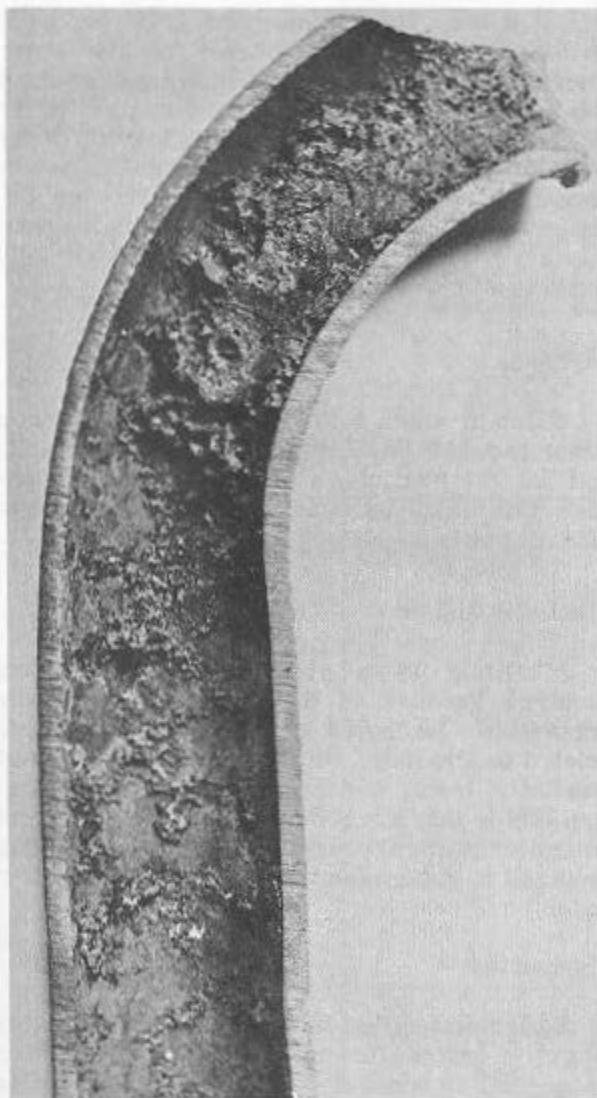
Boiler water treatment cannot be carried out on a hit or miss basis. Before attempting to counteract the effects of impurities in the boiler water, a precise knowledge of the actual condition of the water is essential. This knowledge can only be obtained through tests of the boiler water and of the feed water.

The information given here applies primarily to boiler water tests. Feed water tests are discussed later in the chapter. However, certain



38.139

Figure 4-9.—Scab formed over oxygen pit.



38.140
Figure 4-10.—Evidence of carryover
in superheater tube.

aspects of water testing that apply are given in the present discussion and are not repeated in the section dealing with feed water.

UNITS FOR REPORTING RESULTS OF WATER TESTS

Four units are used for reporting the results of boiler water and feed water tests on steam-driven surface ships. Dissolved oxygen and phosphate are reported in terms of the unit called PARTS PER MILLION (ppm). Chloride,

alkalinity, and hardness are reported in terms of the unit called EQUIVALENTS PER MILLION (epm). The unit known as pH is used on some ships instead of the epm unit for alkalinity. On some ships, the electrical conductivity of the boiler water is measured and the conductivity is reported in the unit called MICROMHOS.

Parts Per Million

Parts per million (ppm) is a weight-per-weight unit that indicates the number of parts of a specified substance in a million parts of another substance. For example, 58.5 pounds of salt in 1,000,000 pounds of water represents a concentration of 58.5 parts per million. Note also that 58.5 OUNCES of salt dissolved in 1,000,000 OUNCES of water, or 58.5 TONS of salt dissolved in 1,000,000 TONS of water, represent the same concentration—that is, 58.5 ppm. Similarly, if 8 pounds of oxygen are dissolved in 1,000,000 pounds of water, the concentration is described as 8 ppm.

Equivalents Per Million

Equivalents per million (epm) can be defined as the number of EQUIVALENT parts of a substance per million parts of some other substance. The word "equivalent" here refers to the chemical equivalent weight of a substance. The chemical equivalent weight is different for each element and compound. The chemical equivalent weight of sodium chloride (common table salt) is 58.5 so a solution containing 58.5 parts of this salt per 1,000,000 parts of water is said to have a concentration of 58.5 ppm OR 1 epm. If a substance has a chemical equivalent weight of 35.5, a solution containing 35.5 parts per million is described as having a concentration of 1 epm. If a substance has a chemical equivalent weight of 35.5, a solution containing 35.5 parts per million is described as having a concentration of 1 epm.

The pH Value

Some ships are required to determine the pH value, rather than the alkalinity, of the boiler water. The pH unit does not measure alkalinity directly; however, it is related to alkalinity in such a way that a pH number gives an indication of the alkalinity or acidity of the water. The pH scale of numbers runs from zero to 14. On this scale, pH 7 is the neutral point. Solutions

having pH values above 7 (as, for example, pH 8 or pH 13) are defined as alkaline solutions. Solutions having pH values below 7 are defined as acid solutions.

Micromhos

The micromho, a unit of electrical conductivity, is used on all ships to report the conductivity content of the boiler water. The electrical conductivity varies according to the amount of ionized dissolved solids in the water.

TYPES OF BOILER WATER TESTS

The boiler water tests that may be performed aboard ship include chloride tests, hardness tests, alkalinity tests, pH tests, and phosphate tests for the dissolved solid content of the boiler water. Note, however, that no ship makes all these tests. The types of boiler water tests required on any particular ship depend on the type of water treatment authorized for that ship and on the equipment that is furnished for making the tests.

Some of the boiler water tests used aboard ship give a direct indication of just what contaminating substance is present, in just what amount. In other cases, however, it is more important to know what EFFECTS the contaminating substances have upon the water than it is to know exactly what the substances are or exactly how much of each is present. Therefore, some water tests are designed to measure PROPERTIES that the water acquires because of the presence of various impurities.

Chloride Content and Dissolved Solid Content

The term "chloride content" really refers to the concentration of the chloride ion, rather than to the concentration of any one sea salt. Because the concentration of chloride ions is relatively constant in sea water, the chloride content may be used as a measure of the amount of solid matter that is derived through sea water contamination. The results of the chloride test are used as one indication of the need for blow-down. Chloride content is expressed in equivalents per million (epm).

The test for chloride content indicates something about the amount of solid matter in the

boiler water, but it indicates only the solid matter that is there because of sea water contamination. It does not tell you anything about other solid matter that may be dissolved in the boiler water. A more accurate indication of the total amount of dissolved solids is obtained by measuring the electrical conductivity of the boiler water, since this is related to the total dissolved solid content. The dissolved solid content is expressed in micromhos.

Hardness

Water in which soap does not readily form a lather is said to be HARD. Hardness is a property that the water acquires because of the presence of certain dissolved salts. Hardness is expressed in epm.

Alkalinity and pH

Alkalinity is a property that the water acquires because of the presence of certain impurities. As noted before, the pH value is related to alkalinity. On ships that make standard alkalinity tests, the results are expressed in epm. Ships that use phosphate control treatment for boiler water are furnished with the equipment required to determine the pH value of the boiler water.

Phosphates

Boiler water that is treated with phosphates must be tested for phosphate content. Boiler water that is treated with standard Navy boiler compounds is not tested for phosphates.

When the phosphate content of boiler water is maintained within the specified limits, the hardness of the water should be zero. Therefore, hardness tests are not required for boiler water when phosphate tests are made. Phosphate content is expressed in parts per million (ppm).

FREQUENCY OF BOILER WATER TESTS

The boiler water tests to be made on any ship and the frequency of these tests depend on the method of boiler water treatment authorized for the ship and on the status of the boilers. The authorized types of water treatment are discussed later in this chapter. The various schedules of boiler water testing are shown in table 4-1.

Table 4-1.—Frequency Of Boiler Water Tests

Authorized Boiler Water Treatment	Type Ships Included	Condition of Boiler	Mandatory Tests of Boiler Water	Frequency of Boiler Water Tests
Standard Navy boiler compound treatment	Most ships with boilers operating at about 600 psig or less	Steaming	Chloride Alkalinity Hardness Conductivity	Daily, and after water treatment or blowdown
		Idle, laid up wet	Chloride Alkalinity Hardness Conductivity	Weekly
Phosphate control treatment	Ships with 1200-psig boilers	Freshly filled	Chloride pH Phosphate Conductivity	Hourly, until proper water conditions have been established
		Steaming	Chloride pH Phosphate Conductivity	Daily, and after water treatment or blowdown
		Idle, laid up wet	Chloride pH Phosphate Conductivity	Weekly
Special treatment for diatomite filter systems	LSD 1-8 class; certain CVE's	Freshly filled	Chloride Alkalinity Phosphate Conductivity	Hourly, until proper water conditions have been established
		Steaming	Chloride Alkalinity Phosphate Conductivity	Daily, and after water treatment or blowdown
		Idle, laid up wet	Chloride Alkalinity Phosphate Conductivity	Weekly

BOILER WATER LIMITS

In order to use the results of boiler water tests as a guide to boiler water treatment, the allowable limits for each substance in (or property of) the boiler water must be known.

The boiler water limits specified for any particular ship depend upon the type of water treatment authorized for the ship. The boiler water limits specified by the Bureau of Ships Technical Manual, chapter 9560 (56) are shown in table 4-2.

Table 4-2.—Boiler Water Limits

Authorized Boiler Water Treatment	Boiler Water Test	Boiler Water Limits
Standard Navy boiler compound treatment	Chloride	2 epm maximum
	Alkalinity	2.5 to 3.5 epm
	Hardness	0
	Conductivity	1300 micromhos/cm maximum
Phosphate control treatment	Chloride	2 epm maximum
	pH	10.4 to 11.0
	Phosphate	10 to 25 ppm
	Conductivity	700 micromhos/cm maximum
Special treatment for diatomite filter systems	Chloride	2 epm maximum
	Alkalinity	2.5 to 3.5 epm
	Phosphate	20 to 100 ppm
	Conductivity	1300 micromhos/cm maximum

MAKING BOILER WATER TESTS

Making boiler water tests is a rather complicated job that requires a great deal of care and attention. A water test result based on careless or inaccurate test procedures is not only useless but may actually be dangerously misleading. Useful information concerning the condition of the boiler water cannot be obtained unless each test is performed with real precision and accuracy.

When boiler water tests are performed, it is most important that the following be accomplished:

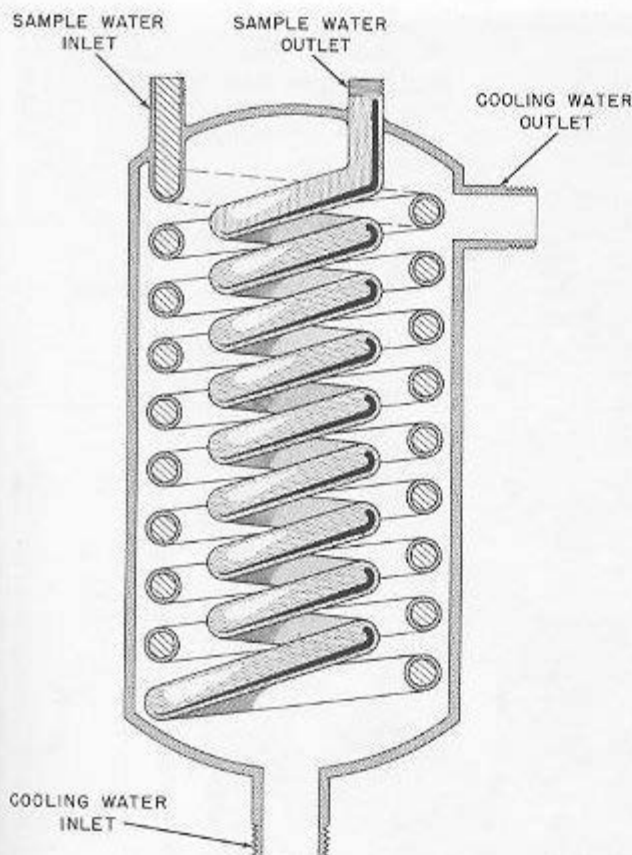
1. Obtain proper samples of boiler water.
2. Use correct chemicals for each test.
3. Measure chemicals accurately.
4. Make all measurements and readings as accurately as possible.
5. Interpret test results correctly.
6. Keep all test equipment clean and in good condition.

Sampling Boiler Water

Samples of boiler water taken for analysis must be truly representative of the water in the boiler. The container into which the sample is drawn must be clean, and the sampling connection must be thoroughly flushed out to remove sediment and stagnant water that may be trapped in the line or in the connection.

The water sample must be protected from contamination during the interval between sampling and analysis. It should not be exposed to air for any long period of time, since an alkaline sample would absorb carbon dioxide from the air; this would result in a false low reading for alkalinity.

Boiler water samples should be cooled down to below 100° F before being tested. A cooling coil of the type shown in figure 4-11 is usually provided in the sampling line. If no provision is made for cooling the sample, as much as one-third of the sample might flash into steam



38.141

Figure 4-11.—Boiler water sample cooler.

and be lost. If such a sample is tested, the results will not reflect the true condition of the water in the boiler.

Boiler Water Testing Equipment

All the equipment required for making hardness, chloride, and alkalinity tests of boiler water is assembled in a standard boiler water testing cabinet (fig. 4-12). Phosphate and pH testing equipment is furnished in kit form. The Taylor comparator kit is used for making phosphate and pH tests on ships that have 1200-psi boilers. The Taylor or the LaMotte phosphate comparator is used for making phosphate tests on ships that have diatomite filter systems. An electrical conductivity meter for determining the conductivity (and hence the dissolved solids) of the boiler water is furnished to all ships.

Each chemical used in making boiler water tests must be prepared and used in strict accordance with the Naval Ship Systems Command.

Some of the chemicals are supplied in ready-to-use form. Others are supplied in solution form but must be diluted before they are used. Detailed instructions for preparing and using the chemicals needed for boiler water tests are given in chapter 9560 (56), Bureau of Ships Technical Manual.

When chemicals required for making boiler water tests are used, all appropriate safety precautions should be observed. Some of the chemicals are very dangerous if they are not handled correctly.

Before starting to use the boiler water testing equipment, it is most important to understand how to use it. Most of the bottles, burettes, cylinders, and other items are calibrated in a metric system unit called milliliters (abbreviated ml). One milliliter is 1/1000 of a liter. A liter is equal to approximately a quart in our regular system of measurement. Extreme care should be taken in making measurements and in taking readings.

The boiler water testing cabinet contains three 1-liter (or 1000-milliliter) bottles for the chemicals used in making the tests for alkalinity, hardness, and chloride. One bottle is for nitric acid, one is for mercuric nitrate, and the other is for soap solution. A 10-ml automatic-zero burette and an aspirator bulb for filling the burette are fitted into the stopper of each bottle. To fill the burette, the aspirator bulb is pressed, and then released. When properly filled, the burette will drain down to the zero mark automatically. All tests must be started with the burettes filled and drained down to the zero mark. The burette tip must always be completely filled with the chemical solution.

A liquid in a burette has a slightly curved surface. This curved surface is called a MENISCUS. When reading a burette, always take the reading from the BOTTOM of the meniscus.

All boiler water testing equipment should be handled carefully so that it will not become damaged. The equipment should be kept absolutely clean at all times. If it is not clean when used, the result of the water test cannot be accurate. The soap solution burette can be cleaned with distilled water or with alcohol. The dishes, pipettes, and graduated cylinders should be rinsed with distilled water and wiped immediately after each use. Soap may be used if necessary to wash this equipment, but the soap must be entirely removed by very thorough rinsing. Lye, scouring powder, or any strong cleanser must not be used to clean chemical

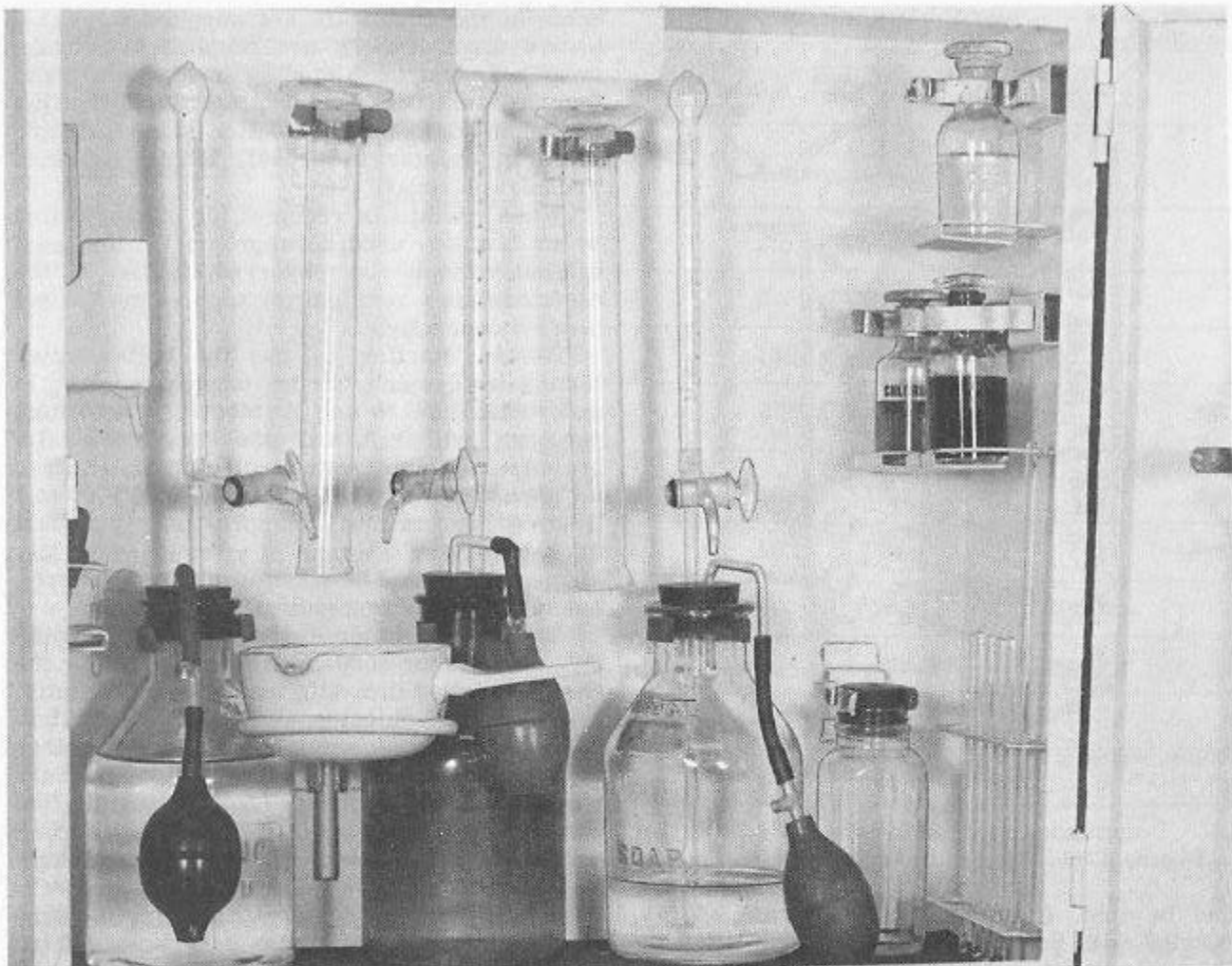


Figure 4-12.—Boiler water testing cabinet.

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glassware and porcelain. If soap and water will not clean the equipment properly, a weak acid solution should be used; all acid should be rinsed off the equipment.

The burette stopcocks must be lubricated occasionally. A special stopcock lubricant is provided in the boiler water testing cabinet.

When the water testing equipment is used, pressure should not be exerted on the burette tip. A burette or a bulb should not be removed from a stopper except when it is necessary to replace a broken burette.

Testing For Alkalinity

There are two methods of testing for alkalinity. The PHENOLPHTHALEIN test is used

for water from steaming boilers and for water from idle boilers which have been steamed. The METHYL-PURPLE test is used for water in freshly filled boilers which have not been steamed. If a boiler has been idle for a long time, it is best to use both tests.

PHENOLPHTHALEIN TEST.—Some of the steps in making the phenolphthalein test for alkalinity are illustrated in figures 4-13 through 4-18.

The phenolphthalein test for alkalinity is performed as follows:

1. Fill the nitric acid burette and allow it to drain down to zero, as shown in figure 4-13.

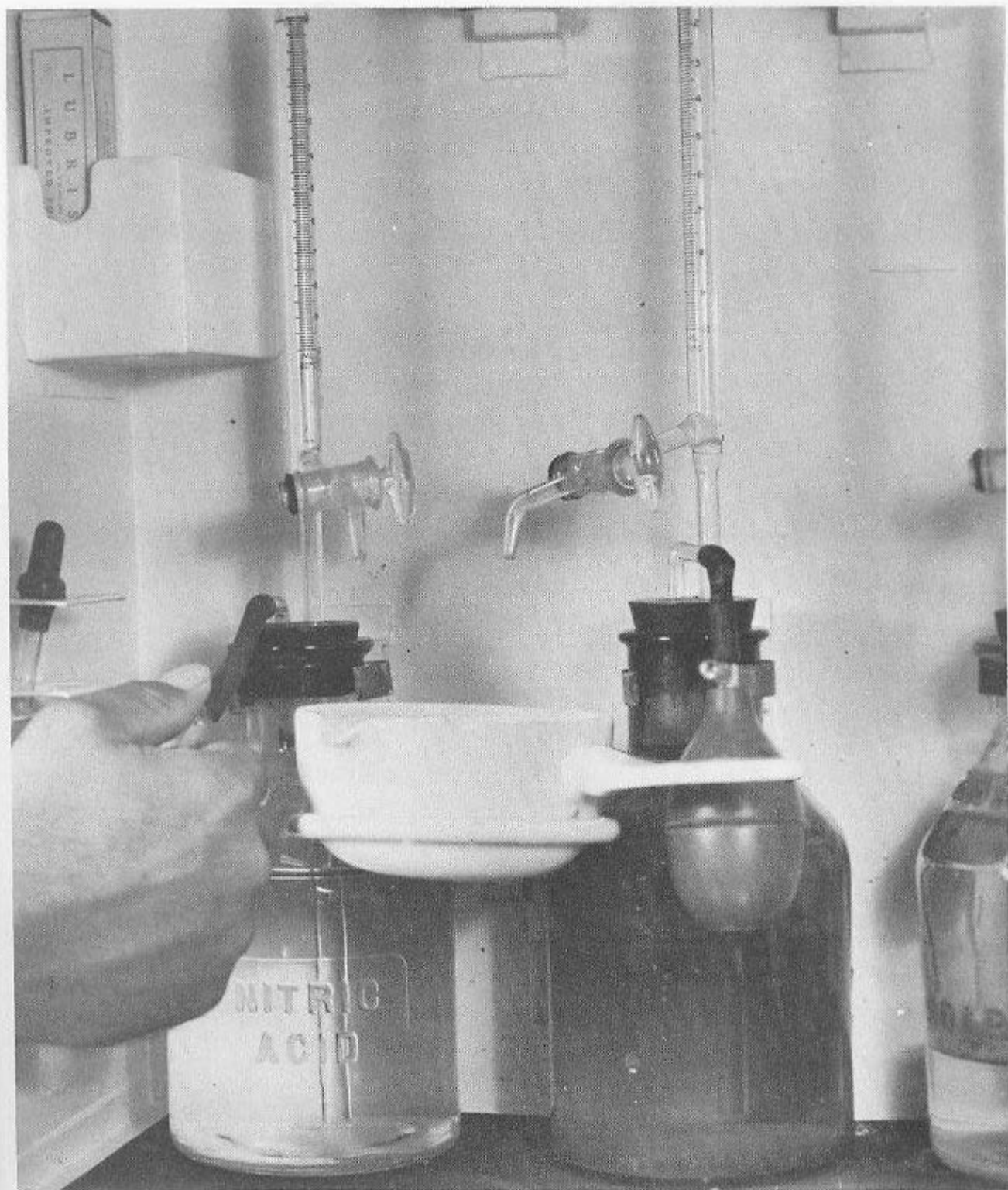


Figure 4-13.—Filling the nitric acid burette (phenolphthalein alkalinity test).

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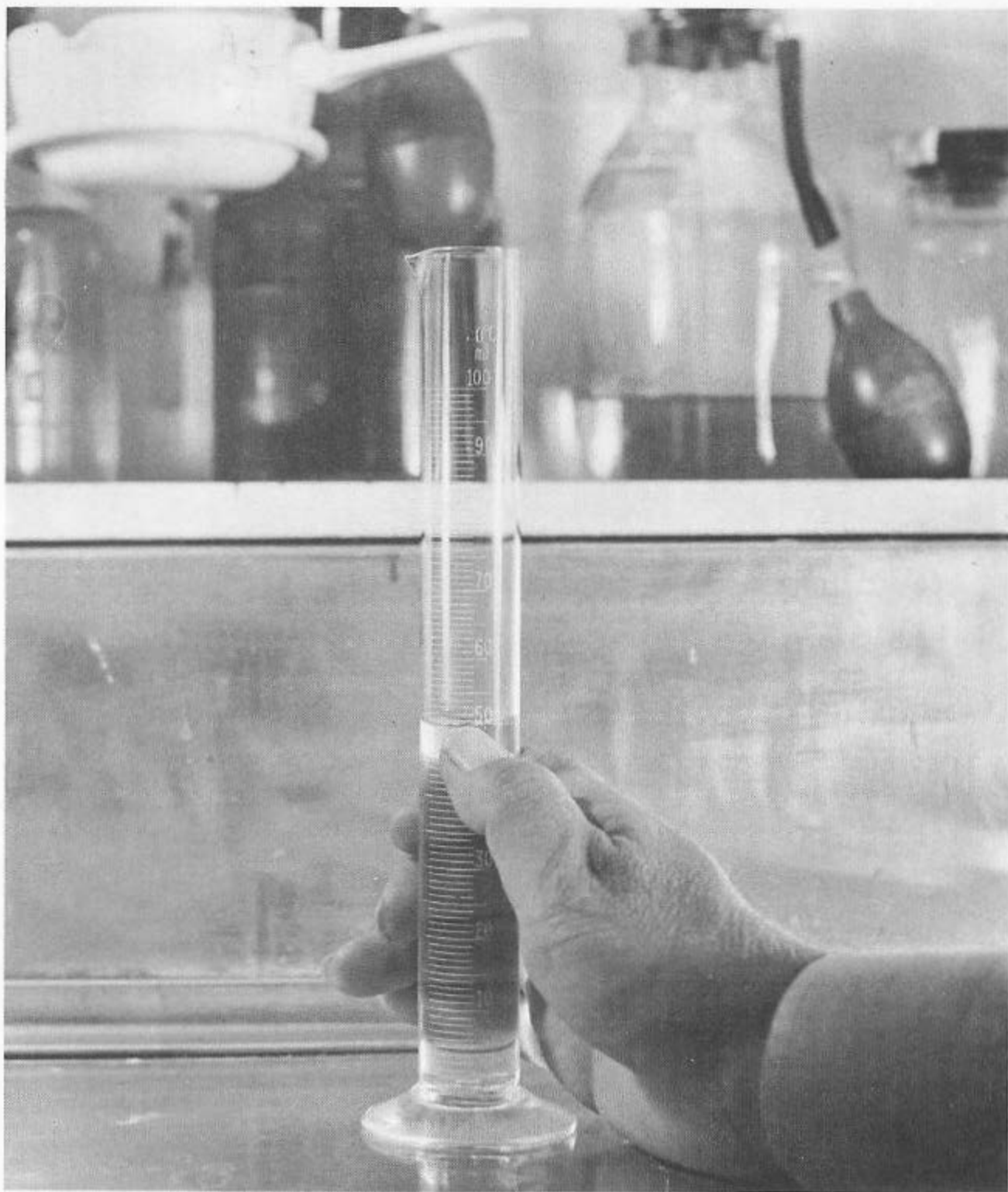


Figure 4-14.—Measuring 50 ml of sample water (phenolphthalein alkalinity test).

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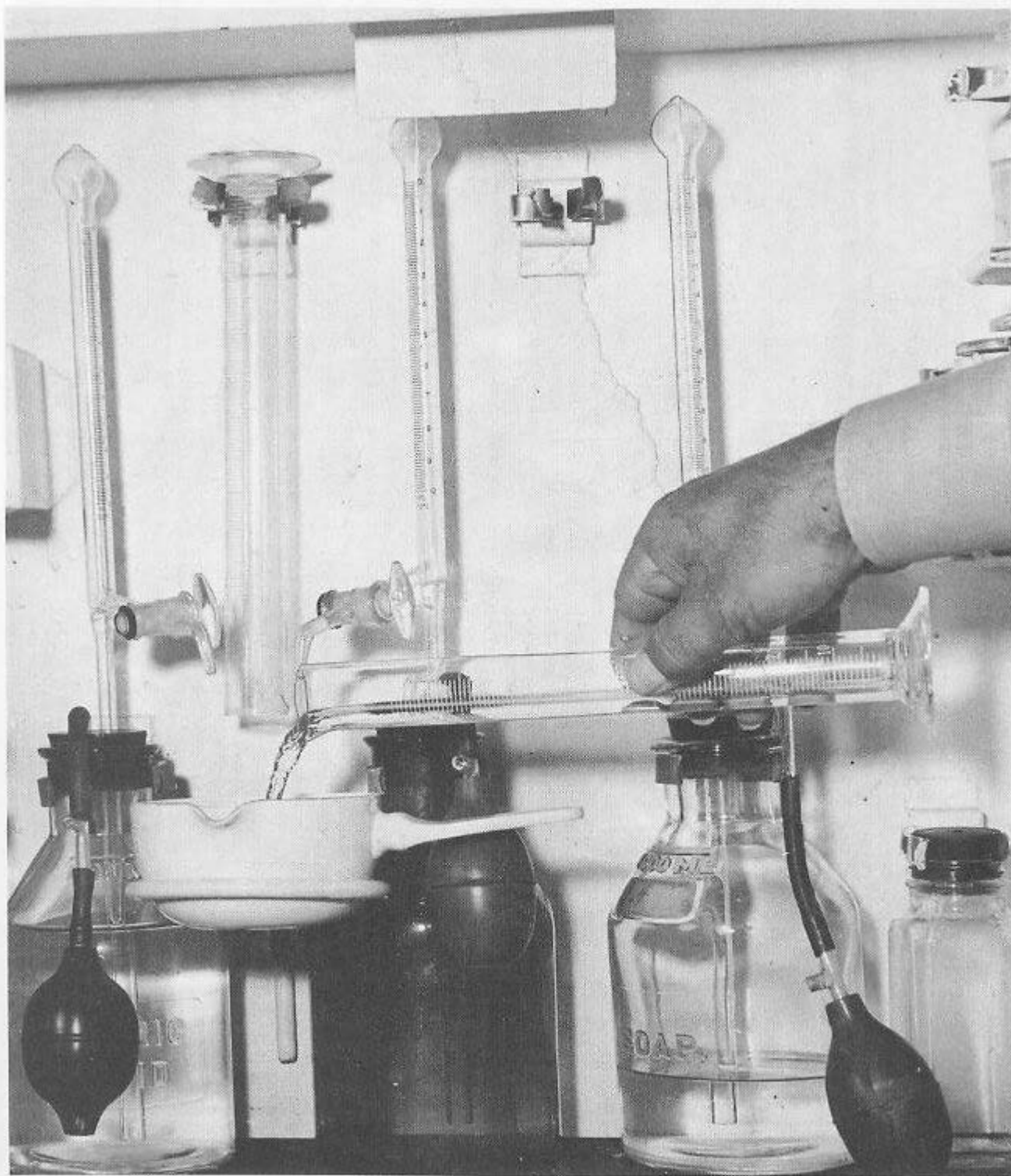


Figure 4-15.—Transferring the 50-ml sample from the graduated cylinder to the casserole (phenolphthalein alkalinity test). 38.145

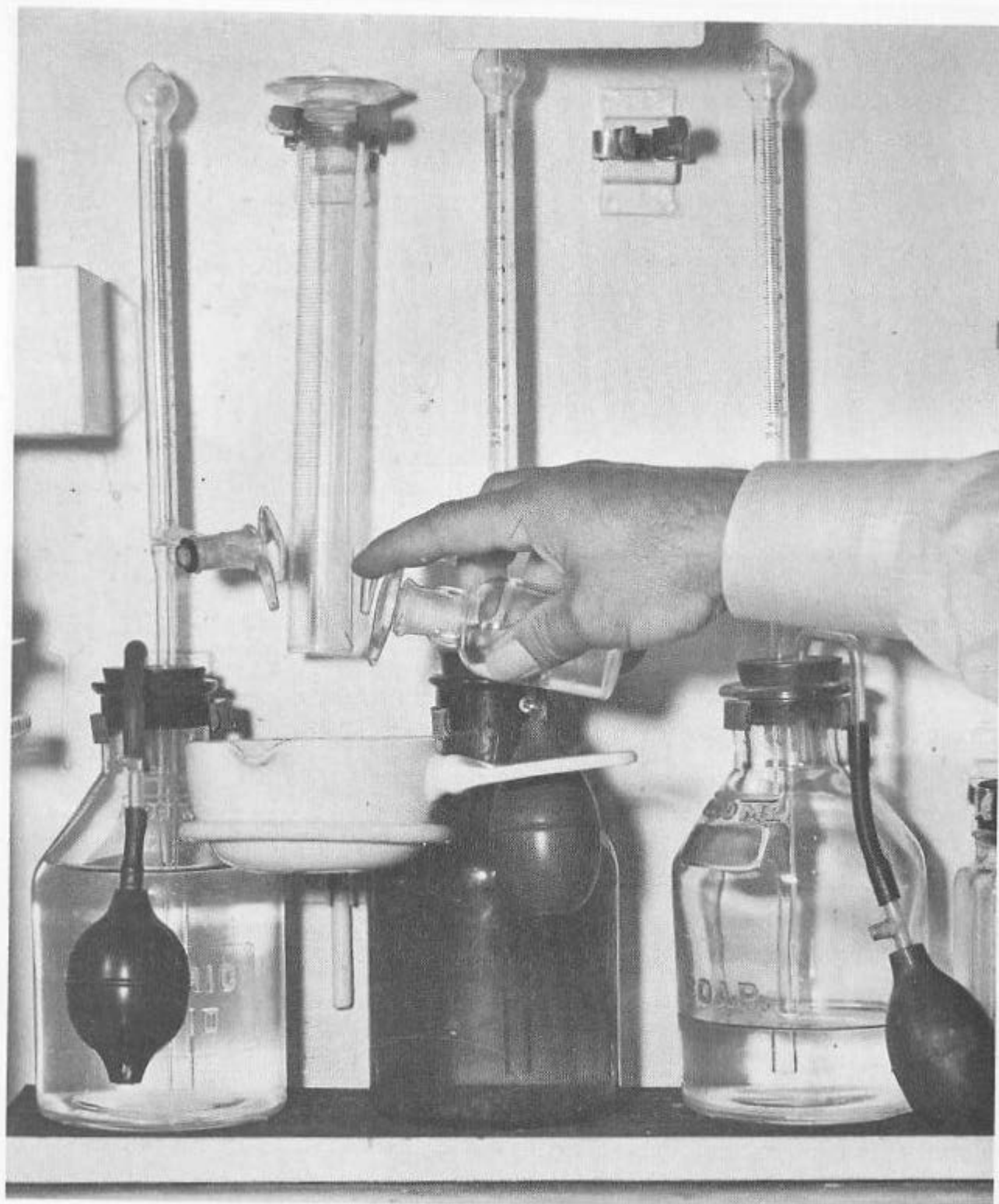


Figure 4-16.—Adding phenolphthalein (phenolphthalein alkalinity test).

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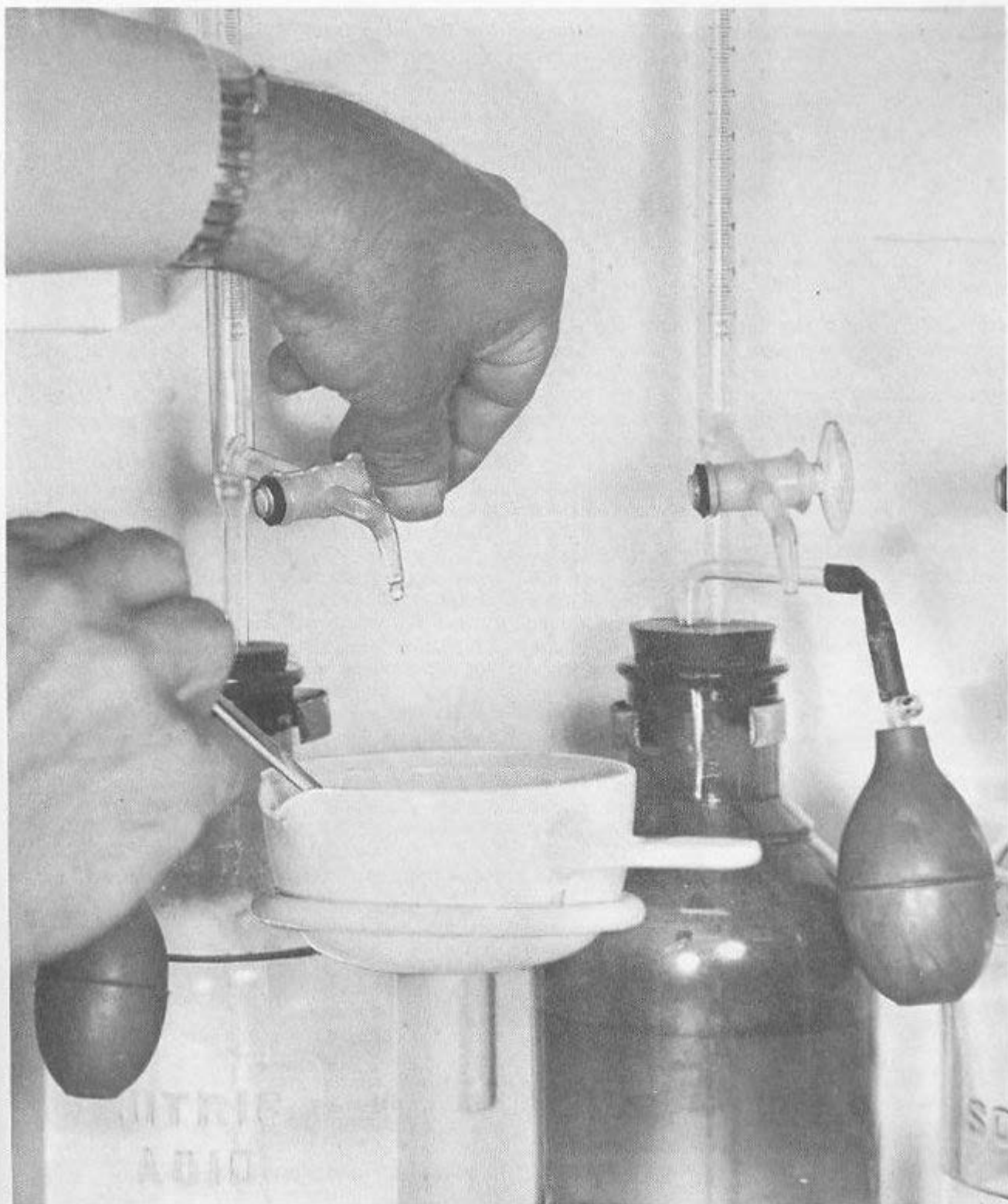


Figure 4-17.—Adding nitric acid (phenolphthalein alkalinity test).

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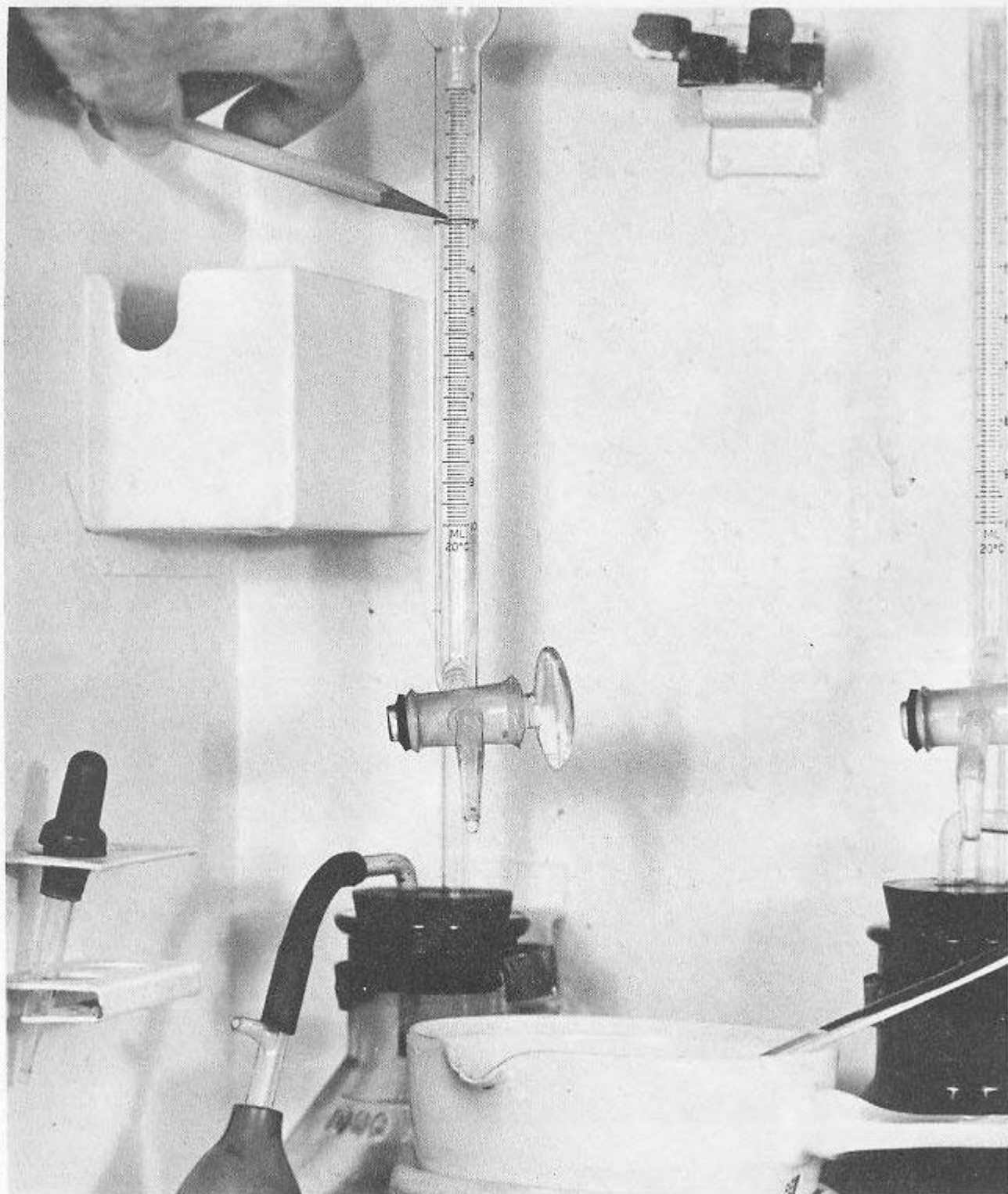


Figure 4-18.—Reading the burette (phenolphthalein alkalinity test).

38.148

Be sure the tip of the burette is full and completely free of air bubbles. A container of some sort must be placed under the burette tip to catch the drop or two of nitric acid that will drip from the tip as you are filling it. It is satisfactory to use the casserole for this purpose, but it must be cleaned thoroughly before it is used for the test.

2. Take a sample of boiler water.
3. Rinse a 100-ml graduated cylinder with some of the sample water. Then fill the cylinder to the 50-ml mark as shown in figure 4-14.
4. Pour the 50-ml sample from the graduated cylinder into a CLEAN casserole, as shown in figure 4-15.
5. Add two or three drops of phenolphthalein indicator, as shown in figure 4-16. If the sample is alkaline, the water will turn a deep pink color.
6. Add nitric acid from the burette to the sample as shown in figure 4-17, while stirring the sample continuously. Add only one drop of acid at a time. The pink color will begin to fade and will presently disappear.
7. As the pink color just disappears, read the burette, as shown in figure 4-18, taking the reading from the bottom of the meniscus. The burette reading in milliliters equals the alkalinity of the sample in equivalents per million. For example, the burette shown in figure 4-18 reads 2.9 milliliters; this means that the sample has an alkalinity of 2.9 epm.

METHYL-PURPLE TEST.—The methyl-purple test for alkalinity is performed as follows:

1. Measure 50 milliliters of sample water into a clean porcelain casserole.
2. Add two drops of methyl-purple indicator. If the sample is alkaline, the water will turn green.
3. Stirring the sample, add nitric acid solution until the color changes to purple. A gray tint precedes the purple end point color and gives warning of its approach.
4. As the color of the sample changes to purple, read the burette. The burette reading is numerically equal to the alkalinity of the sample in epm.

The color change from green to purple is quite easily seen in clear water but is not so easily seen in water that contains suspended iron compounds. The water for the test should, of course, be as free of suspended matter as

possible. If it is not possible to obtain a sample that is clear enough for the methyl-purple test, an approximate value for the alkalinity of the water in an unsteamed boiler can be obtained by making a phenolphthalein test and multiplying the results by two.

Testing for Hardness

The procedure for testing boiler water for hardness is as follows:

1. Use the 100-ml graduated cylinder to transfer 50 ml of the sample water to the square 8-ounce bottle, as shown in figure 4-19.
2. Fill the soap solution burette, as shown in figure 4-20 and allow it to drain down to zero. Be sure the burette tip is full.
3. As shown in figure 4-21, add 0.4 ml of soap solution to the sample. This amount (0.4 ml of soap solution is called the LATHER FACTOR, since it is the amount of soap solution required to produce a lather that will persist for 5 minutes over the entire surface of a 50-ml sample of pure water. Until recently, the lather factor had to be determined for each new lot of soap solution. However, the lather factor appears to be very close to 0.4 ml for all soap solutions used in the hardness tests, so the lather factor is now assumed to be 0.4 ml in all cases.
4. Stopper the bottle and shake it vigorously, as shown in figure 4-22.
5. Lay the bottle on its side, as shown in figure 4-23, and start a stopwatch. If the lather persists for 5 minutes over the entire surface of the water, as shown in figure 4-23, report ZERO HARDNESS.
6. If the lather does not persist (fig. 4-24) for 5 minutes over the entire surface of the water, some hardness is present. In this case, add more soap solution (about 0.1 to 0.2 ml), stopper the bottle, shake it, lay it on its side, and start the stopwatch. Repeat this procedure as often as necessary to obtain a lather that persists for 5 minutes and completely cover the surface of the water sample.
7. Read the burette, as shown in figure 4-25, taking the reading from the bottom of the meniscus.
8. Calculate the hardness. Subtract the lather factor (0.4 ml) from the burette reading and multiply the result by 0.2 to obtain the hardness of the sample. The reading on the burette shown in figure 4-25 is 0.7 ml; therefore

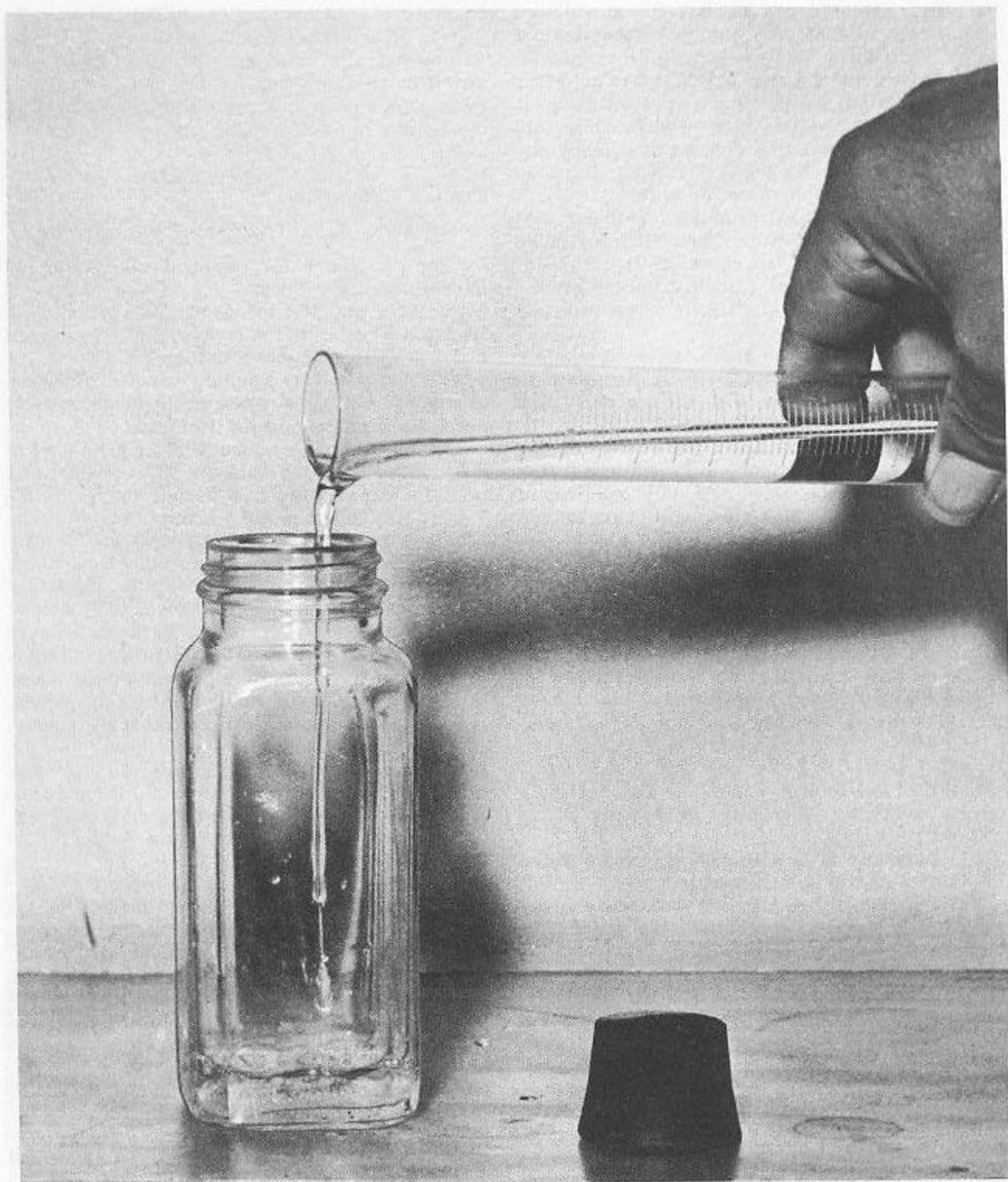


Figure 4-19.—Transferring the 50-ml sample to the square bottle (hardness test).

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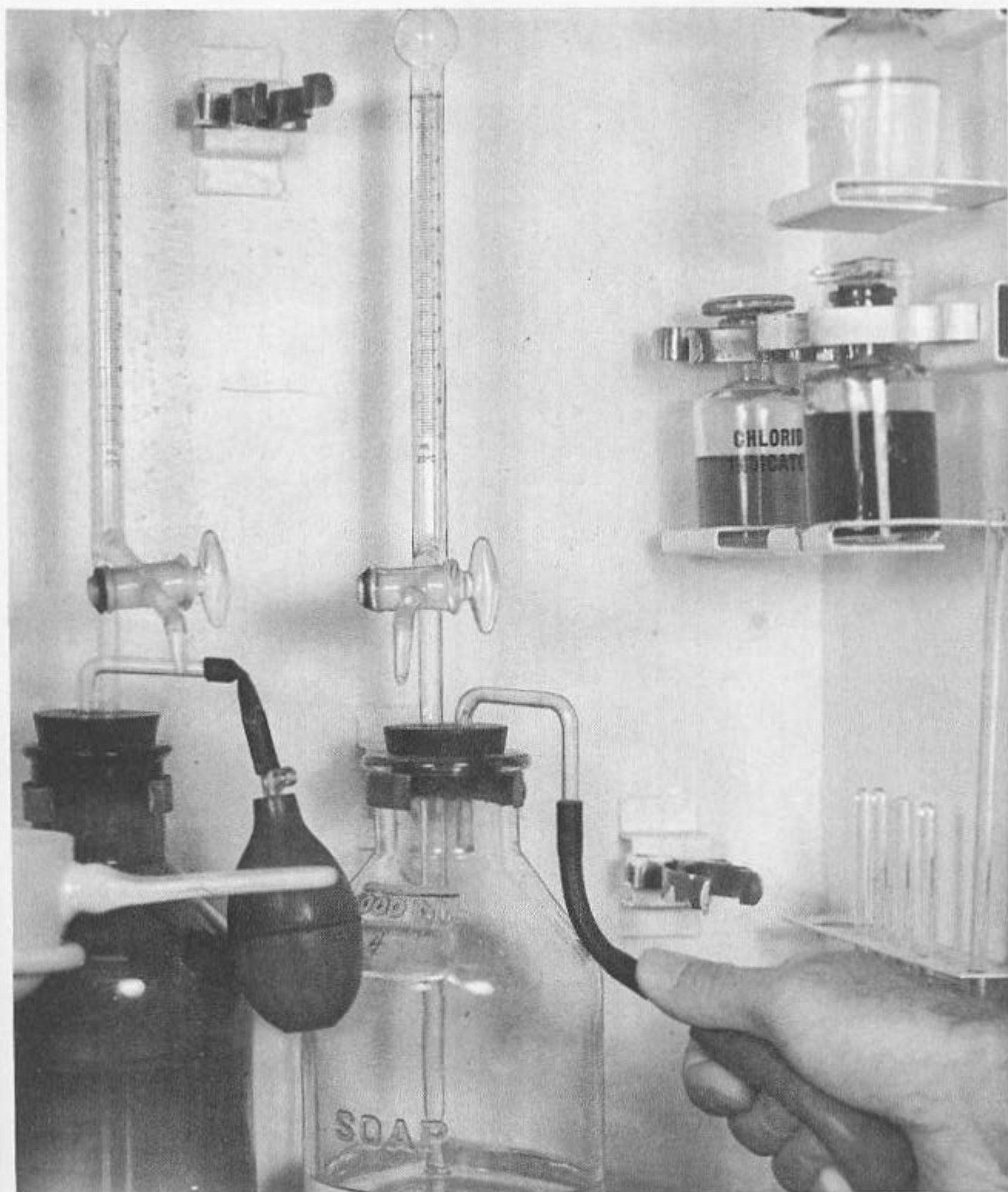


Figure 4-20.—Filling the soap solution burette (hardness test).

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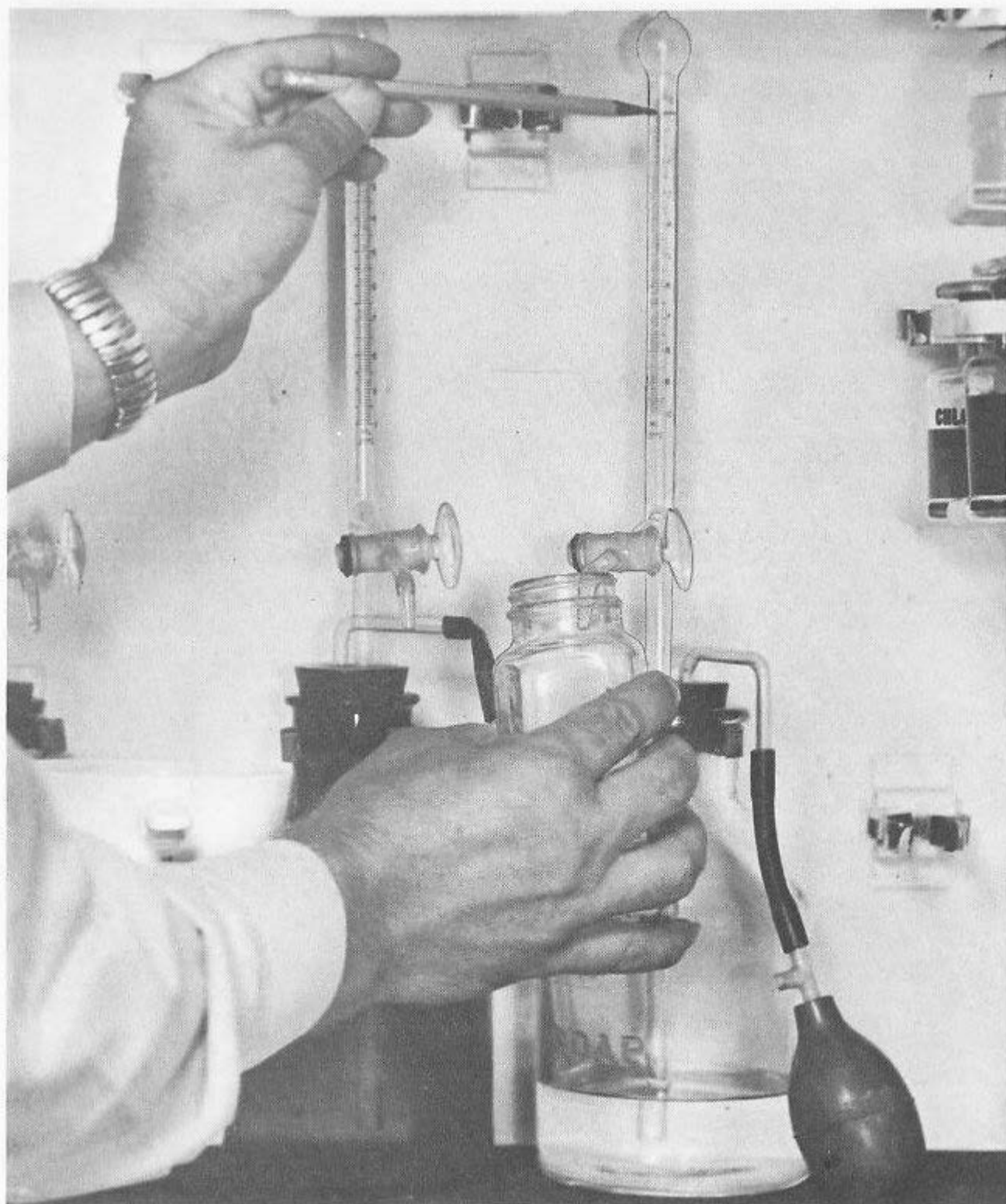


Figure 4-21.—Adding 0.4 ml of soap solution to the sample (hardness test).

38.151

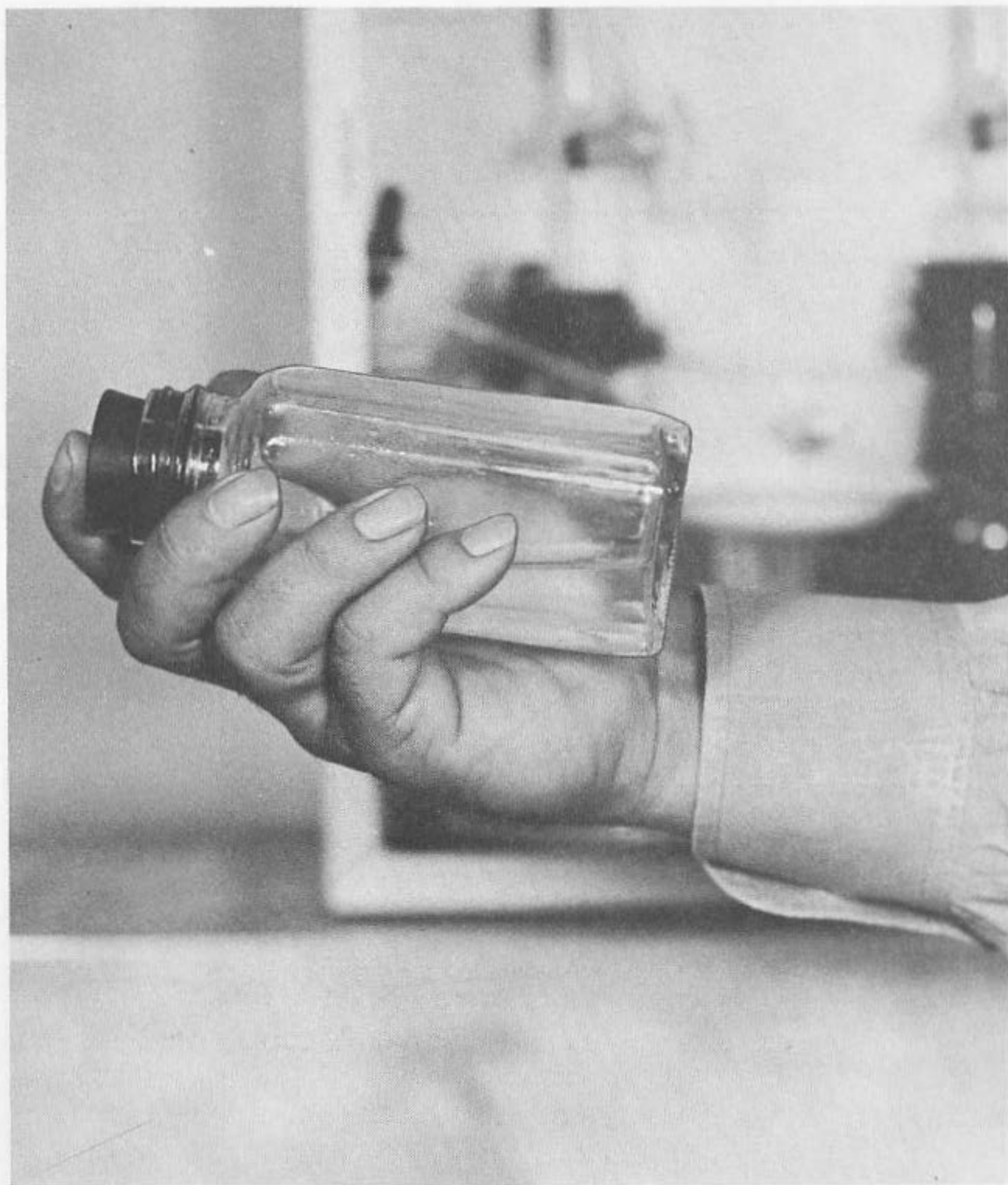
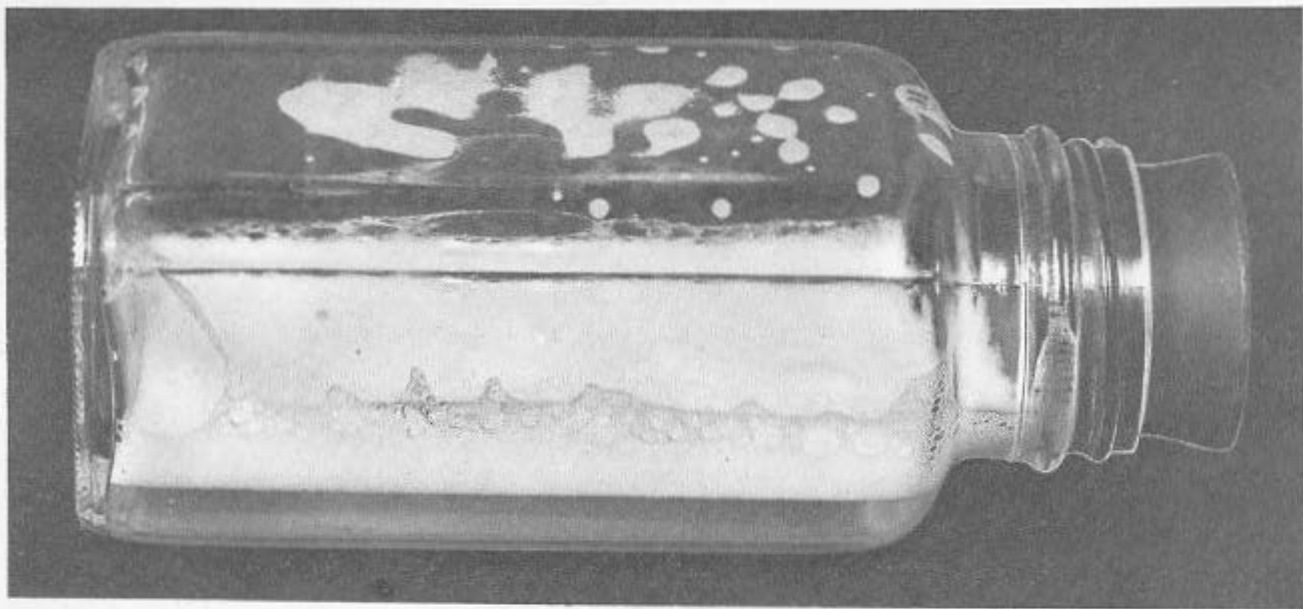


Figure 4-22.—Shaking the sample bottle (hardness test).

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Figure 4-23.—Zero hardness: Lather persists for 5 minutes over entire surface of sample.



38.154

Figure 4-24.—Water is hard: Lather does not persist for 5 minutes over entire surface of sample.

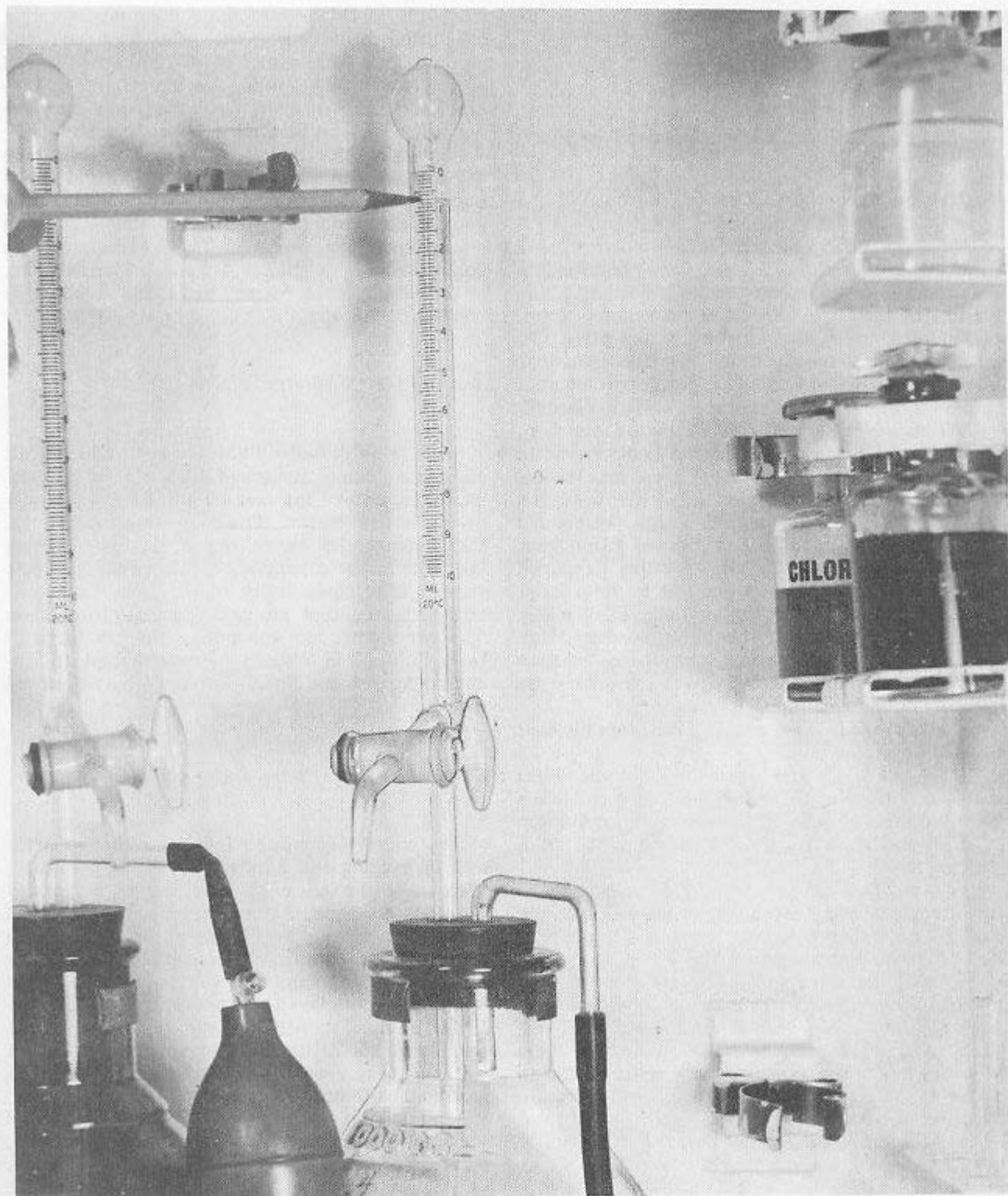


Figure 4-25.—Reading the soap solution burette (hardness test).

38.155

the hardness of this sample is calculated as follows:

$$(0.7 - 0.4) \times 0.2 = 0.06$$

In other words, the hardness of this sample is 0.06 epm.

Testing for Chloride Content

Until recently, the chloride indicator used in making the chloride test was furnished in solution form, ready to use. This solution deteriorated after being stored for some time, particularly if it was stored in a hot place. To prevent this deterioration, chloride indicator is now supplied dry, in capsule form, so that it can be made up into solutions as it is needed.

To make up a chloride indicator solution, one capsule of the dry indicator is dissolved in 50 milliliters of a specified type of alcohol. The resulting solution is identical with the solution previously furnished for shipboard use, and it is used in exactly the same way.

The chloride indicator solution prepared from the capsules is also subject to deterioration from prolonged storage and should be made up in small batches. It should not be used after it has been kept in solution form for more than 9 months. It must not be stored for prolonged periods in hot locations.

The procedure for making the chloride test is as follows:

1. Rinse a 100-ml graduated cylinder with some of the sample water, and then measure 25 ml of the sample in the graduated cylinder.
2. Pour the 25-ml sample into a clean casserole.
3. Add five drops of chloride indicator to the sample in the casserole, as shown in figure 4-26. The water will turn blue-violet or red, depending on how alkaline it is.
4. Fill the nitric acid burette and allow it to drain down to zero. Be sure the tip of the burette is full.
5. Add nitric acid to the sample, one drop at a time, stirring continuously, until the blue-violet or red color just disappears. The water will probably be pale yellow.
6. Add exactly 1.0 ml more nitric acid.
7. Fill the mercuric nitrate burette, as shown in figure 4-27, and allow it to drain down to zero. Be sure the burette tip is full.
8. As shown in figure 4-28, add mercuric nitrate from the burette, stirring continuously,

until the pale yellow color disappears and a pale blue-violet color persists throughout the sample. The blue-violet color indicates the end point of the test. Add the mercuric nitrate fairly rapidly at first, but add it very slowly—drop by drop—as the end is approached.

9. Read the burette, as shown in figure 4-29. Take the reading from the bottom of the meniscus. The burette reading in milliliters equals the chloride content of the sample in equivalents per million. The reading on the burette shown in figure 4-29 is 1.3 milliliters, so the sample of boiler water has a chloride content of 1.3 epm.

Testing for Conductivity

As far as dissolved solids are concerned, all ships are being furnished with electrical conductivity meters for measuring the conductivity of the boiler water. The purpose of measuring the conductivity is to obtain an indication of the amount of dissolved solids present in the water. The conductivity meter is a simple and rugged instrument which is very easy to operate. The procedure for conducting the conductivity test for solids should be performed in accordance with the Naval Ship Systems Command instructions.

Testing for pH and Phosphates

As noted before, special kits are provided for use in making the shipboard pH and phosphate tests of boiler water (The Taylor comparator and the LaMotte phosphate comparator). Both the pH and the phosphate tests are color comparison tests. Certain chemicals are added to the sample of boiler water, and the resulting color of the sample is compared with standard colors provided in the kit. Although the pH and phosphate tests are not difficult to make, a great deal of practice is required before colors can be matched with the required degree of accuracy.

Detailed instructions for making the pH and phosphate tests are given in chapter 9560 (56), Bureau of Ships Technical Manual. (In addition, ships having 1200-psi boilers are furnished with a special technical manual that gives detailed instructions for making the water tests required on these ships.)

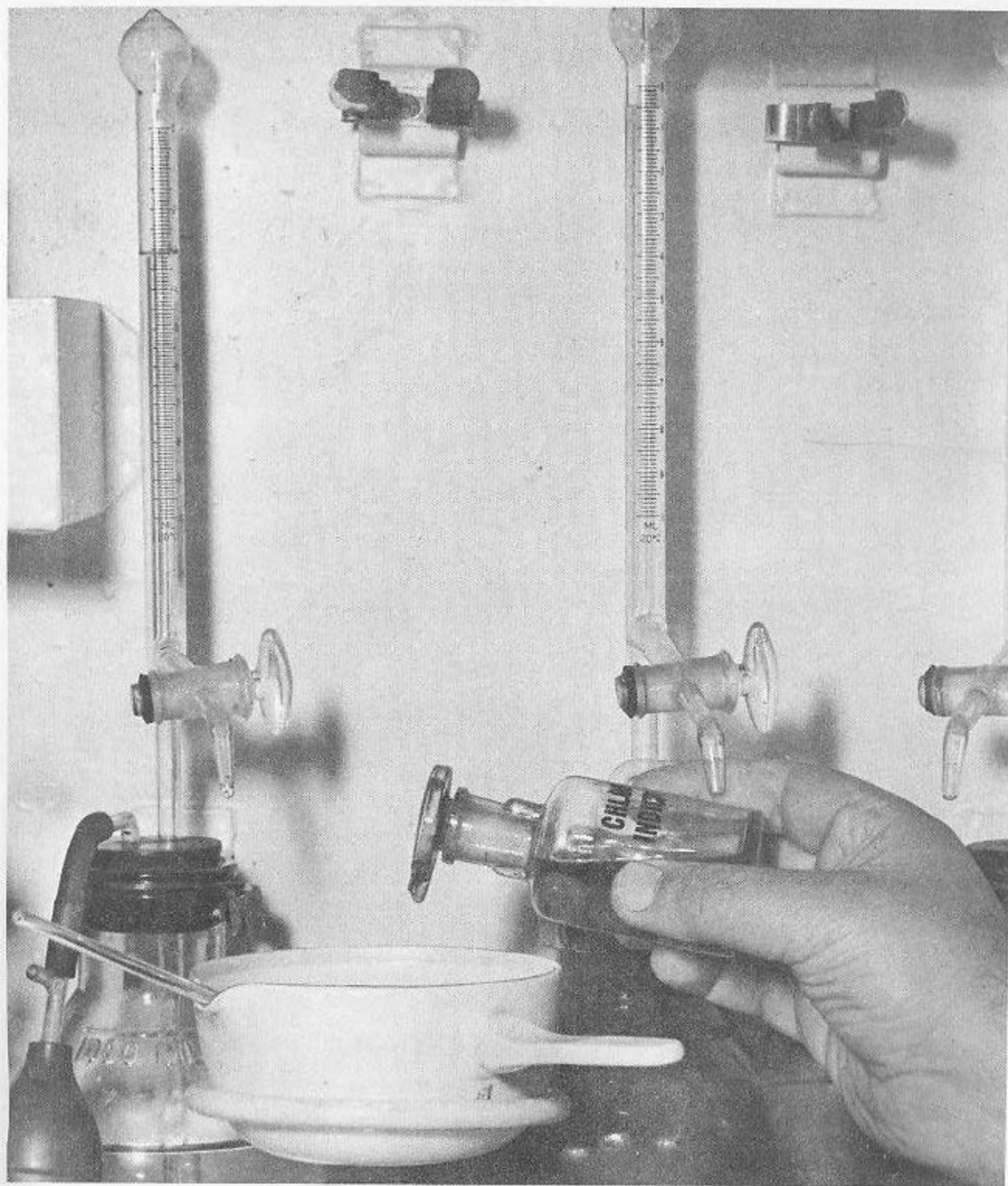


Figure 4-26.—Adding chloride indicator to sample (chloride test).

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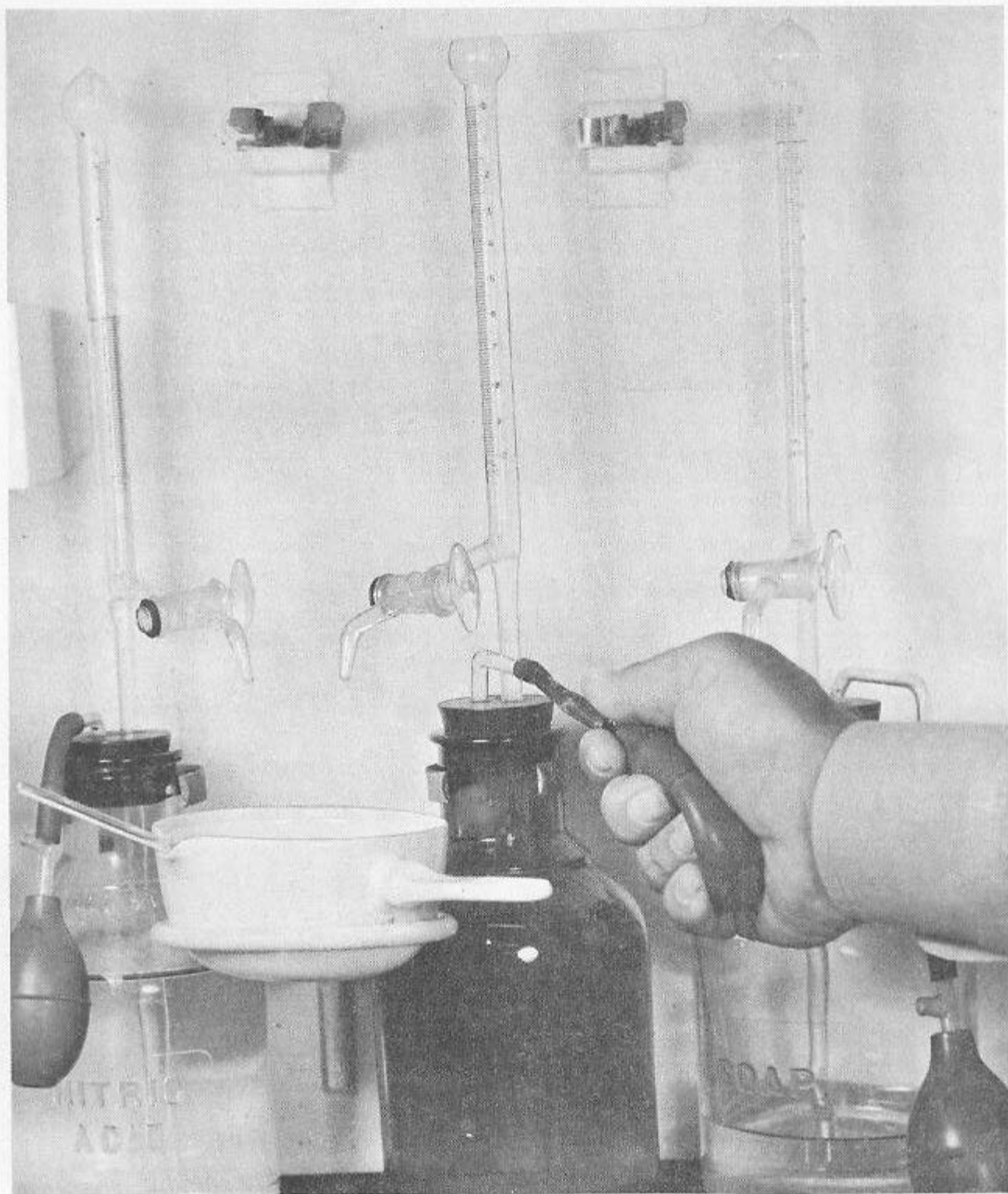


Figure 4-27.—Filling the mercuric nitrate burette (chloride test).

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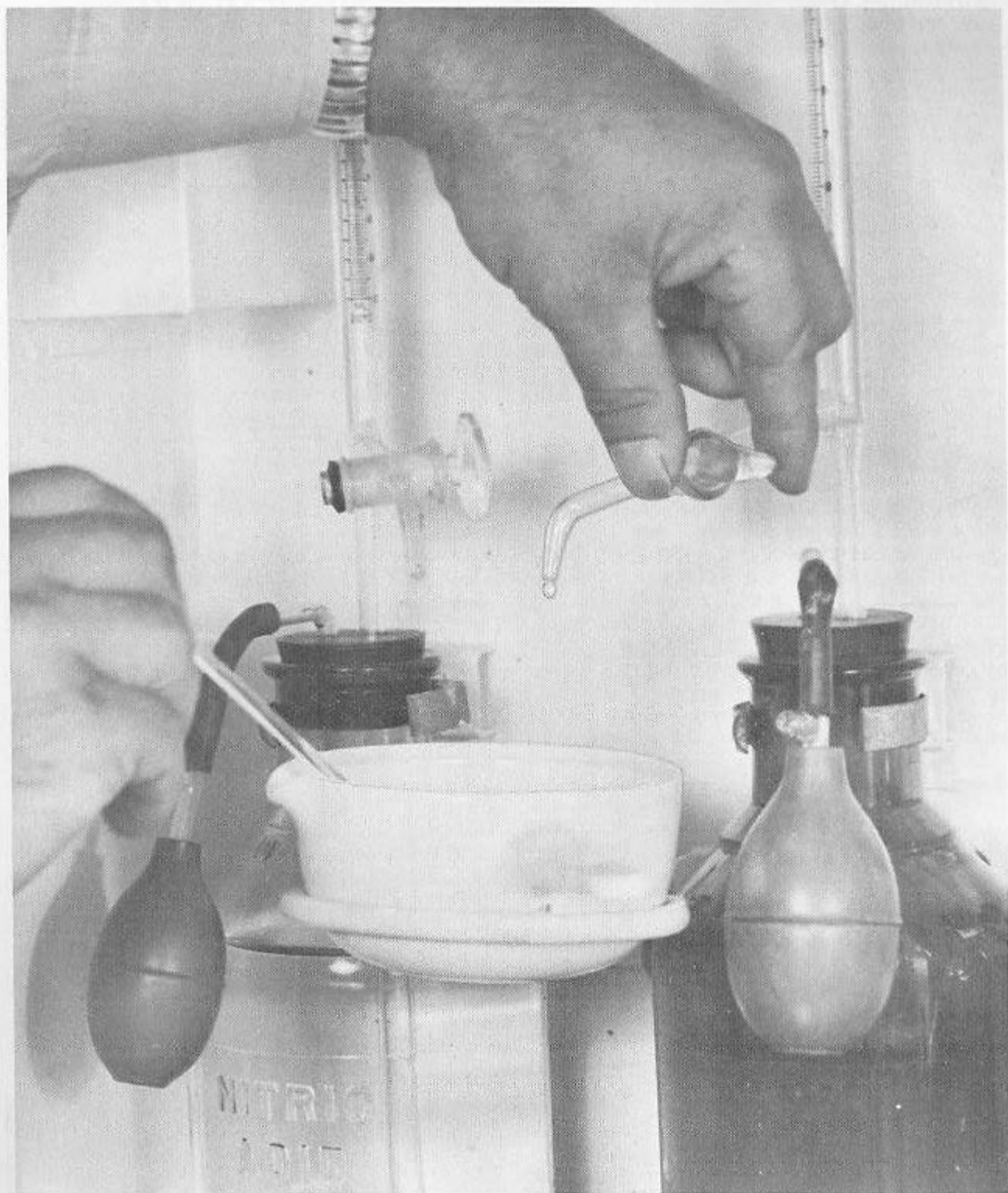


Figure 4-28.—Adding mercuric nitrate (chloride test).

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Figure 4-29.—Reading the burette (chloride test).

38,159

BOILER WATER TREATMENT

As mentioned previously, boiler water is bound to be contaminated to some extent. The contaminating substances present in boiler water cause waterside deposits, waterside corrosion, and carryover. The most direct methods of controlling these problems are (1) chemical treatment of the boiler water, and (2) use of blowdown.

CHEMICAL TREATMENT

At the present time there are three authorized methods of chemical treatment for boiler water on steam-driven surface ships. Each method is designed to completely eliminate hardness and to maintain the alkalinity (or the pH) within the prescribed limits. The method of boiler water treatment specified for each ship is the method that will best perform these two functions and, at the same time, take into account the total concentration of solids that can be tolerated in the particular type of boiler.

The three types of chemical water treatment now in use are (1) standard Navy boiler compound treatment, (2) phosphate control treatment, and (3) special treatment for systems with diatomite feed water filters.

Standard Navy Boiler Compound Treatment

Boiler water treatment with Navy boiler compound is standard for most ships that have boilers operating at about 600 psi or less. Navy boiler compound is a mixture of disodium phosphate, sodium carbonate (soda ash), and cornstarch. These chemicals work together to convert scale-forming salts into relatively harmless sludges. The sodium carbonate serves the additional vital purpose of providing the necessary control of alkalinity.

The addition of Navy boiler compound increases the alkalinity of the water and, at the same time, reduces the hardness. Navy boiler compound is a perfectly balanced combination of chemicals designed to counteract the impurities derived from sea water. The amount of compound needed to bring the water to zero hardness also puts the boiler water within the prescribed alkalinity range of 2.5 to 3.5 epm.

It is important to remember the Navy boiler compound is perfectly balanced ONLY for use in treating water that is originally derived from sea water. The compound is NOT balanced

for use in treating water that is distilled from shore water or for use with other water that contains unusual contaminating substances.

The amount of Navy boiler compound that must be added to boiler water depends upon (1) the capacity of the boiler at steaming level, and (2) the condition of the boiler water. When these two factors are known, the calculation of dosage may be made from the charts shown in figures 4-30 and 4-31.

Figure 4-30 shows the chart used for calculating boiler compound dosage for a steaming boiler, on the basis of the results of the alkalinity test. Place a straight edge across the chart from the point of alkalinity (right-hand scale) to the water capacity of the boiler at steaming level (left-hand scale). The point where the line crosses the middle scale indicates the amount of compound that must be added to bring the alkalinity up to the upper limit of 3.5 epm.

Figure 4-30 should also be used to determine the boiler compound dosage required when a boiler has been emptied and is being filled to steaming level with fresh feed water. In this case, place the straight edge across the chart from ZERO alkalinity to the water capacity of the boiler at steaming level.

When a boiler is to be laid up full of water, the amount of boiler compound that must be added to maintain proper alkalinity may be determined as follows:

1. Before filling the boiler from steaming level to the aircocks, test the boiler water for alkalinity. Calculate the dosage (if any) required to bring this water within the prescribed alkalinity limits.

2. Find out how much additional feed water will be required to raise the water from steaming level to the aircocks. To do this, the DIFFERENCE must be taken between the water capacity of the boiler when filled to the aircocks and the water capacity at steaming level.

3. Lay a straight edge across the chart, using ZERO alkalinity for the right-hand scale and the figure obtained in step 2 for the left-hand scale. This indicates the amount of ADDITIONAL boiler compound that must be added to give proper alkalinity to the fresh feed water that is to be added.

4. Add the dosage calculated in step 1 and the dosage calculated in step 3. This will give the total boiler compound dosage required to give proper alkalinity to the boiler water when the boiler is full to the aircocks.

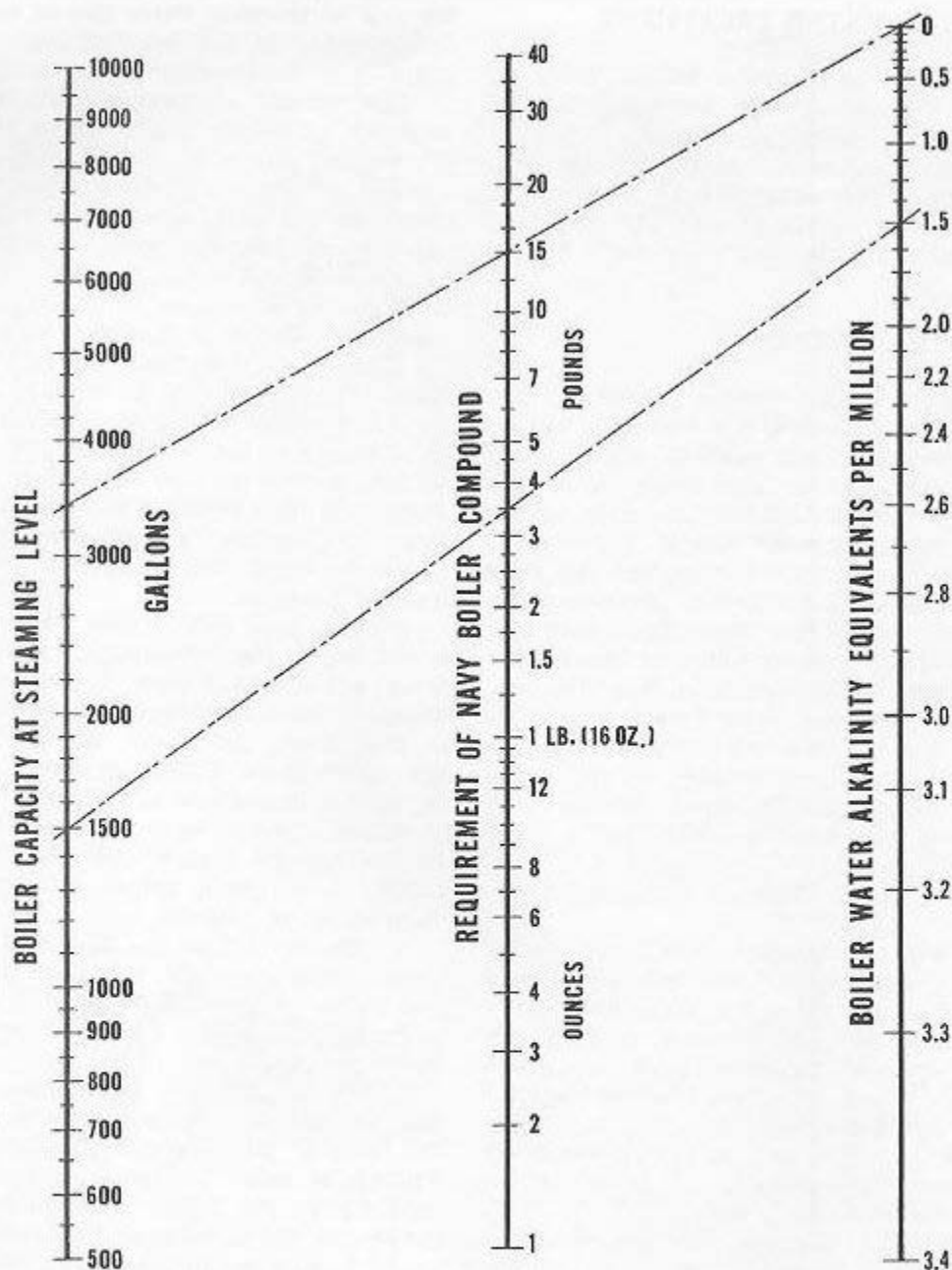


Figure 4-30.—Chart for calculating Navy boiler compound dosage from boiler water alkalinity. 38.160

The chart shown in figure 4-31 is used for calculating boiler compound dosage when the boiler water tests indicate any hardness in the same way as the alkalinity chart. The right-hand scale shows boiler water hardness, the left-hand scale shows water capacity at steaming level, and the middle scale shows the

amount of compound required to bring the water down to zero hardness.

An alkalinity test must always be made again after boiler compound has been added. If the alkalinity test shows more than 3.5 epm, the excess alkalinity must be removed by blow-down. If the boiler compound was added because

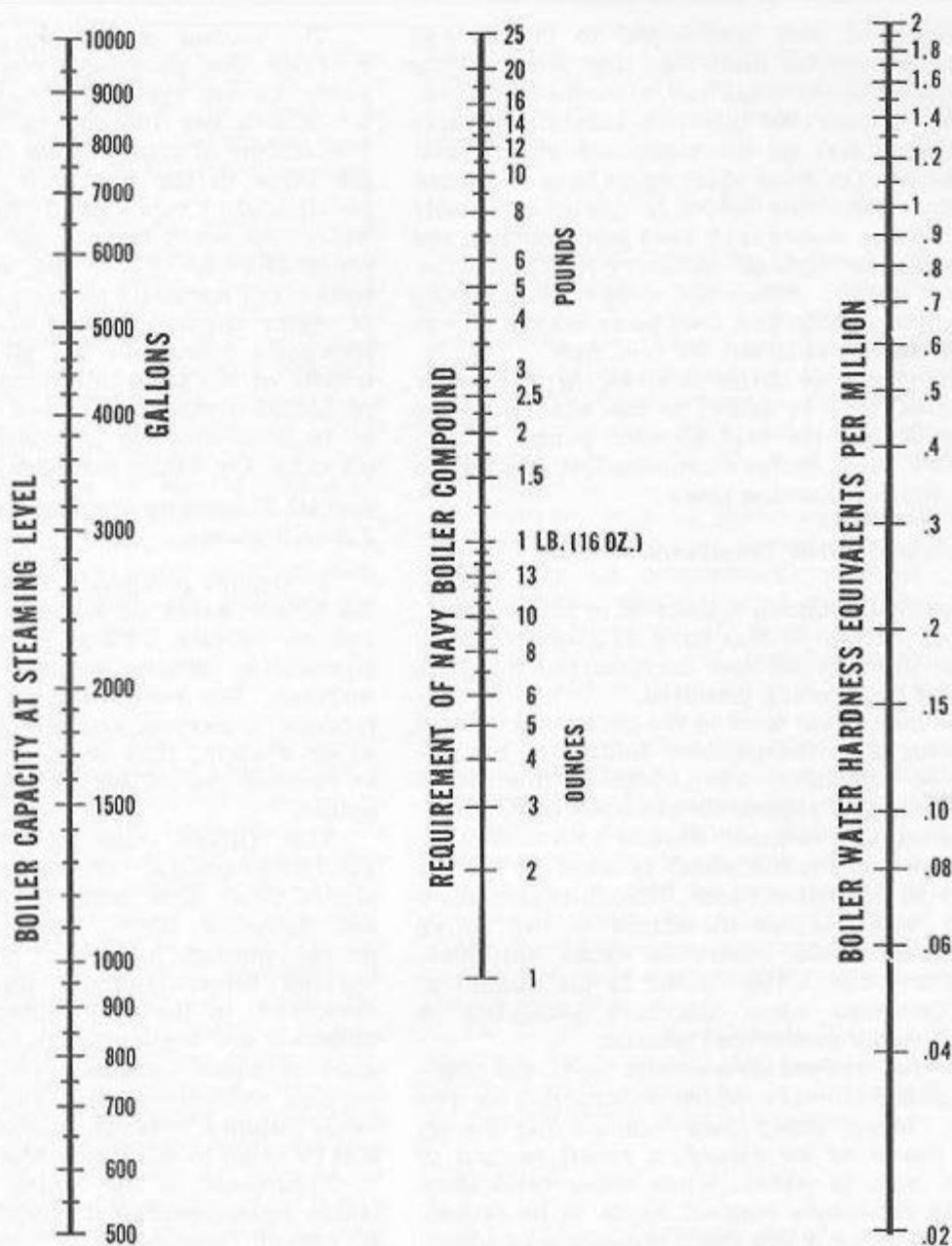


Figure 4-31.—Chart for calculating Navy boiler compound dosage from boiler water hardness. 38.161

of hardness, a new hardness test and a new alkalinity test must be made.

Boiler compound must be added to each boiler individually, in accordance with the requirements indicated by the water tests. The compound may be added in a single dose or in several doses, but it should not be added in a continuous diluted stream.

The compound must be completely dissolved in hot (preferably boiling) water before it is added. Mix about 1 pound of boiler compound in about 5 quarts of water, and stir vigorously until all the compound is dissolved.

The arrangements used for adding boiler compound vary on different types of ships. On most ships the boiler compound is added to an

injection tank and discharged to the desired boiler through the main feed line. When adding boiler compound in this way, allow the feed water to run through the injection tank for several minutes so that all the compound will be well flushed out. On ships which do not have compound injection tanks, the boiler compound is usually added to the emergency feed pump suction and discharged through the auxiliary feed line to the desired boiler. After the compound has been added, the emergency feed pump should be run long enough to wash out the feed line.

When only one boiler is steaming, the boiler compound may be added to the suction of the feed pump (or the feed booster pump) in use. Do NOT add boiler compound to the fresh water drain collecting tanks.

Phosphate Control Treatment

Phosphate control treatment of boiler water, used on all ships that have 1200-psi boilers, will be used on all new construction in which 1200-psi boilers are installed.

The chemicals used in the phosphate control treatment give independent control of pH (instead of alkalinity) and phosphate (instead of hardness). Two chemicals are used in the phosphate control treatment. Sodium hydroxide (better known as caustic soda) is used to control the pH of the boiler water. Disodium phosphate reacts with various materials in the boiler water that would otherwise cause hardness. Therefore, the boiler water is maintained at zero hardness when disodium phosphate is present in the prescribed amount.

The two chemicals—caustic soda and disodium phosphate—are added separately, as required. When water tests indicate that the pH value needs to be raised, a small amount of caustic soda is added. When water tests show that the phosphate content needs to be raised, a small amount of disodium phosphate is added.

The disodium phosphate must be completely dissolved in several gallons of HOT water before it is fed to the boiler. The caustic soda must be completely dissolved in several gallons of COLD water before it is fed to the boiler. CAUTION: The caustic soda solution is very strong. It should not come in contact with the eyes or the skin. If it does get in the eyes or on the skin, it should be rinsed immediately with plenty of cold water and the area treated with a boric acid solution. Medical attention should be obtained immediately.

The amount of disodium phosphate required to raise the phosphate content of the boiler water to the specified limit is approximately 0.5 ounces per 100 gallons of untreated water. The amount of caustic soda required to raise the pH value to the specified upper limit is approximately 1 ounce per 100 gallons of untreated water. As noted before, the two chemicals are added SEPARATELY. The water in a steaming boiler will normally require about 1 to 4 ounces of either chemical at any one time to bring the phosphate content or the pH value to about the middle of the allowable limits. The water must be tested again after either chemical is added, to be sure that the phosphate content and the pH value are within the allowable limits.

Special Treatment for Diatomite Filter Systems

A special phosphate treatment is used for the boiler water on ships of the LSD 1-8 class and on certain CVE's. These ships have reciprocating steam engines instead of steam turbines. The reciprocating steam engines introduce a certain amount of oil into the feed water system, thus requiring the use of filters to remove the oil before the water enters the boiler.

The filters, usually called DIATOMITE FILTERS, consist of screens on which are placed filter aids made of diatomaceous earth and asbestos fiber. As the hot feed water passes through the filter, oil is removed and various minerals from the filter aids are dissolved in the feed water. Some of these minerals are serious scale formers. The presence of these minerals causes the water to become extremely hard, and thus disturbs the usual balance between hardness and alkalinity that is found in sea water distillate.

Treatment of the boiler water with Navy boiler compound is not effective in these ships. If enough compound is used to completely eliminate hardness, the boiler water will have an extremely high alkalinity. If the alkalinity is maintained within proper limits, the boiler water will be hard. Therefore, hardness and alkalinity must be controlled separately in these boilers.

For these boilers, caustic soda is used to increase alkalinity; disodium phosphate is used to reduce hardness without significantly increasing alkalinity; and cornstarch is used to aid in the removal of sludges. The caustic soda and the disodium phosphate are added separately,

about 2 to 4 ounces at a time, as the water tests indicate the need. Cornstarch is added whenever disodium phosphate is added; the cornstarch should be added in an amount equal to one fourth the weight of the disodium phosphate that is added.

To prepare the disodium phosphate and starch, dissolve the disodium phosphate in several gallons of hot water. Add a small amount of cold water to the starch and stir until it forms a paste. Then stir the starch paste into the hot disodium phosphate solution.

To prepare the caustic soda, dissolve the required amount in several gallons of COLD water. The solution must not be allowed to come in contact with the eyes or skin. If it does get in the eyes or on the skin, it should be rinsed immediately with plenty of cold water and then the area treated with a boric acid solution. Medical attention should be obtained immediately.

BLOWDOWN

Chemical treatment of the boiler water increases, rather than decreases, the need for blowdown. The chemical treatment counteracts the effects of many of the impurities in the boiler water; but, at the same time, it increases the total amount of solid matter in the water and thus increases the need for blowdown.

Although the chloride test is frequently used as a way of determining when blowdown is needed, it should not be the only guide. The chloride content of the boiler water is closely related to the total solid content of the water, insofar as the solids are derived from sea water. But the chloride test gives no indication of solid matter that is derived from the use of water treatment chemicals or from other sources. The electrical conductivity of the boiler water gives a more accurate picture of the total dissolved solids content.

Each steaming boiler must be given a surface blow at least once a day, and more often if the chloride concentration is high or if the conductivity limit is exceeded. Bottom blows are more effective than surface blows in removing sludges and other heavy materials that tend to settle in the lower drums and headers. Bottom blows are most effective when they are given about 1 hour after the boiler has been secured.

CAUTION: Division wall headers, water wall headers, water screen headers, and water

drums that are connected to headers by floor tubes must NEVER be blown down while the boiler is steaming or while any burner is in operation.

FEED WATER TESTS

As mentioned earlier in the chapter, feed water and boiler water can never be totally free of contamination even when all possible precautions are taken to prevent the entrance of contaminating substances. By its very nature, sea water distillate contains some contaminants derived from sea water; and still other contaminants are bound to enter the system at various points.

However, only an extremely small amount of contamination can be tolerated in feed water. Practically all contaminants present in feed water must eventually find their way to the boilers. It is essential, therefore, to maintain the feed water at the highest possible level of purity and as free as possible of dissolved oxygen.

Feed water must be tested routinely for chloride, hardness, and dissolved oxygen. Alkalinity, pH, and phosphate tests are not normally made on feed water. However, alkalinity tests must be made on each lot of shore water that is to be used as emergency feed. To be acceptable even as emergency feed, shore water should show no color with phenolphthalein and should show a green color with the methyl-purple indicator.

On ships having diatomite filter condensate systems, tests should also be made at frequent intervals to determine the amount of emulsified oil present in the filtered condensate.

CHLORIDE TEST

The chloride content of feed water may be determined either by the chemical chloride test or by taking readings on the electrical salinity indicators. Electrical salinity indicator readings should be checked frequently by the chemical chloride test.

When making a chemical test for chloride content in feed water, the same procedure as in testing boiler water for chloride is used. However, the feed water sample must be 100 ml in size rather than 25 ml, and the burette reading must therefore be divided by 4. For example, on a boiler water test, a burette reading of 2.0 would indicate a chloride content

of 2 epm; but on a feed water test, a burette reading of 2.0 would indicate a chloride concentration of 0.5 epm—that is, 2.0 divided by 4.

Electrical salinity indicators are installed in almost all naval ships. Since the electrical resistance of a water solution varies according to the amount of ionized salts in the solution, it is possible to measure salinity by measuring the electrical resistance. Resistance varies also with the temperature of the solution, so a temperature compensator is provided. The compensator must be set at a value corresponding to the temperature of the solution in which salinity is being measured. Temperature compensation must be accomplished manually in the older types of salinity indicators; the newer types have automatic temperature compensators.

Electrical salinity indicators were formerly calibrated in a measuring unit called grains of sea salt per gallon. This unit is no longer used for reporting the results of water tests. All—or practically all—electrical salinity indicators now in naval use have been converted to give readings in equivalents per million.

HARDNESS TEST

Normal feed water that has been distilled from sea water is tested for hardness in exactly the same way that boiler water is tested for hardness. The calculation of hardness is also identical.

If shore water is to be used as emergency feed, a second hardness test must be made because shore waters sometimes show false end points on the first hardness tests. The procedure for making a second hardness test and for calculating the hardness of shore water is given in chapter 9560 (56), Bureau of Ships Technical Manual.

DISSOLVED OXYGEN TEST

Feed water used in modern naval boilers must be as completely free of dissolved oxygen as possible. Dissolved oxygen is not good for any type of boiler, but it can cause very serious trouble in boilers that operate at high pressures and high temperatures. The corrosive effects of dissolved oxygen are greatly speeded up in high pressure, high temperature boilers.

The modern pressure-closed feed system is designed to keep the condensate and feed water from being exposed to air, and the deaerating

feed tank is designed to remove a great deal of the oxygen that does become dissolved or entrained in the water. However, there are still many ways in which oxygen can get into the system and become dissolved in the water. Defects in the deaerating feed tank may result in water merely passing through the tank without being deaerated. Incorrect operation of the deaerating feed tank can have the same effect. Dissolved oxygen can also result from air leakage at various points of the condensate and feed system.

Probably the most common cause of dissolved oxygen, however, is failure to lay up idle boilers in accordance with prescribed procedures. For example, one sure way to get oxygen into the system is to secure a boiler and leave the water at steaming level. When the water is at the boiling temperature, it cannot hold any oxygen in solution. But oxygen becomes more soluble in water as the temperature goes down. As the boiler cools, therefore, a great deal of oxygen will become dissolved in the water.

On ships equipped with deaerating feed tanks, tests must be made to determine the dissolved oxygen content of the feed water on the discharge side of each operating deaerating feed tank. All ships that have deaerating feed tanks either have or will soon be furnished with the equipment for making dissolved oxygen tests.

Water from various other parts of the system should occasionally be tested for dissolved oxygen. Such testing is useful in helping to locate sources of oxygen contamination.

Some ships are equipped with instruments that automatically analyze and record the dissolved oxygen content of feed water discharged from the deaerating feed tank. These instruments operate on several different principles; consult the manufacturer's technical manual for detailed instructions. NOTE: Ships that are furnished with dissolved oxygen analyzers and recorders are still required to make the regular chemical test for dissolved oxygen in deaerated feed water.

The materials and equipment required for making the dissolved oxygen test are kept in a special cabinet of the type shown in figure 4-32. The main items in this cabinet are:

1. Three 400-ml bottles, each with a side-arm aspirator and a 2-ml automatic-zero pipette. These bottles, which are labeled OXYGEN I, OXYGEN II, and OXYGEN III, are for the three chemical solutions required to fix the sample. The bottle identified as OXYGEN I

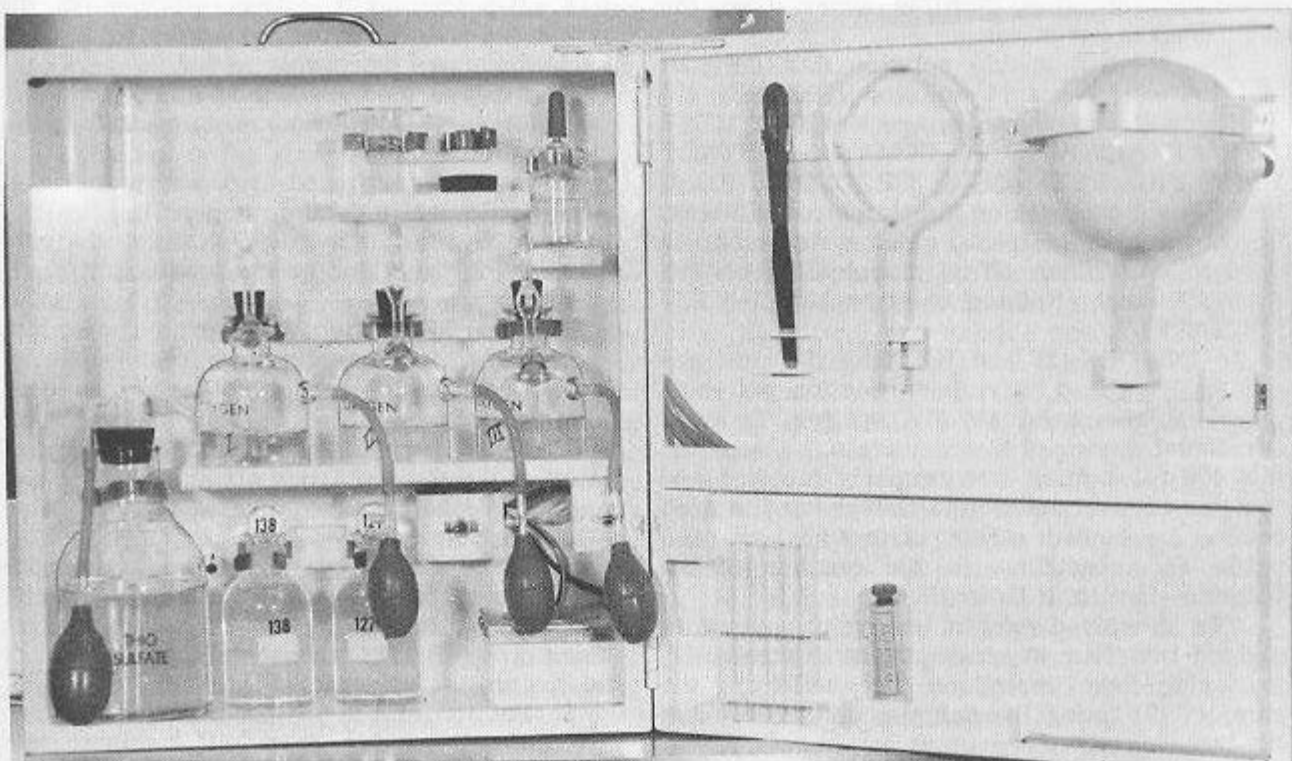


Figure 4-32.—Dissolved oxygen testing cabinet.

38.162

is for the solution of manganous sulfate. The bottle identified as OXYGEN II is for the solution of alkaline iodide. The bottle identified as OXYGEN III is for the solution of sulfuric acid.

2. A 1-liter bottle with an aspirator and a 10-ml automatic-zero burette. This is for the sodium thiosulfate solution.

3. Two 300-ml sample bottles with cone-shaped stoppers. Each glass stopper is specially made to fit snugly in one particular bottle. Do not use a stopper for one sample bottle in another sample bottle—it may or may not fit properly. As shown in figure 4-32, each sample bottle is marked with a number, and the same number appears on the stopper. Various numbers may be used; just be sure the number on the bottle matches the number on the stopper.

4. A large casserole.

5. A hot plate and a 150-ml beaker for use in preparing the starch solution.

6. A bottle of soluble starch.

7. A dropping bottle for the starch solution.

8. Glass tubing and rubber tubing, for use in obtaining the water samples.

9. A spatula.

10. A thermometer.

11. A tube of lubricant for use ONLY on the stopcocks of the OXYGEN I and OXYGEN III pipettes.

Special care must be taken to keep all the dissolved oxygen testing equipment in good condition. Some of the chemicals used in this test are very likely to clog the pipette tips. The alkaline iodide solution (OXYGEN II) will in addition corrode the glass of its pipette and cause the pipette stopcock to freeze if the solution remains in the pipette for more than 8 hours. To prevent these difficulties, the pipette must be cleaned immediately after use. A pipette is cleaned by filling the beaker with distilled water and raising it slowly onto the tip of the pipette. The stopcock on the pipette should be in the open position. Then the beaker should be lowered and the stopcock tip allowed to drain. This operation should be repeated several times, using at least two changes of water. The plug for the stopcock of the OXYGEN II pipette (alkaline iodide) must be kept in the beaker,

covered with clean distilled water, when the testing kit is not in use.

The alkaline iodide solution (OXYGEN II) and the sulfuric acid solution (OXYGEN III) are very strong corrosive agents. THEY MUST NOT BE ALLOWED TO COME IN CONTACT WITH THE EYES, SKIN, OR CLOTHING. If these chemicals get on the skin or on clothing, large amounts of fresh, clean water must be used to wash them off. If chemicals get in the eyes, medical attention must be obtained IMMEDIATELY.

If OXYGEN II and OXYGEN III are accidentally mixed, a violent reaction will take place and the chemicals will spatter. To avoid accidental mixing of the chemicals, be sure that the 400-ml bottles are properly labelled and that the correct solution is always used in each bottle. An etched circle is provided on each bottle for pencilling in the number of the solution—that is, I, II, or III.

The dissolved oxygen testing procedure is divided into four separate steps or phases: (1) preparing the solutions; (2) collecting the sample; (3) fixing the sample; and (4) making the test.

Preparing The Solutions

The fixing solutions (OXYGEN I, OXYGEN II, and OXYGEN III) are supplied in proper strength for use in the 400-ml bottles. Do NOT fill the bottles more than half full. Be SURE you put the right solution in the correct bottle.

The sodium thiosulfate solution must be made up fresh once a week. Sodium thiosulfate is supplied in stock solution which is 20 times the proper strength for use in the dissolved oxygen test. To make up a solution of the proper strength, the following procedure is used:

1. Remove the burette-and-stopper assembly from the sodium thiosulfate bottle and rinse the bottle several times with distilled water.

2. Take a 50-ml pipette or a graduate from the boiler water testing cabinet. Rinse it with distilled water and then with the stock solution of sodium thiosulfate.

3. Use the 50-ml pipette or the graduate to transfer exactly 50 ml of the stock solution into the sodium thiosulfate bottle. Fill the bottle to the 1000-ml (or 1-liter) mark with distilled water.

4. Put the solid rubber stopper in the sodium thiosulfate bottle. Shake the bottle until the contents are thoroughly mixed.

5. Replace the burette-and-stopper assembly in the neck of the sodium thiosulfate bottle and fill the burette.

6. On the roughened area above the label of the bottle, write the date in pencil.

7. At the end of 1 week, discard whatever remains of the solution and make up a fresh solution.

The starch solution used for the dissolved oxygen test must be prepared fresh each day. The procedure for making up the starch solution is as follows:

1. Rinse the 150-ml beaker with distilled water.

2. Fill the beaker three-fourths full of distilled water.

3. Place the beaker on the hot plate in the cabinet and heat the water to the boiling point.

4. Put a small amount of soluble starch (about 1/4 to 1/2 teaspoonful) on the end of the spatula.

5. Put the starch in the boiling water and stir the solution for about half a minute with the blade of the spatula.

6. Turn off the hot plate, remove the beaker, and allow the solution to cool.

7. Rinse the starch dropping bottle with distilled water and fill it with the cooled starch solution.

Collecting The Sample

All samples for dissolved oxygen determinations must be cooled to below 70° F as they are being collected. If a sample is at a higher temperature when the test is made, the test will not show dissolved oxygen even if it is present.

To collect a sample, attach the rubber tubing to the outlet nipple of the sample cooler. Insert one end of the glass tubing in the free end of the rubber tubing. Start the water flowing at a fairly rapid rate. Allow the hot sample to flow through the cooler for at least 5 minutes to flush the line and the cooler. Then start a flow of cooling water through the cooler and, at the same time, throttle back the flow of sample water to about 300 ml per minute. At first, the rate of flow will have to be estimated. After starting to collect the sample, check the flow rate by noticing how long it takes for the 300-ml sample bottle to fill up; it should take about 1 minute.

When the sample is flowing from the cooler at a temperature below 70° F, as measured with the thermometer from the testing cabinet, begin to collect the sample. Insert the glass tubing in a clean sample bottle, making sure that the end of the glass tubing is almost at the bottom of the bottle, as shown in figure 4-33. Allow the sample water to flow continuously for at least seven times the period required to fill the bottle the first time. If the sample bottle is filled at the proper rate, the sample water should be allowed to flow for 7 minutes.

Keep the glass stopper wet with the water that overflows from the bottle. Slowly, without interrupting the flow, withdraw the glass tubing from the bottle and insert the stopper in the neck of the sample bottle immediately. Give the stopper a twist to make sure it is properly fitted. Hold the stopper in place and turn the bottle upside down. If a bubble—even a very small one—appears when the bottle is turned upside down, discard the sample and collect a new one. Follow the collecting procedure just described until a sample entirely free of bubbles, is obtained.

Fixing The Sample

After a satisfactory sample has been collected, it must be fixed. In the following instructions, the pipettes are identified as OXYGEN I pipette, OXYGEN II pipette, and OXYGEN III pipette, to indicate the solution being used.

1. Put the plug in the stopcock of the OXYGEN II pipette, as shown in figure 4-34. This plug is normally stored in water in the beaker when the testing equipment is not in use. The plug must be wet when it is put into the stopcock.

2. Close the stopcocks on all three pipettes.

3. Using the aspirator bulb, fill each pipette with its proper solution (fig. 4-35). The pipettes have a very small capacity; care must be taken to avoid forcing excess solution out of the vent hole as each pipette is filled. When pressing on the aspirator bulb is stopped, excess solution will siphon back into the bottle. After filling a pipette, drain a small amount from the pipette into the 150-ml beaker; when the tip of the pipette is full of solution and free of air bubbles, refill the pipette. Discard the solution that was drained into the beaker. Rinse the beaker

thoroughly before performing the same operation on the next pipette. Small amounts of OXYGEN II solution and OXYGEN III solution must not be mixed.

4. Remove the stopper from the filled sample bottle and raise the sample bottle onto the tip of the OXYGEN I pipette until the tip is submerged in the sample water. Open the stopcock on the pipette, as shown in figure 4-36, and allow the contents to drain into the sample.

5. As the level in the pipette drops into the tip, lower the sample bottle from the tip of the OXYGEN I pipette. Close the stopcock, and immediately raise the sample bottle onto the tip of the OXYGEN II pipette until the tip is submerged in the sample water. Open the stopcock of the OXYGEN II pipette (fig. 4-37) and allow the contents to drain completely into the sample bottle. Lower the sample bottle as the liquid level drops into the tip of the pipette.

6. Replace the stopper in the sample bottle, as shown in figure 4-38, and close the stopcock of the OXYGEN II pipette.

7. Pour off the excess liquid above the stopper of the sample bottle.

8. As shown in figure 4-39, hold the neck of the sample bottle between two fingers and keep your thumb on top of the stopper. Swing the sample bottle until the contents are thoroughly mixed.

9. When the contents of the sample bottle have been thoroughly mixed, the sample will look cloudy because small particles will form as the chemicals react with each other. These small particles are called a PRECIPITATE. Allow the sample to stand until the precipitate has settled to the lower part of the bottle, leaving the sample clear in the upper part of the bottle (figure 4-40).

10. Remove the stopper and raise the sample bottle onto the tip of the OXYGEN III pipette until the tip of the pipette is submerged in the sample water. Open the stopcock of the OXYGEN III pipette and allow the contents to drain into the sample, as shown in figure 4-41.

11. Close the stopcock in the OXYGEN III pipette and replace the stopper in the sample bottle.

12. Swing the sample bottle to mix the contents thoroughly. As the OXYGEN III solution mixes with the sample, it will dissolve the precipitate that was previously formed. When all precipitate had been dissolved and the sample is clear, as shown in figure 4-42, the sample is fixed. It may now be exposed to air.

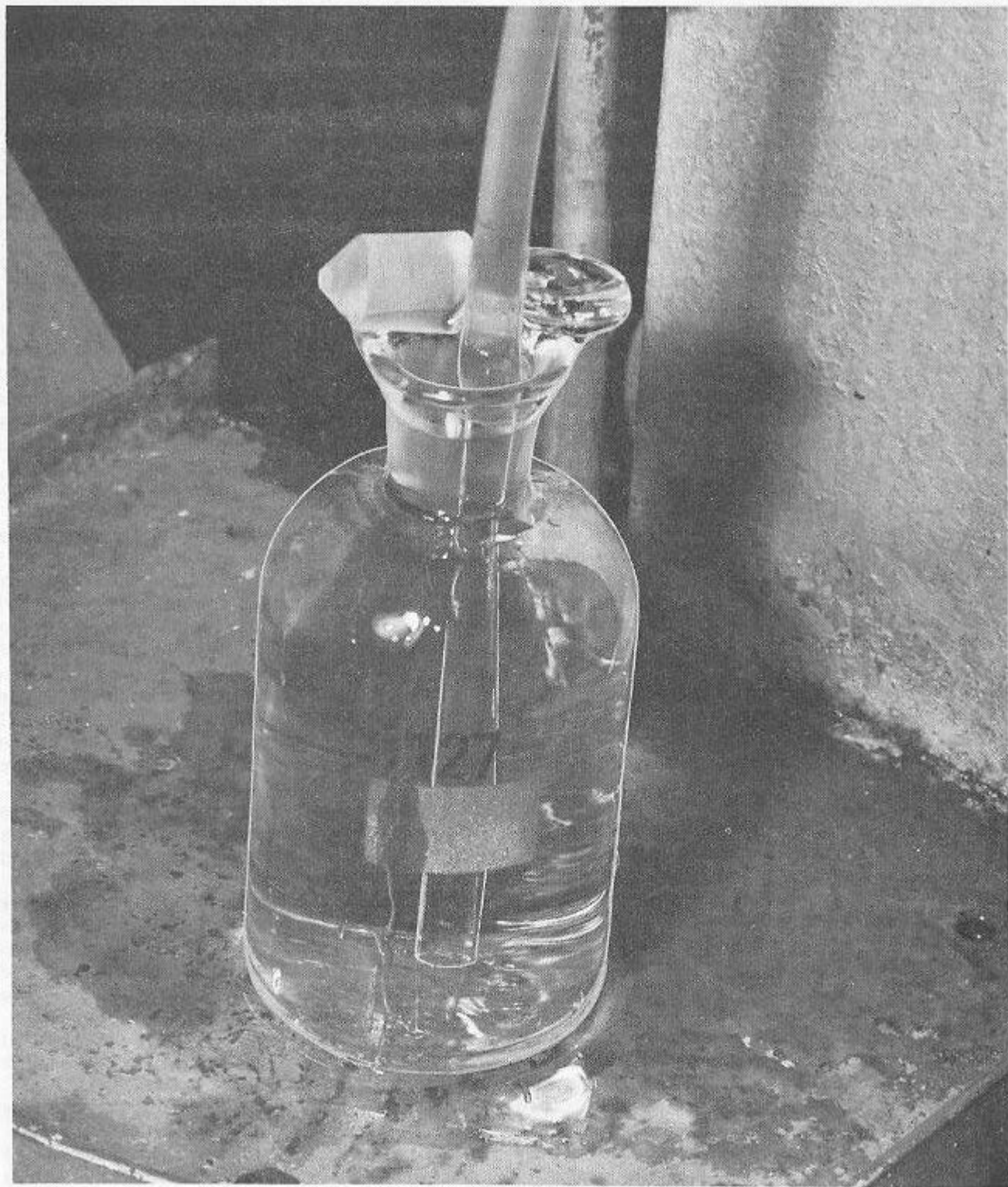


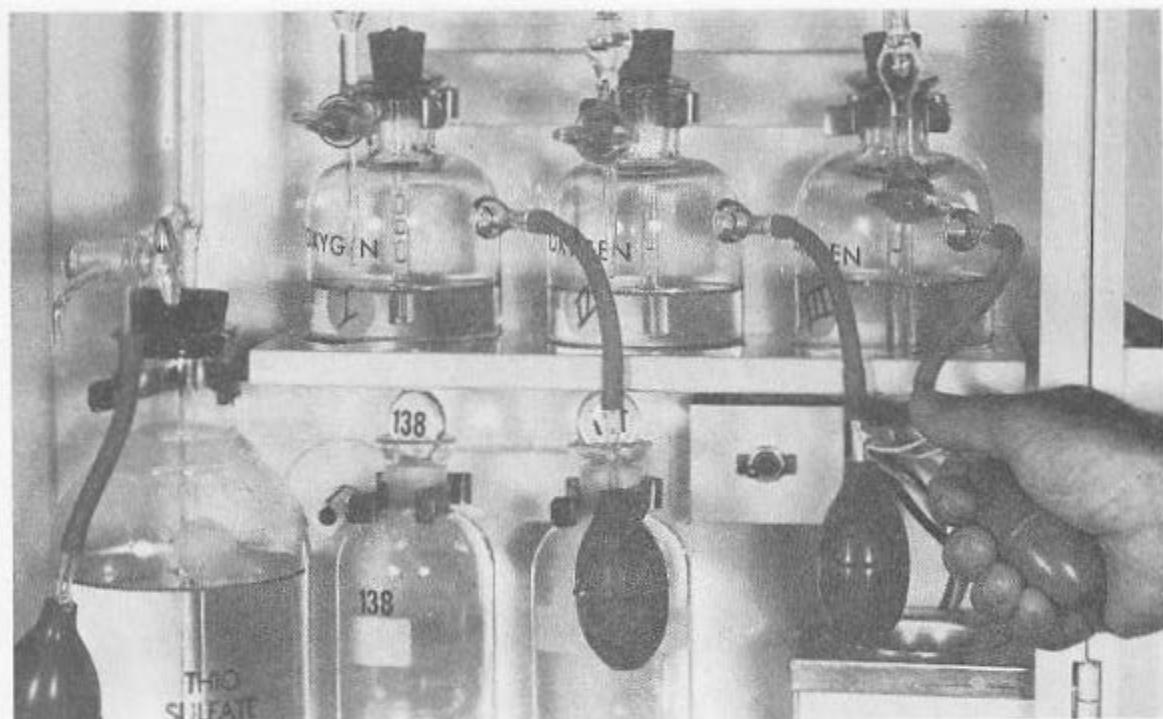
Figure 4-33.—Collecting the sample (dissolved oxygen test).

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Figure 4-34.—Replacing the plug in the stopcock of the OXYGEN II pipette (dissolved oxygen test).



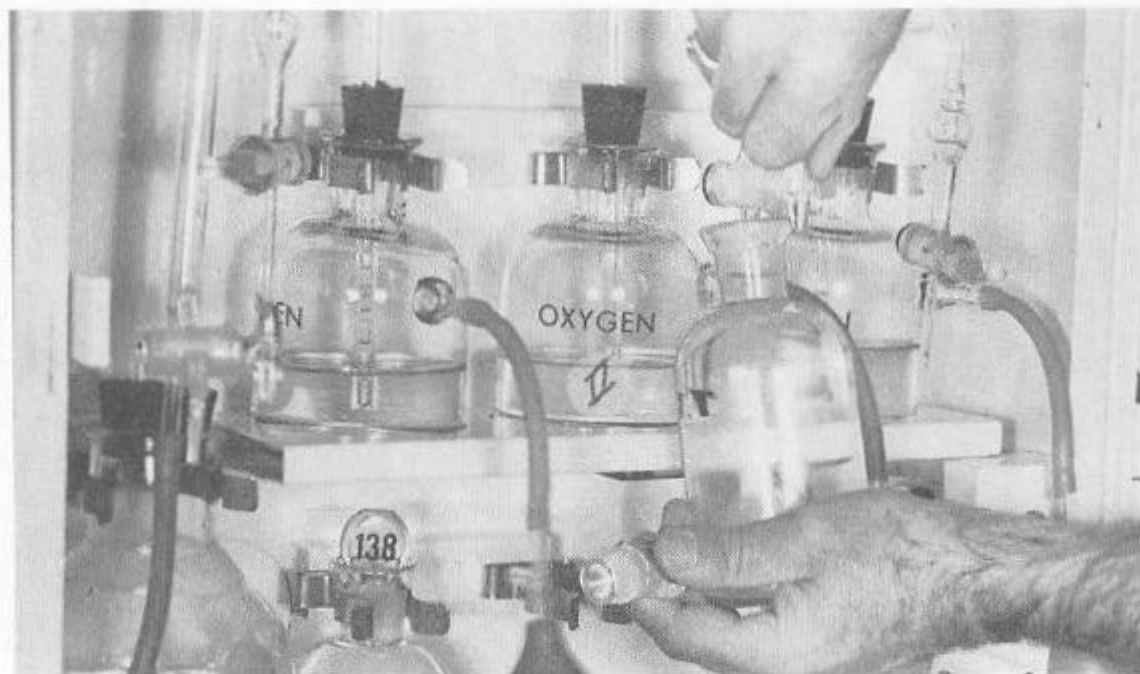
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Figure 4-35.—Filling the pipettes (dissolved oxygen test).



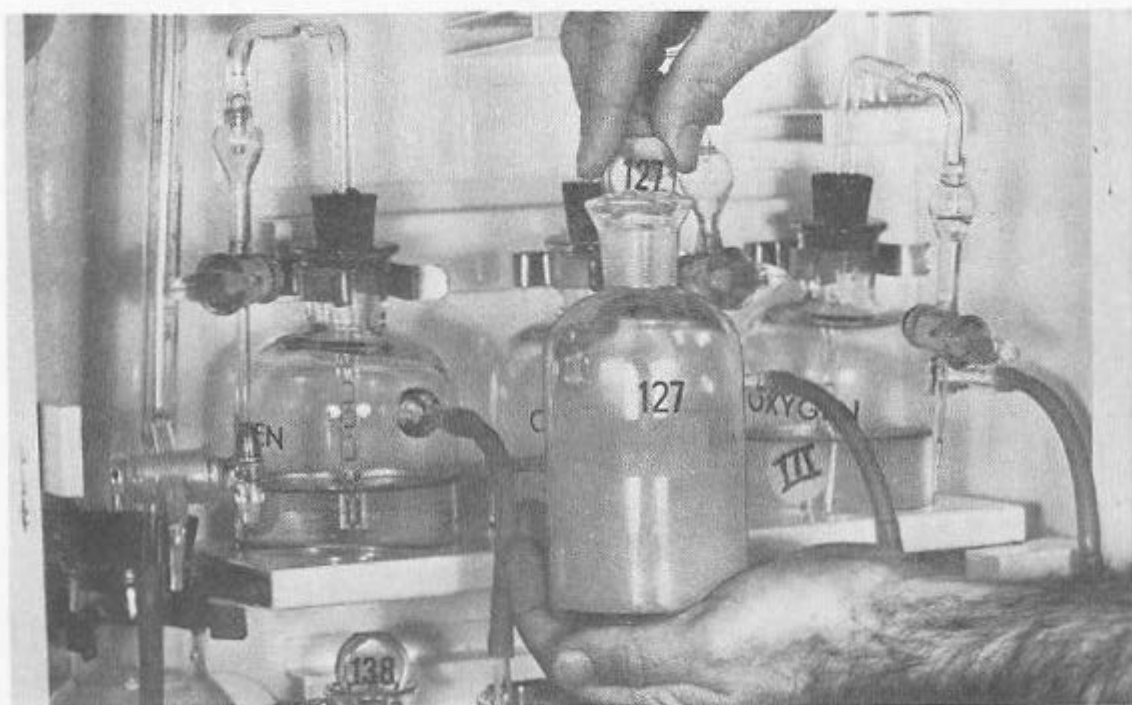
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Figure 4-36.—Adding OXYGEN I solution to the sample (dissolved oxygen test).



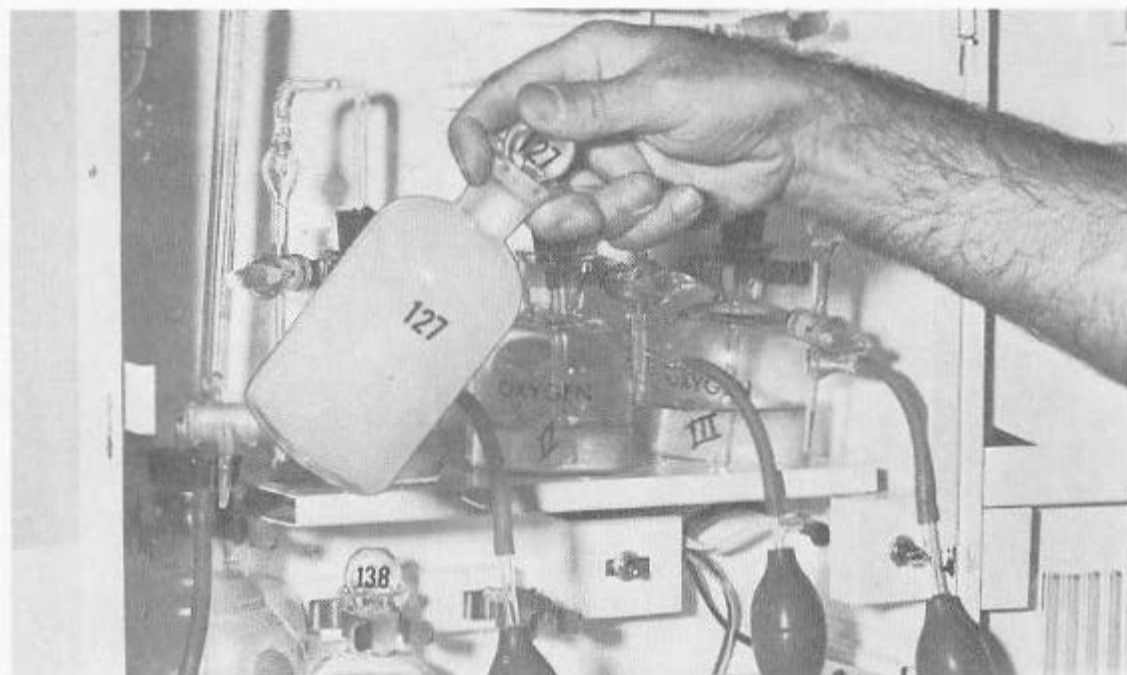
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Figure 4-37.—Adding OXYGEN II solution to the sample (dissolved oxygen test).



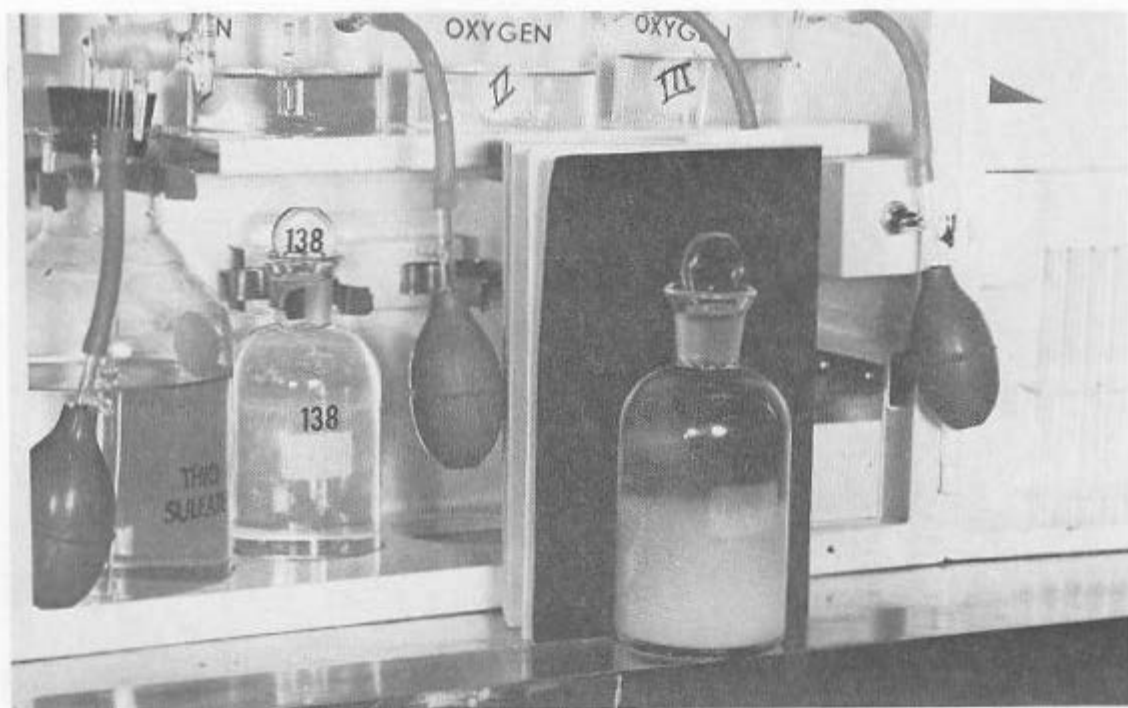
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Figure 4-38.—Replacing the stopper in the sample bottle dissolved oxygen test).



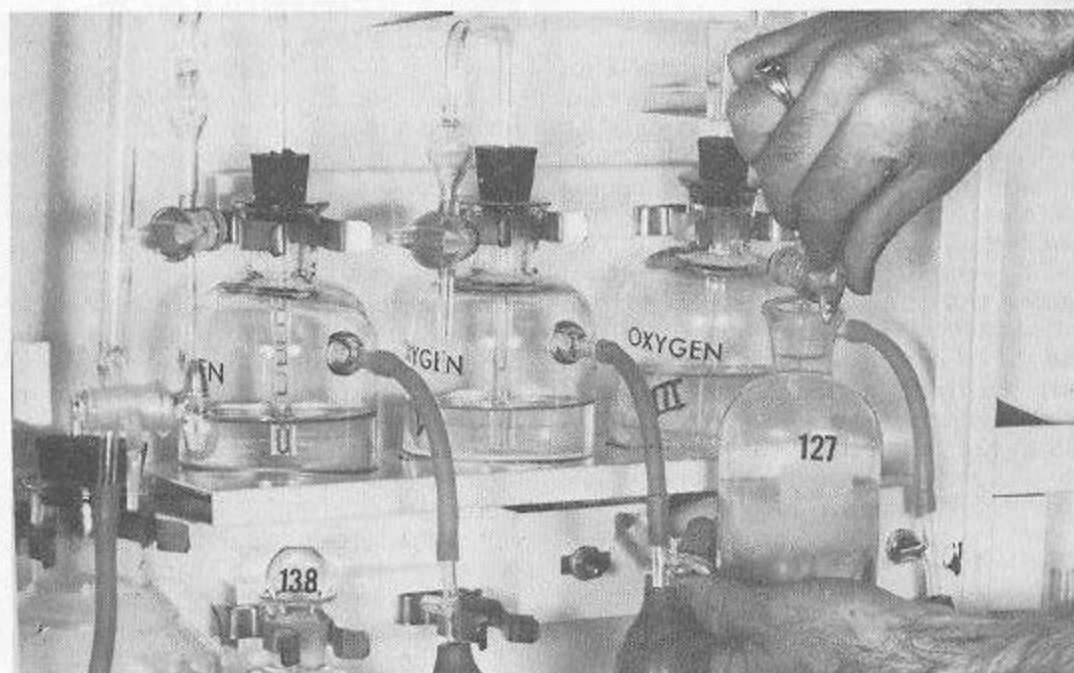
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Figure 4-39.—Mixing the contents of the sample bottle (dissolved oxygen test).



38.170

Figure 4-40.—Allowing the precipitate to settle in sample bottle (dissolved oxygen test).



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Figure 4-41.—Adding OXYGEN III solution to the sample (dissolved oxygen test).



38.172

Figure 4-42.—All precipitate has dissolved, and sample is fixed (dissolved oxygen test).

Making The Test

The sample should be tested immediately after it has been fixed. Testing should be completed within 15 minutes after the sample has been fixed, and preferably within 30 minutes after the sample was collected. The temperature of the sample MUST be below 70° F before the test is begun. If necessary, the TIGHTLY STOPPERED sample bottle should be placed in cold water until the sample is cool enough to test. CAUTION: The bottle must NOT be submerged.

To test the fixed, cooled sample, the following procedure is used:

1. Using the aspirator fill the sodium thiosulfate burette (figure. 4-43) and allow it to drain down to zero. Be sure the tip is full.

2. Place the iron ring in the holder, which is located between the sodium thiosulfate bottle and the rack for sampling bottles (fig. 4-44).

3. Place the clean casserole in the ring beneath the tip of the sodium thiosulfate burette.

4. Pour off any liquid that may remain above the stopper of the sample bottle. Remove the stopper, and pour the entire contents of the sample bottle into the casserole (fig. 4-45).

5. Add about 10 drops of starch solution from the starch dropping bottle to the sample in the casserole (fig. 4-46). Remember, the starch solution must be made up fresh each day.

6. If the solution does not turn blue, report the dissolved oxygen content of the sample as ZERO (fig. 4-47).

7. If the solution does turn blue, add sodium thiosulfate solution from the burette, drop by drop, stirring continuously with a glass rod or a piece of glass tubing (fig. 4-48). Keep adding drops of sodium thiosulfate solution and stirring until the blue color has just disappeared. Then read the burette.

8. Calculate the dissolved oxygen content of the sample. Multiply the burette reading by 0.4 and then add 0.02 to the result, to obtain the dissolved oxygen content in parts per million. For example, if the burette reading is 0.4 ml, calculate the dissolved oxygen content of the sample as follows.

$$0.4 \times 0.2 = 0.08$$

$$0.08 + 0.02 = 0.10$$

Therefore, this sample contains 0.10 parts per million of dissolved oxygen.

TEST FOR EMULSIFIED OIL IN FILTERED CONDENSATE

The Tyndall light-cone test is used to determine the amount of emulsified oil present in filtered condensate, on ships that have diatomite filter condensate systems.

The Tyndall light-cone test is based on the principle that small particles suspended in water will reflect light in a certain way. The test is simple to make. A narrow beam of strong light is passed through the water sample. If the sample contains emulsified oil—that is, oil which is so finely divided that it mixes with the water—the light is reflected from the small oil particles in such a way that a glowing cone-shaped area of light can be seen in the sample. (Incidentally, a similar effect in air may be observed; when a very small opening admits a beam of sunlight into a darkened room, a cone-shaped area of light can be seen as the sunlight is reflected from small dust particles in the air.)

In the Tyndall light-cone test, the narrow beam of light is passed upward through the water sample. If the water is free of emulsified oil and other suspended particles, the sample will not show a cone-shaped area of light (fig. 4-49). If the water contains emulsified oil a Tyndall cone similar to the one shown in figure 4-50 will be visible.

The Tyndall light-cone test can be used to determine the amount of emulsified oil present in a sample of water, as well as the mere fact that oil is present. Standard water samples containing known parts per million of soluble oil are prepared aboard ships that make the Tyndall light-cone test. By comparing the Tyndall cone seen in a sample with the Tyndall cones visible in the standard samples, the amount of emulsified oil present in the sample can be determined. Amounts of emulsified oil as small as 0.1 ppm can be detected in this way.

The apparatus required for making this test is very simple, consisting basically of a container to hold the sample and a Tyndall light. The container must be clear; a glass bottle is usually used. In order to obtain accurate comparisons, the sample container must be identical with the containers in which the standard samples are stored. The Tyndall lamp (figs. 4-51 and 4-52) can be made from a regular 60-watt light bulb covered with a tin can. The tin can has a small hole (drill size no. 50) in the top. The can-and-lamp assembly is mounted on a wooden base, as shown in figure 4-52.

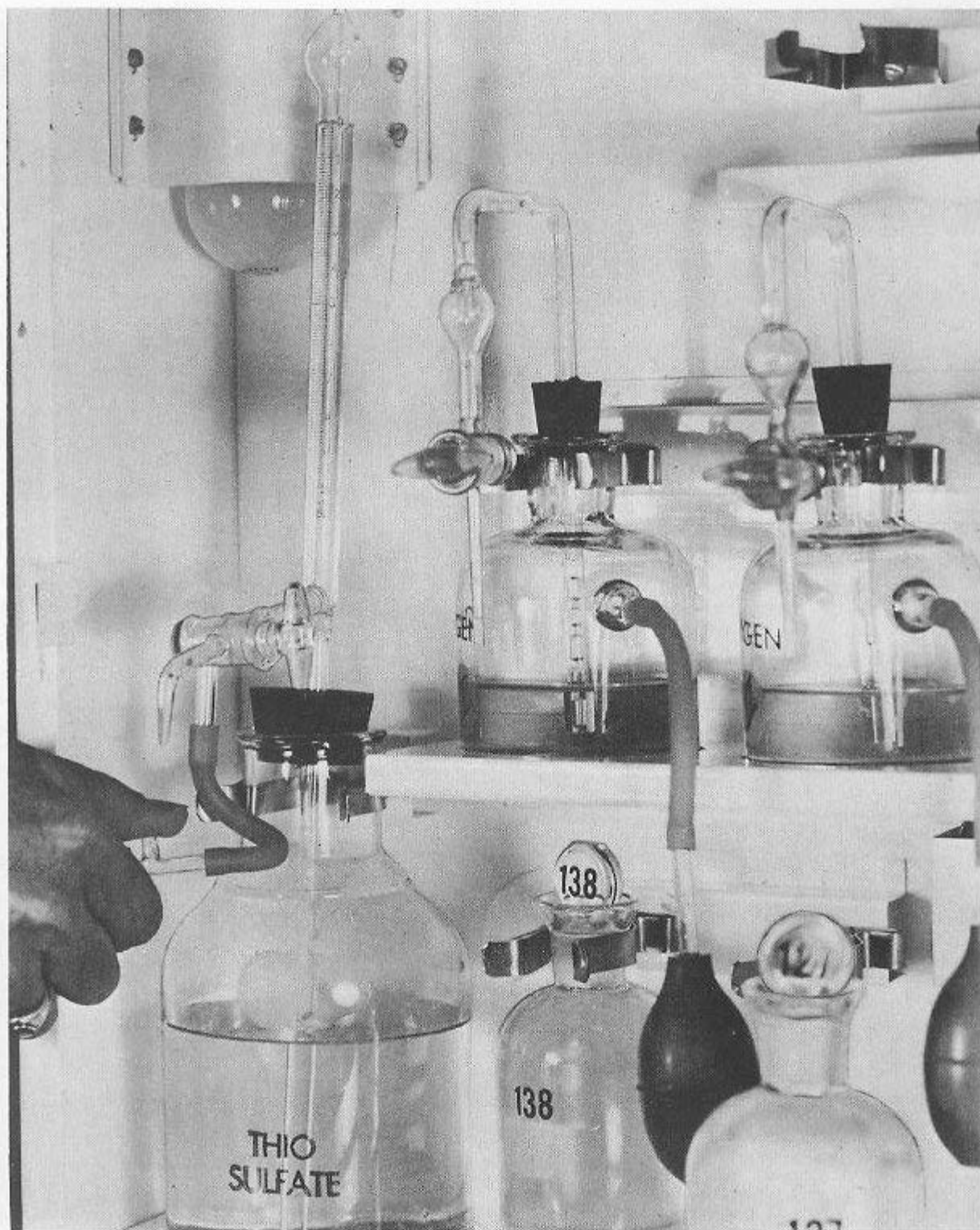


Figure 4-43.—Filling the sodium thiosulfate burette (dissolved oxygen test).

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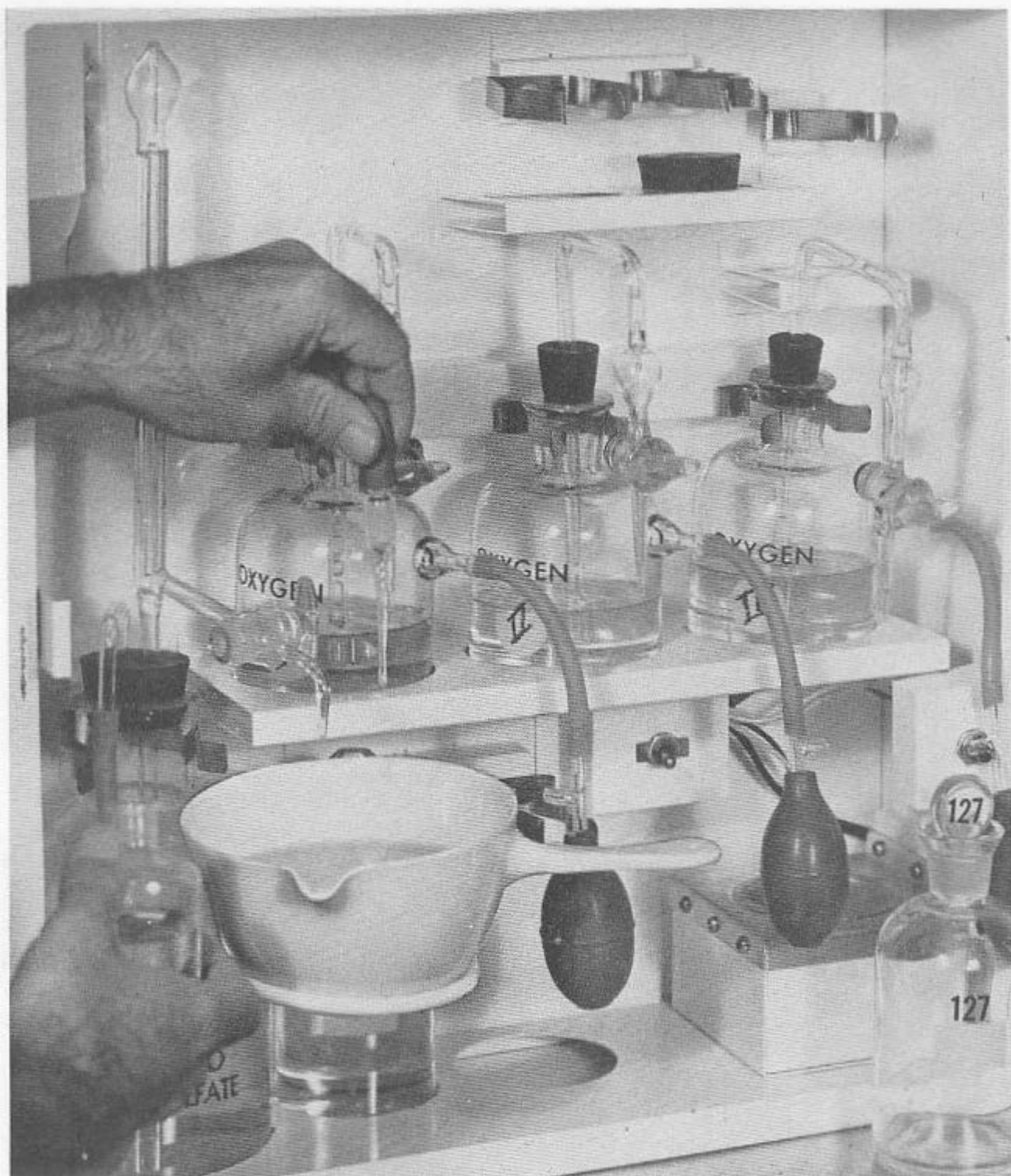


Figure 4-44.—Inserting iron ring in holder (dissolved oxygen test).

38.174

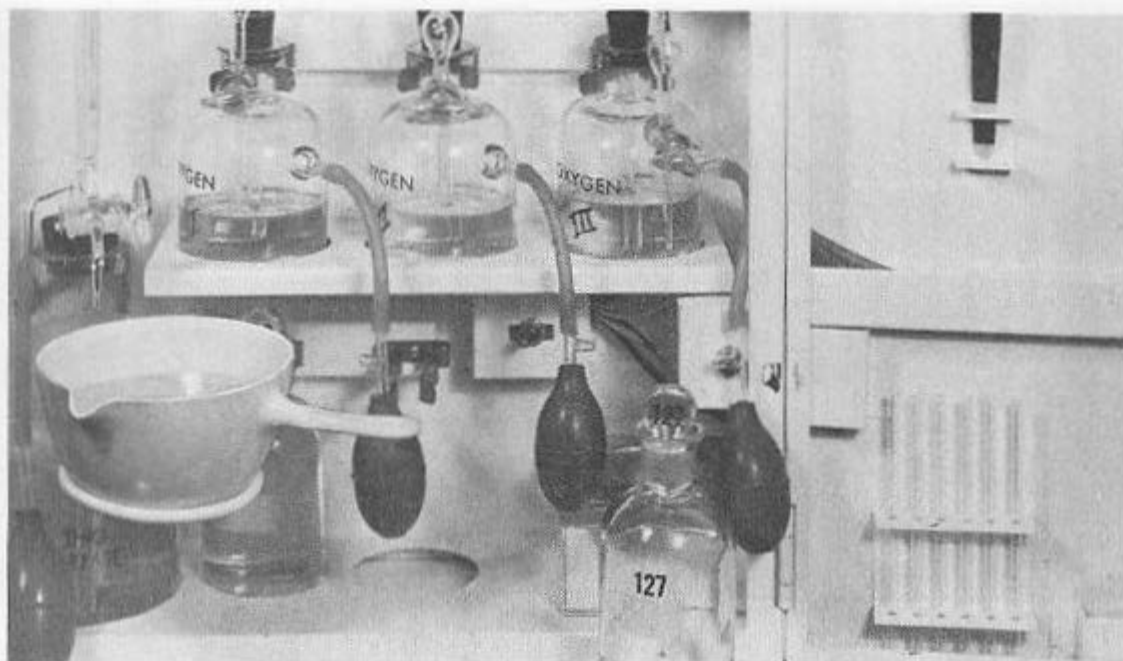


Figure 4-45.—Pouring the fixed sample into the casserole (dissolved oxygen test), 38.175



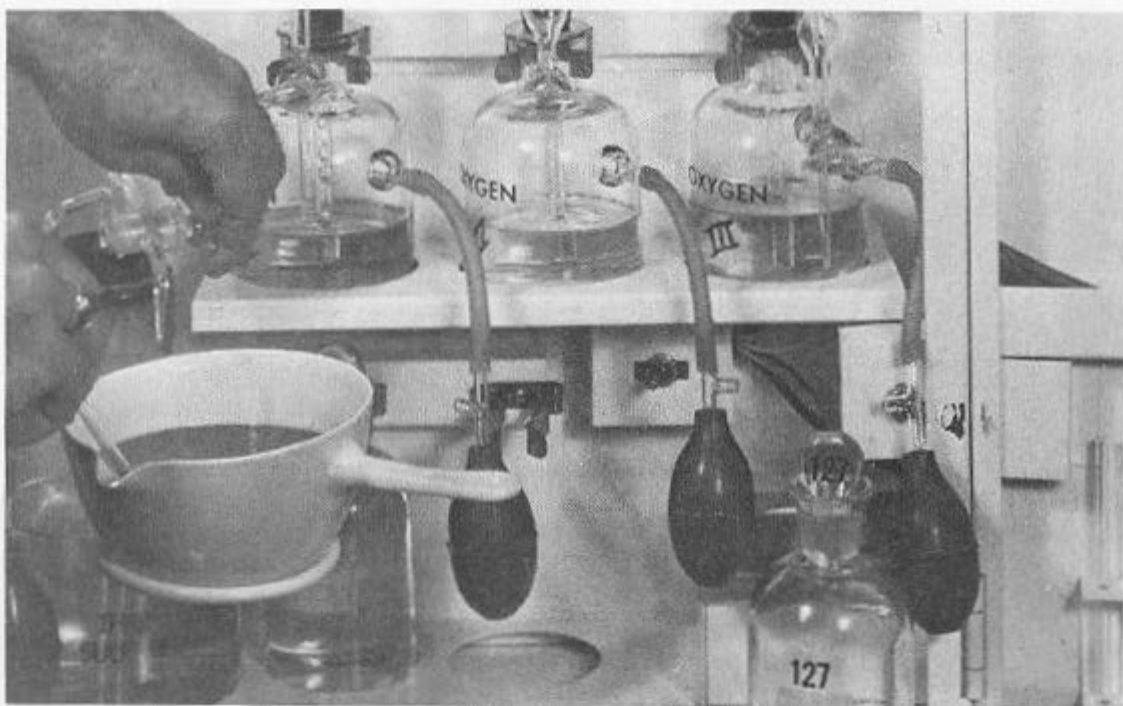
38.176

Figure 4-46.—Adding starch solution from the starch dropping bottle (dissolved oxygen test).



38.177

Figure 4-47.—Zero dissolved oxygen: Sample does not turn blue when starch solution is added.



38.178

Figure 4-48.—Adding sodium thiosulfate to blue sample (dissolved oxygen test).

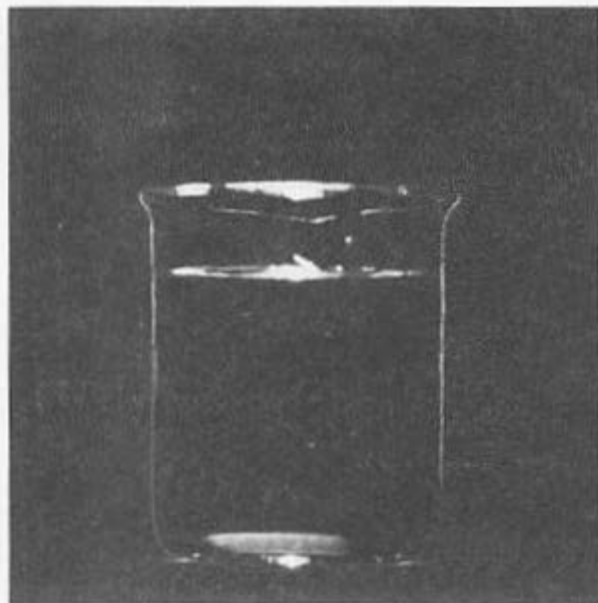


Figure 4-49.—Appearance of oil-free water with Tyndall light. 38.179

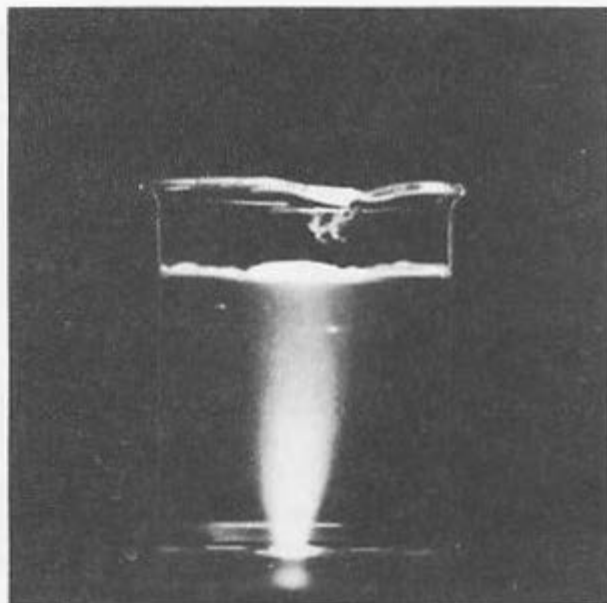


Figure 4-50.—Appearance of Tyndall cone in water containing emulsified oil. 38.180

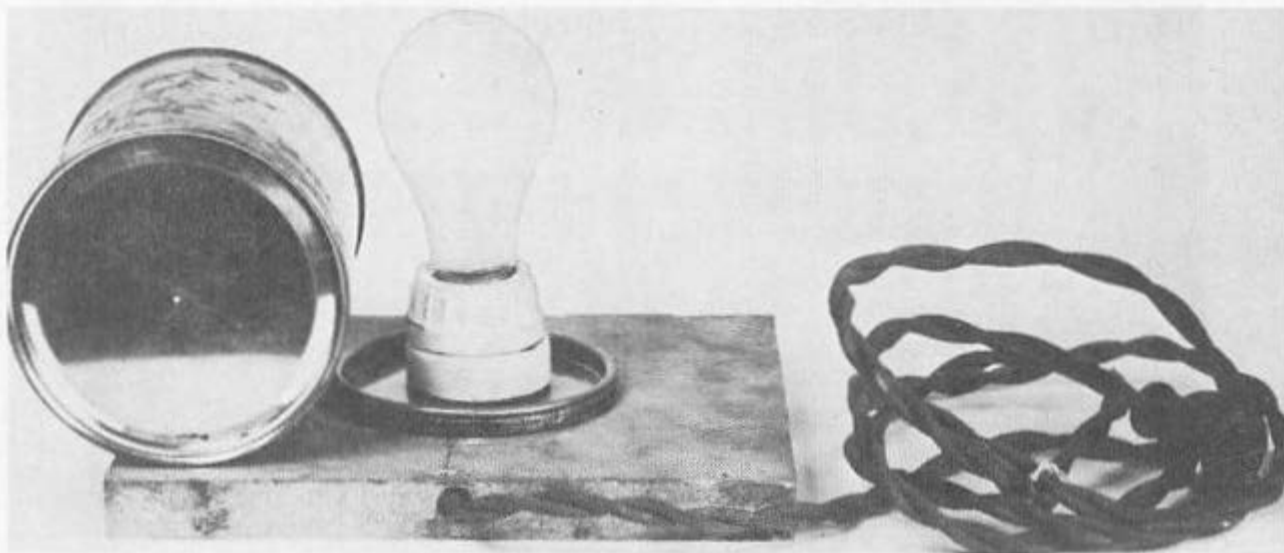
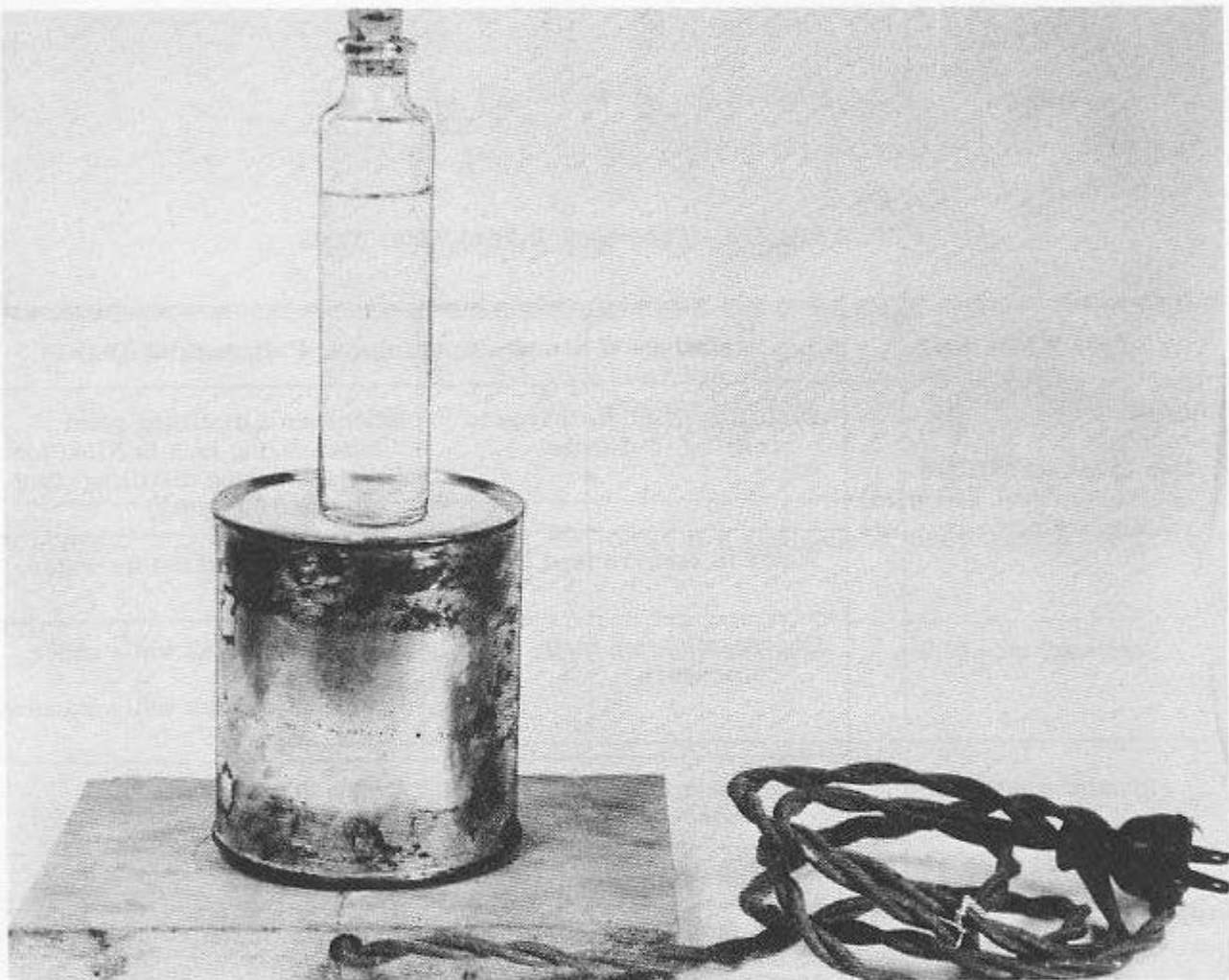


Figure 4-51.—Components of Tyndall lamp. 38.181



38.182

Figure 4-52.—Assembled Tyndall lamp.

FREQUENCY OF FEED WATER TESTS

The intervals at which feed water must be tested for chloride, hardness, and dissolved oxygen are shown in table 4-3. Note that these intervals are the same for all ships, regardless of the type of water treatment used or the type of waterside cleaning schedule authorized for the ship.

FEED WATER LIMITS

The feed water limits specified by the Naval Ship Systems Command for chloride, hardness, and dissolved oxygen are shown in table 4-4. As may be seen, the limits are the same for all

ships except for those on the extended schedule of waterside cleaning.

The limits given for dissolved oxygen require a word of explanation. Deaerated feed water should not contain more than 0.014 ppm of dissolved oxygen, and deaerating feed tanks are guaranteed by the manufacturers to reduce the dissolved oxygen content to this figure or below. However, the test used aboard ship to determine the dissolved oxygen content cannot detect concentrations of less than 0.02 ppm. Therefore any indication of dissolved oxygen during a shipboard test must be taken as a warning that the feed water is not properly deaerated. Laboratory tests, being far more sensitive, can detect dissolved oxygen in concentrations of less than 0.014 ppm.

Table 4-3.—Frequency of Feed Water Tests

Feed Water Test	Source of Sample	Frequency of Test
Chloride Use chemical test frequently to check electrical salinity indicator readings	Distilling plant discharge to reserve feed tanks	Whenever a distilling plant measuring tank is filled (on ships having distilling plant measuring tanks)
	Water in reserve feed tanks	Weekly, and just before water is used
	Condensate from main condensers	Every 15 minutes while under way Every 30 minutes while standing by
	Condensate from auxiliary condensers	Every 30 minutes
	Water in deaerating feed tank	Once each watch
	Water in feed tanks being used and water in standby tanks	Once each watch
Hardness	Water in feed tanks being used and water in standby tanks	Daily, and just before water is used
	Water in reserve feed tanks	Weekly, and just before water is used
Dissolved oxygen	Water in operating deaerating feed tanks	Daily

Table 4-4.—Feed Water Limits

Feed Water Test	Source of Sample	Feed Water Limits For Ships on Regular Schedule of Waterside Cleaning	Feed Water Limits For Ships on Extended Schedule of Waterside Cleaning
Chloride	Distilling plant discharge to reserve feed tanks	0.065 epm maximum	0.065 epm maximum
	Condensate (main and auxiliary condensers)	0.1 epm maximum	0.05 epm maximum
	Water in all feed tanks—use tanks, standby tanks, reserve feed tanks, and deaerating feed tanks	0.5 epm maximum	0.25 epm maximum
Hardness	Water in all feed tanks	0.5 epm maximum	0.2 epm maximum
Dissolved oxygen	Water in operating deaerating feed tanks	Less than 0.02 ppm maximum by ship-board test	Less than 0.02 ppm maximum by ship-board test
		0.014 ppm maximum by laboratory test	0.014 ppm maximum by laboratory test

CHAPTER 5

TURBINE OPERATION

Steam turbines are used for ship propulsion and for driving many of the auxiliary machinery units associated with the propulsion plant, such as lubricating oil pumps, condensate pumps, feed pumps, circulating pumps, fuel oil pumps, forced draft blowers, and ship's service generators.

As an officer of the engineering department, you will be required to know a great deal of general information concerning propulsion plants and associated auxiliary machinery, and you will need specific information about the operation of the propulsion machinery installed in your ship.

This chapter deals with the principal types of steam turbine propulsion plants, and main and auxiliary steam turbines (from the standpoint of basic design features and operating principles) engineering operating procedures, and casualties with turbine installations. Maintenance of turbines is covered in Chapter 6.

It is important to note that most of the information contained in this chapter is of a general nature only. Turbine installations vary to such an extent that it is necessary to consult the various manufacturers' technical manuals for detailed information for any given unit. Further information may be obtained from the Bureau of Ships Technical Manual, Chapter 9410 (41), Section I—Turbines, and Chapter 9500 (50), Auxiliary Steam Turbines.

STEAM TURBINE PROPULSION PLANTS

The two principal types of steam turbine ship propulsion plants in use today are the geared-turbine drive and the turbo-electric drive. The direct-drive type turbine propulsion plant, which was the forerunner of the present day plants, will be found on only a few naval ships.

Steam turbines must operate in a relatively high range of revolutions per minute (rpm) in order to obtain the maximum amount of work

per pound of steam used. Propellers (assume fixed-blade type for this discussion) however, operate most efficiently in a much lower rpm range. In the direct drive installation, it is generally true that neither the modern turbine nor the propeller can operate in its ideal rpm range, when both operate at the same speeds. Steam consumption, and consequently fuel consumption, in these plants was tremendously high. Only by redesigning the high-speed turbine to a large-diameter slow-speed turbine of many stages (50 or more) can the turbine efficiently approach the required value. The need for suitable means of operating both turbine and propeller within their respective efficient rpm ranges brought about the development of the geared-turbine drive and the turbo-electric drive.

In the geared-turbine drive, a reduction gear unit is used as the means for reducing high turbine rpm to the much lower propeller shaft rpm. In the direct-connected electric drive, the necessary speed reduction is brought about electrically. That is, the turbine drives a generator at high rpm, and the generator furnishes power to drive an electric propulsion motor which operates in a low rpm range. The turbine installations in these two types of drives differ considerably, as will be pointed out in the succeeding paragraphs. However, there is essentially no difference (in design and operational features) in the auxiliary machinery and equipment such as pumps, condensers, and coolers associated with these two types of propulsion drives.

GEARED-TURBINE DRIVE

In the geared-turbine drive, the parts or sections which make up the individual propulsion units consist of the main turbines and the reduction gear.

Figure 5-1 shows the general arrangement of the turbines and gears in a geared-turbine propulsion unit. Not all geared turbine plants have the cruising turbine; generally such turbines are found in only the smaller ships such as frigates and destroyers of WW II vintage.

In a typical destroyer propulsion plant, the speed reduction ratio between cruising turbine shaft and high pressure turbine shaft is approximately 1.8 to 1. The speed ratio between high pressure turbine shaft and propeller shaft is 16 to 1, and the ratio between low pressure turbine and propeller shaft is 13 to 1. In other words, in operation, if the propeller shaft is revolving at 100 rpm, at cruising speed, the cruising turbine will be revolving at 2880 rpm ($1.8 \times 16 \times 100$), the high pressure turbine at 1600 rpm (16×100), and the low pressure turbine at 1200 rpm (12×100). However, at full-power speed (300 to 400 rpm for a DD), the units will run as high as 10,000 rpm for the cruising turbine, 5000 to 7000 rpm for the H. P. unit, and 4000 to 6000 rpm for the L. P. unit, with gear ratios accordingly.

Figure 5-1 shows two astern elements, one at each end of the low pressure turbine. This arrangement is typical for combatant type ships; auxiliary type ships usually have one astern element instead of two, and that one invariably is located at the forward end of the low pressure turbine (the end farthest from the reduction gear).

The PROPULSION SHAFT, extending from the main gear (low speed) shaft of the reduction

gear to the propeller, is supported and held in alignment by the SPRING BEARINGS, the STERN TUBE BEARINGS, and the STRUT BEARING. The axial thrust, acting on the propulsion shaft as a result of the pushing effect of the propeller, is absorbed in the MAIN THRUST BEARING. In many ships, the main thrust bearing is located at the forward end of the main shaft, within the reduction gear casing. In other ships, however, the main shaft thrust bearing is located farther aft in a machinery space or a shaft alley.

In submarine applications and other ships utilizing single-casing turbines geared to a single propeller shaft, there is usually a clutch, as well as an emergency electric motor.

TURBO-ELECTRIC DRIVE

Unlike geared-turbine propulsion plants, which have one or more ahead turbine elements and one or two astern elements for each propulsion shaft, the turbo-electric drive installations have a single turbine unit for each installed shaft. Figure 5-2 shows the diagrammatic arrangement of a turbo-electric propulsion unit. This unit includes a turbine, main generator, propulsion motor, a direct current generator for supplying excitation current to the generator and the propulsion motor, and a propulsion control board.

The speed reduction ratio between turbine and propeller in the turbo-electric drive is approximately the same as in the geared-turbine

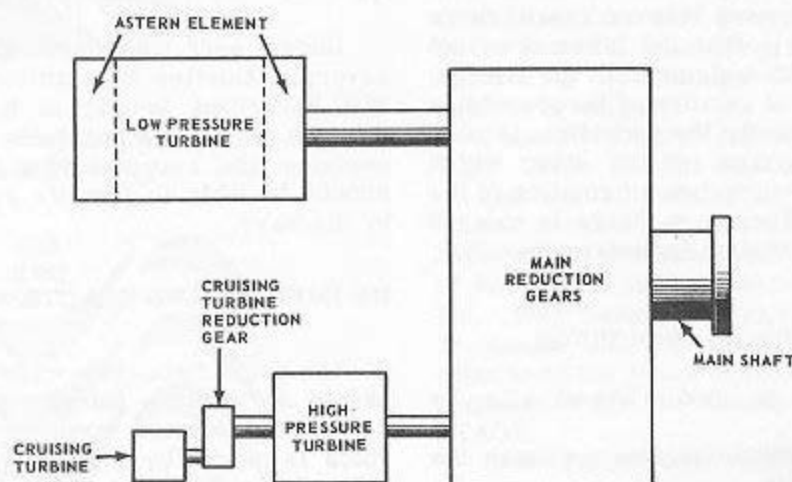


Figure 5-1.—Geared turbine propulsion unit.

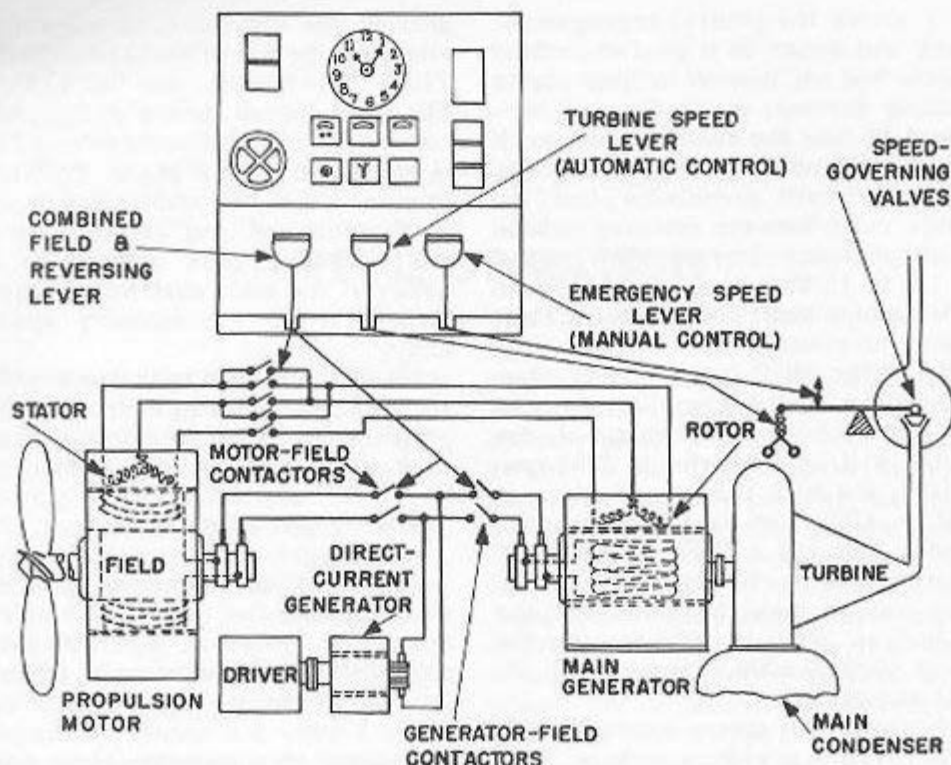


Figure 5-2.—Diagram of the turbo-electric drive.

47.2

drive, and is brought about electrically. For example, in one class of turbo-electric drive type destroyer escort, the normal operating range fixed speed ratio between the turbine-generator set and the propulsion motor is 14 to 1.

One of the differences between geared drive and electric drive is that the latter does not have an astern turbine element. In the electric drive, the direction of rotation of the propulsion motor, and consequently the propeller, is controlled by the electrical switch setup which reverses the direction of rotation of the propulsion motor. Therefore, there is no need to reverse turbine rotation for astern operation.

STEAM TURBINE GROUPINGS

Turbines may be grouped in five ways i.e.; by the:

1. Manner in which the steam causes the turbine rotor to rotate.
2. Type of staging and compounding of steam pressure and velocity.

3. Division of the steam flow.
4. Direction of the steam flow.
5. Repetition of steam flow (including single entry, single re-entry, and double re-entry type turbines) may also be used.

Under each of these groups, there are several varieties of turbines, some of which are described briefly in the following paragraphs. After reading these descriptions and studying the accompanying illustrations, you should be able to identify every turbine used by the Navy.

BY IMPULSE AND REACTION PRINCIPLES

The basic distinction made between turbines has to do with the manner in which the steam causes the turbine rotor to move. When the rotor is moved by a push or "impulse" from a high velocity jet of steam that strikes blades mounted on the periphery of a rotor wheel, the turbine is said to be an **IMPULSE TURBINE**.

When the rotor is moved by the force of reaction, the turbine is said to be a **REACTION TURBINE**.

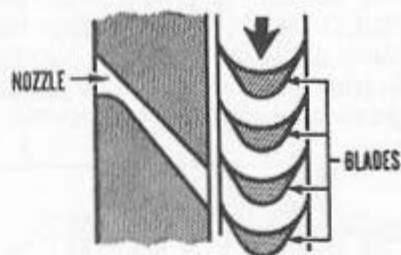
The angle at which the steam hits the moving blades and the shape of the moving blades are the two main factors which determine whether the rotor is moved by a direct impulse or by reaction to an impulse. Figure 5-3 shows the nozzle and blade arrangement in an impulse turbine. Figure 5-4 shows the fixed blades and the moving blades in a reaction turbine.

Impulse Turbines

In the impulse turbine, the steam expands through stationary nozzles only and so loses pressure but gains velocity. In the moving blades, the steam loses velocity but the pressure remains constant. Actually, an impulse turbine utilizes both the impulse of the steam jet and, to a lesser extent, the reactive force which results from the fact that the curving blades cause the steam to change its direction.

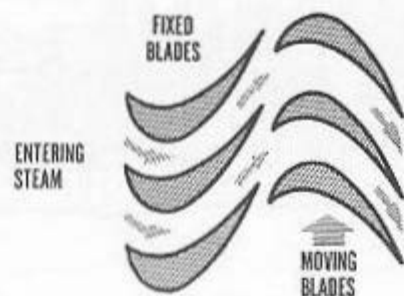
Reaction Turbines

In the reaction turbine, the steam enters through the row of fixed blades which expand



38.76X

Figure 5-3.—Impulse turbine nozzle and blades.



38.77X

Figure 5-4.—Fixed and moving blades in a reaction turbine.

and direct the flow of steam to the moving blades. The fixed blades and the moving blades are very similar in shape (see fig. 5-4). Steam expansion takes place in both sets of blades.

A reaction turbine is moved by (1) the reactive force produced on the moving blades when the steam increases in velocity, and (2) the reactive force produced on the moving blades when the steam changes direction. However, some of the motion of the rotor is actually caused by the impact of the steam on the blades; and, to a certain extent, therefore, the reaction turbine operates on the impulse principle as well as on the reaction principle.

Basic Differences Between Impulse And Reaction Turbines

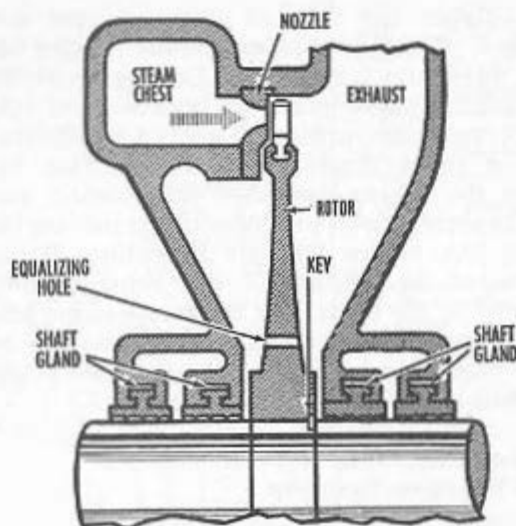
Regardless of the number of fixed and moving blade rows in an impulse turbine, the pressure remains the same throughout the blading of each stage. In the reaction turbine, however, the steam pressure decreases in every row of fixed and moving blades. There are no nozzles in the reaction turbine; the fixed blades serve the same purpose as the nozzles of an impulse turbine.

BY STAGING AND COMPOUNDING

In an impulse turbine, a **STAGE** is defined as one set of nozzles and the succeeding row or rows of moving and fixed blades. Another way of defining a stage is to say that it includes the nozzles and blading in which only one pressure drop takes place. (In an impulse turbine, remember, the only pressure drop takes place in the nozzles. Therefore, the number of sets of nozzles in an impulse turbine indicates the number of stages.)

Figure 5-5 shows a **SIMPLE IMPULSE TURBINE**. This turbine has one stage, consisting of one set of nozzles and one row of moving blades mounted on the rotor. Simple impulse turbines do not completely utilize the velocity of the steam, and are therefore not very efficient. They have the advantage of being simple in design and construction, however, and are often used for small auxiliary units. The simple impulse stage is usually called a **RATEAU STAGE**.

In the **REACTION TURBINE**, the steam pressure successively drops in each row of blades (whether fixed or moving). The combination of a row of fixed blades with a row of moving blades in these turbines is sometimes referred to as

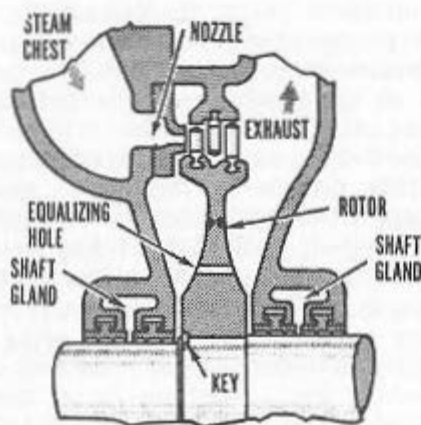


38.78X

Figure 5-5.—Simple impulse turbine.

a DOUBLE STAGE (also known as a single REACTION STAGE).

One way to increase the efficiency of a single stage impulse turbine is to add another row (or even two more rows) of moving blades to the rotor wheel. Figure 5-6 shows a turbine which has two rows of moving blades. This turbine is called a VELOCITY COMPOUNDED



38.79X

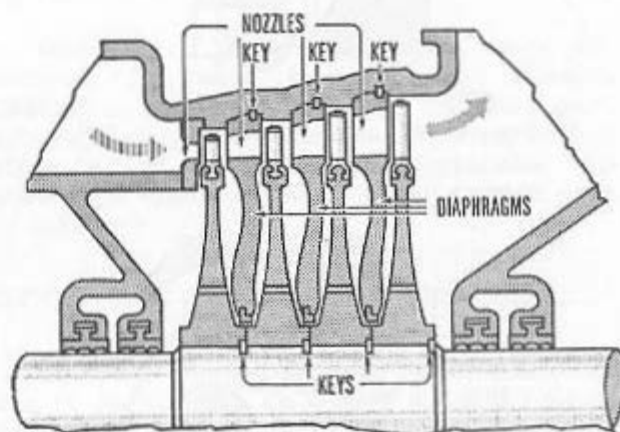
Figure 5-6.—Velocity compounded impulse turbine.

IMPULSE TURBINE because the residual velocity of the steam leaving the first row of moving blades is utilized in the second row of moving blades; and, if a third row is added, the velocity of the steam is utilized again in the third row. The fixed blades, which are fastened to the casing rather than to the rotor, serve to direct the steam from one row of moving blades to another.

The velocity compounded impulse turbine shown in figure 5-6 has only one pressure drop and therefore, by definition, only one stage. This kind of velocity compounded impulse stage is usually called a CURTIS STAGE. Many of the auxiliary turbines used for pumps and forced draft blowers consist of one Curtis stage.

(Velocity compounding can also be achieved when only one row of moving blades is used, provided the steam is directed in such a way that it passes through the blades more than once. This point will be taken up in greater detail in the discussion of types of steam flow.)

Another way to increase the efficiency of an impulse turbine is to arrange two or more simple impulse stages in one casing. The casing is internally divided by diaphragms which contain nozzles so that the residual steam pressure of one stage is utilized in the following stage. This type of turbine is known as a PRESSURE COMPOUNDED IMPULSE TURBINE because a pressure drop occurs in each stage, as the steam expands through each set of nozzles. Figure 5-7 shows a pressure compounded impulse turbine



38.80X

Figure 5-7.—Pressure compounded impulse turbine.

with four stages. A pressure compounded impulse turbine is often called a RATEAU TURBINE, since it is essentially a series of simple impulse (Rateau) stages arranged in sequence in one casing. Pressure compounded impulse turbines are not commonly used for small auxiliary units.

The PRESSURE COMPOUNDED REACTION TURBINE (all reaction turbines are pressure compounded) employs alternate rows, or stages, of fixed and moving blades which compound the total pressure drop into as many steps as there are rows, of such blades. This pressure staging lowers the steam velocity in each stage.

The COMBINATION IMPULSE AND REACTION TURBINE employs a velocity compounded impulse (Curtis) stage at the high pressure end of the turbine. This effects large temperature and pressure drops in the first-stage nozzles, as well as a high initial utilization of thermal energy. It also enables the remaining pressure

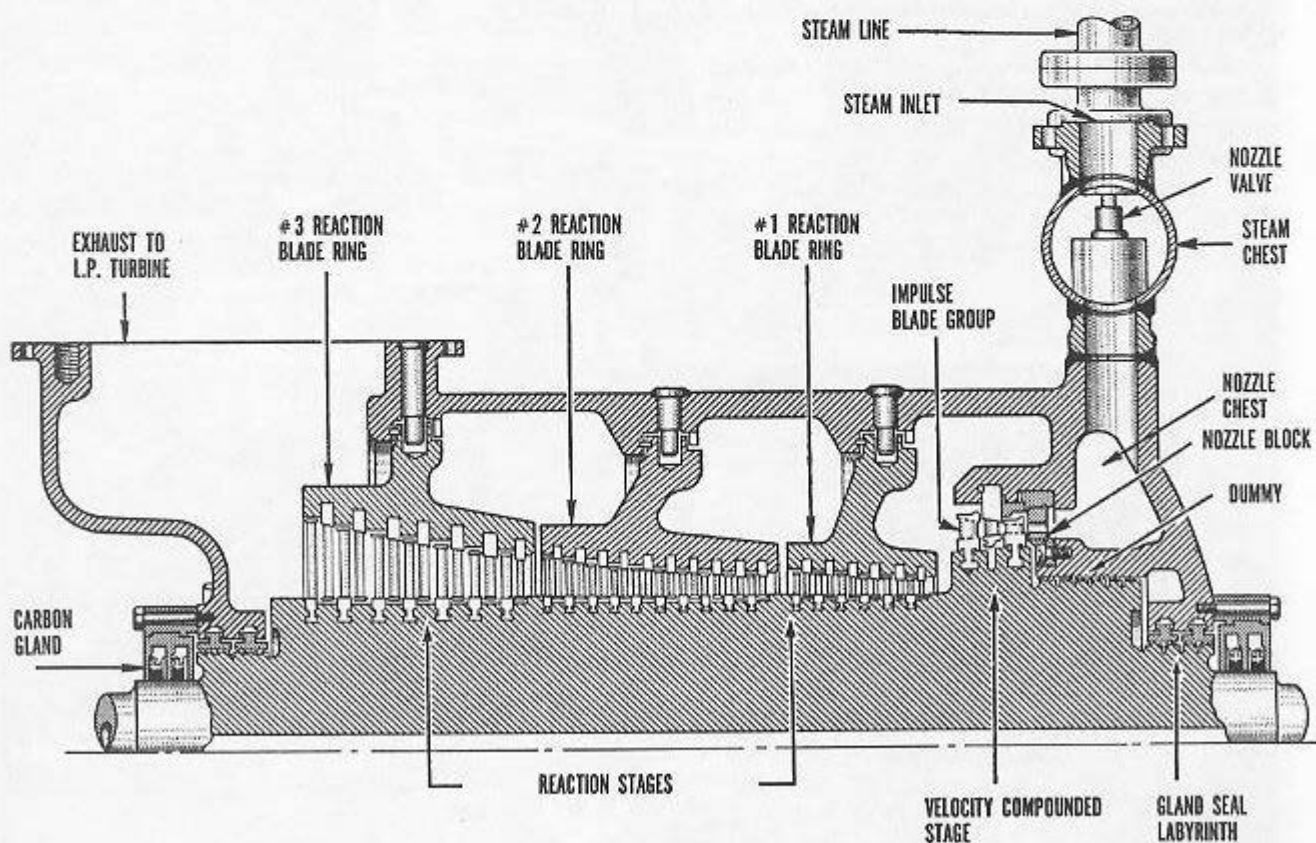
compounded reaction stages of the turbine to work more efficiently and with less tendency to distortion in the turbine parts. Figure 5-8 illustrates diagrammatically the design of this type of turbine, which is often referred to as a MODIFIED PARSONS TURBINE.

BY DIVISION OF STEAM FLOW

The next classification of turbines concerns the number and type of divisions in the steam flow through the several elements which comprise the complete turbine. The turbine types under this grouping include single-flow turbines, cross-compound turbines, and double-flow turbines.

Single-Flow Turbines

In single-flow turbines, the steam enters at the inlet or throttle end, flows once through the



47.3X

Figure 5-8.—Combination impulse and reaction turbine.

blading in a line approximately parallel to the rotor or shaft, and emerges at the exhaust end of the turbine. Figure 5-9 illustrates this type of turbine.

The steam passing through a multistage impulse turbine does not exert any appreciable axial thrust to the rotor since the pressure drop actually takes place in the nozzles. The EQUALIZING HOLES provided in the turbine wheel also help to prevent the development of axial thrust upon the individual wheel of the rotor. In a reaction turbine considerable axial thrust is developed from the steam pressure drop occurring in the moving and the stationary blades. In single-flow reaction turbines, this axial thrust is partially counterbalanced by use of a dummy piston and dummy cylinder arrangement such as is shown in figure 5-10. In this arrangement, space A surrounds the inlet end

face area of the turbine rotor and is connected to space B, which surrounds the outlet face end area of the rotor, by an equalizing pipe. The dummy piston and cylinder which form a close running sealing surface serve to prevent the entry of large amounts of steam from the inlet passage into space A. (The difference in steam pressure across the dummy causes a thrust toward the high pressure end of the turbine, partially counterbalancing the thrust in the opposite direction caused by the pressure drop in the rotor blading.)

In some combination impulse and reaction turbines (fig. 5-8), a dummy piston cylinder arrangement similar to the one just described was used to help offset the axial thrust effect caused by the reaction blading of the turbine. In reaction turbines of the double-flow type, discussed later in this chapter the dummy piston and

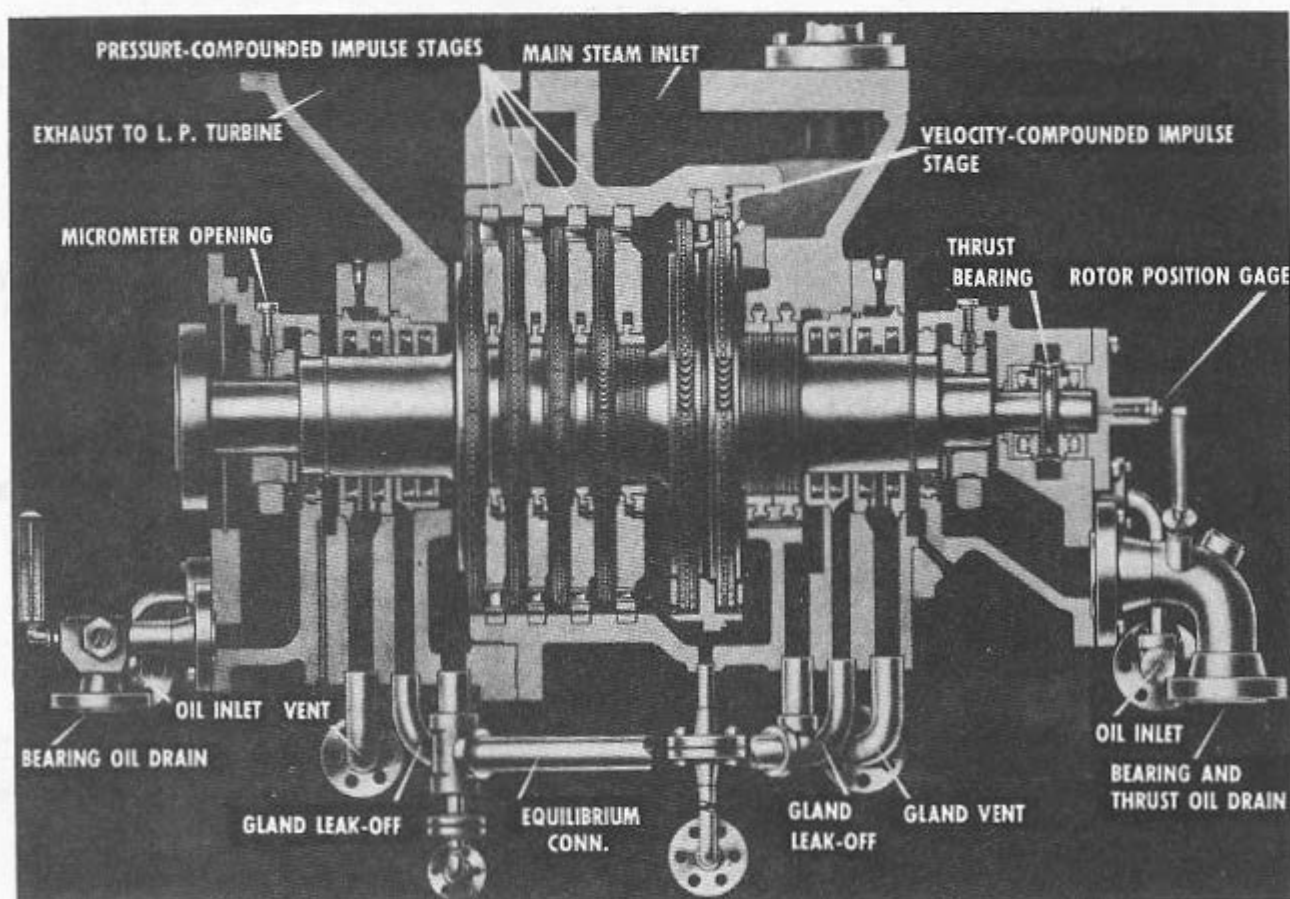


Figure 5-9.—Single flow, pressure velocity compounded impulse turbine.

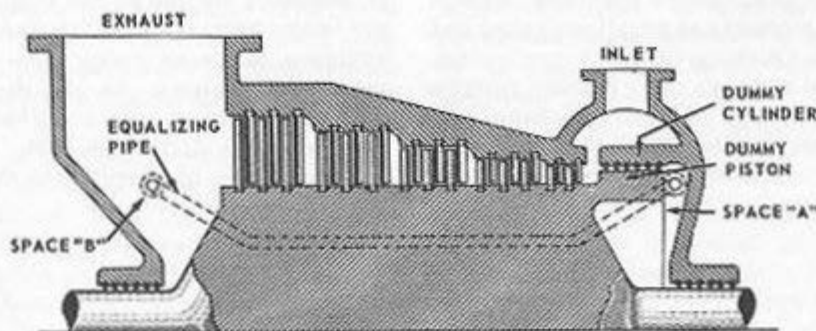


Figure 5-10.—Dummy piston and dummy cylinder.

47.4X

cylinder are not necessary since the axial thrusts developed at each end counterbalance each other.

Compound Turbine Units

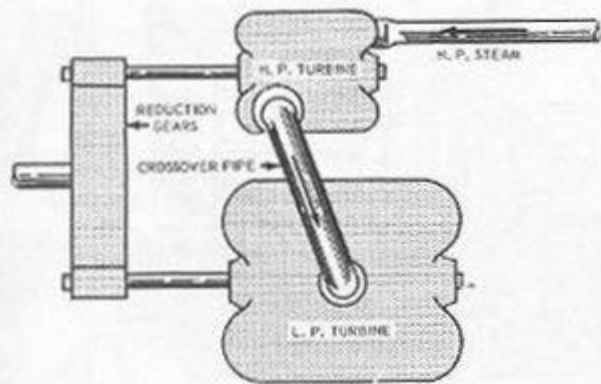
In turbine units of small or moderate power, complete expansion of the steam, and resultant utilization of the latent energy, can be provided for in a single casing. For greater power requirements, however, this type of turbine would require casings and rotors of such great size as to create serious difficulties in construction. The size of these parts would be such as to create serious potential problems due to differential expansion.

High-power geared turbine installations are, therefore, generally built as compound turbine units. In this type, the steam is partially expanded in a HIGH PRESSURE TURBINE (enclosed in

a casing of its own), and then exhausted, through a crossover pipe, to a LOW PRESSURE TURBINE where the expansion is completed. The energy-depleted steam is then exhausted to the main condenser. In older DD designs, a CRUISING TURBINE precedes the high pressure turbine. This turbine is operated over the cruising range and may be bypassed at higher powers or speeds.

In more recent designs, a series-parallel turbine is being used. It consists of a single high pressure-intermediate pressure rotor and casing, and a conventional low pressure unit. The high pressure-intermediate pressure steam chest and nozzle-control valves are arranged so that steam is admitted only to the high pressure element for speeds in the cruising range. The steam then passes through an external pipe to the intermediate pressure element and is exhausted to the low pressure unit. For this condition, the turbine is said to be operating in "series." For speeds in excess of the cruising range, main steam is admitted to both the high pressure and intermediate pressure elements, and the turbine is operating in "parallel." Both the high pressure and intermediate pressure elements exhaust to the low pressure element.

There were originally two general arrangements of compound turbine units in use—the crosscompound and the tandem-compound—but the cross-compound type is the only one now used in the Navy. In these CROSS-COMPOUND TURBINE installations (fig. 5-11), the high and low pressure units are on separate shafts. The two turbine shafts are connected, through reduction gears, to a common shaft which drives the ship's propeller.



47.6

Figure 5-11.—Diagrammatic arrangement cross-compounded turbine.

CRUISING TURBINES are generally similar in design to the high pressure turbines, except that the cruising turbines are smaller in size and flow volume. When cruising turbines are in use, steam passes first through the cruising turbine before going to the high pressure turbine (fig. 5-12A). In this way, the steam is expanded through a greater number of pressure stages.

This extracts more energy from the steam than is possible by use of the high pressure and low pressure turbines. When speeds in excess of the cruising turbines range are desired or anticipated, the steam is led directly to the high pressure turbine, bypassing the cruising turbine, as shown in figure 5-12B. In some designs, cooling steam is supplied to the cruising turbine

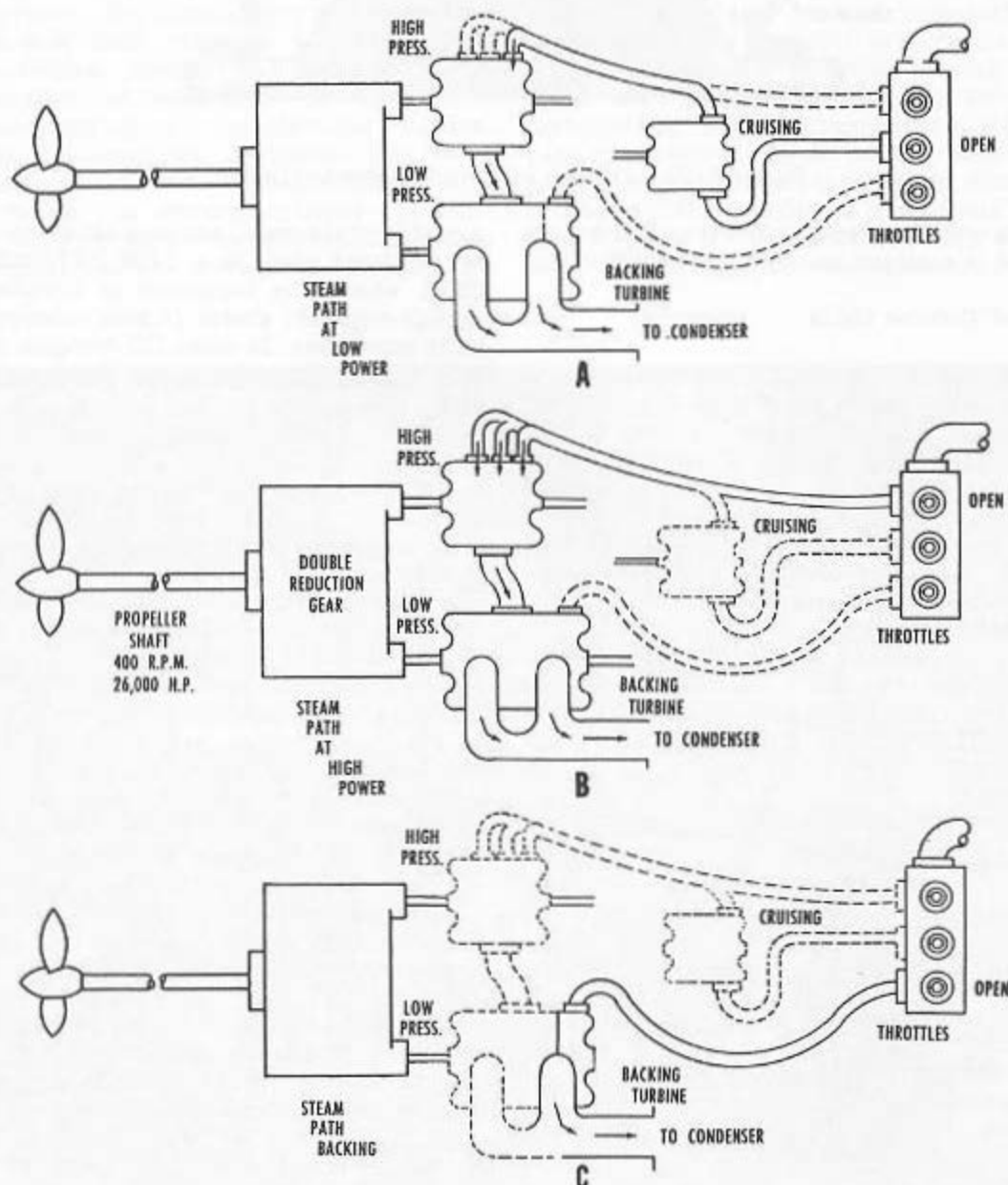


Figure 5-12.—Schematic diagrams showing steam flow to cruising, high pressure, and astern turbines.

from the high pressure turbine to prevent damage from overheating caused by friction of rotation; in other designs this is achieved solely by vacuum. Reduction gears and shafting are used to connect the high pressure turbine and the cruising turbine.

Steam should not be admitted to the backing or astern turbine while steam is being admitted to the ahead turbines. (See fig. 5-12C.) Steam may be admitted to an astern turbine when a ship is going ahead at any time it is desired to slow, stop, or back the ship, providing the ahead throttle is closed. Astern turbines which may be either single-flow or double-flow impulse turbines, develop about one-tenth to one-fifth the maximum power of the ahead turbines, but have a torque capability from 90 to 120% of that of the ahead elements.

In noncombatant ships, the astern turbine usually consists of one or two velocity-compounded impulse (Curtis) stages mounted in the exhaust end of the single-flow low-pressure ahead turbine.

Most submarines have one or more single-casing turbines, each fitted with an astern element. Most combatant surface ships, with geared turbine installations, have an astern element of one or two velocity-compounded (Curtis) stages installed in each end of the double-flow low pressure turbine. This dual element provides

higher astern power than is possible with a single astern element. In addition, the axial thrust developed by one element is opposed and balanced by an equal axial thrust developed by the other element.

Double-Flow Turbines

Single-flow turbines with a large capacity and a low exhaust pressure require excessively long blades (or a very large turbine diameter) at the low pressure stages to allow free passage of the expanded steam, and to maintain the desired efficiency. To overcome these disadvantages, **LOW PRESSURE TURBINES** are frequently constructed as a double-flow type (fig. 5-13). This turbine consists of two single-flow units installed on one shaft, in the same casing, with steam inlet at the center. The blading is arranged to permit steam flow from the center toward both ends, and to give the rotational effect in the same direction at both ends.

Since equal amounts of steam flow from the center toward each end in the double-flow turbine, the steam thrust (pressure toward end of turbine) is balanced, and the undesirable axial thrust is eliminated. The majority of low pressure compound turbine units are of this type of construction.

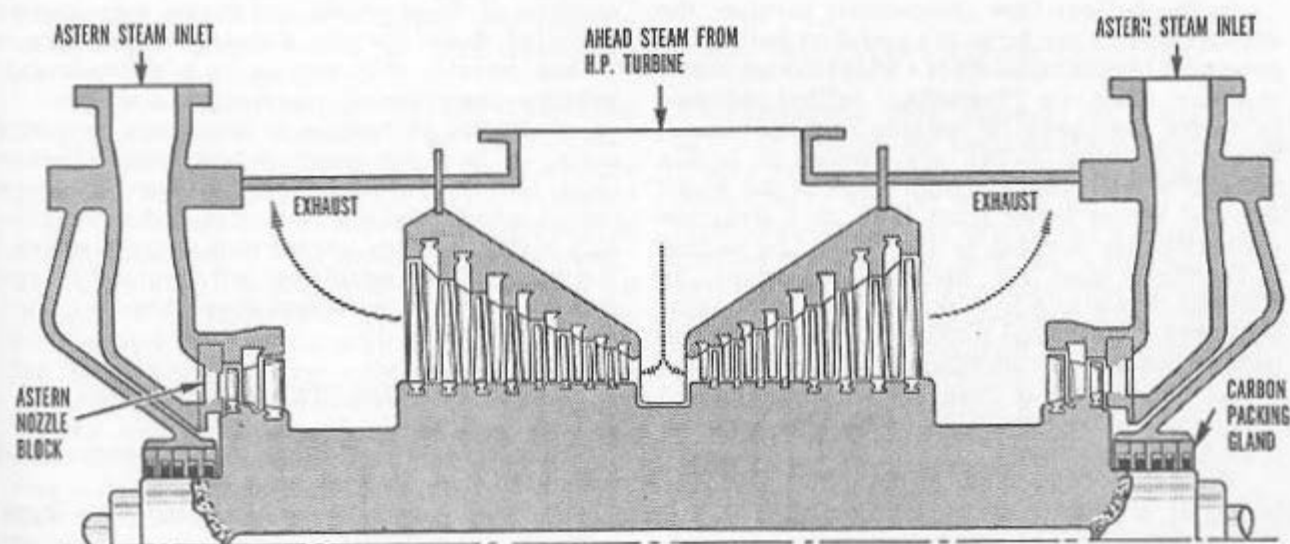


Figure 5-13.—Low pressure double-flow reaction turbine.

BY DIRECTION OF STEAM FLOW

Turbines may be grouped by axial flow, helical flow, or radial flow, according to the direction of the flow of steam relative to the turbine wheel. The Navy uses only axial flow units for main propulsion; helical flow turbines are widely used for driving auxiliary machinery; and radial flow turbines are used to a limited extent for small pump drives.

Axial Flow Turbines

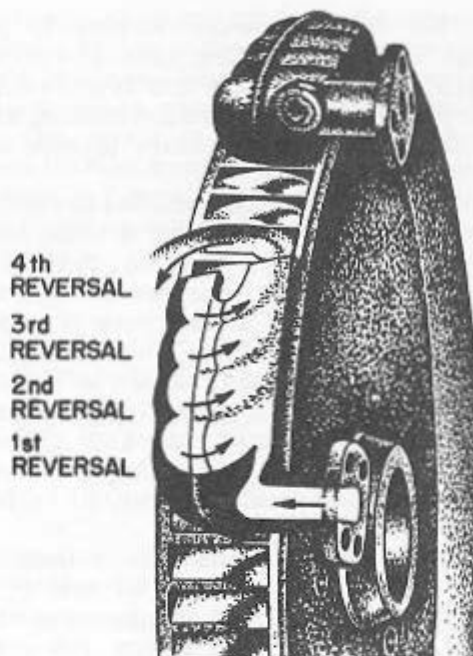
Most steam turbines (especially those of medium and high power) are of the axial flow type. In such turbines, the steam flows in a direction approximately parallel to the axis of the wheel or rotor, the blades being set so that they project radially from the periphery of the rotor.

As already indicated, the desired degree of steam expansion in this type turbine is provided for by: increasing the number of rows of blades; increasing the length of blades in successive rows; increasing the diameter of the wheels or rotor upon which the blades are mounted; changing the shapes of the blades or variously spacing them; or a combination of two or more of these methods.

Helical Flow Turbines

In the helical flow (tangential) turbine, the steam flows in the form of a spiral or helix. The rotating element consists of a wheel having semi-circular slots, or "buckets," milled obliquely in its periphery or outside circumference. The nozzles (fig. 5-14), are located in such a manner around the circumference of the wheel that the steam flows from them in a direction approximately tangent to the wheel, or so that it impinges upon the slots of the wheel. In this way, the steam is directed into the buckets, and gives a rotational impulse to the wheel. The moving buckets are so shaped that the direction of the steam flow is reversed within them, and the steam is sent back out of the side opposite from where it entered.

The steam coming out of the moving buckets is caught in stationary buckets or REVERSING CHAMBERS, where its direction is again reversed and the steam flows back through the moving buckets. This reversing and redirecting process is repeated several times, after which the steam passes out through the exhaust opening.



33.45X
Figure 5-14.—Phantom view of steam path in a Strutevent helical flow turbine.

A nozzle and the accompanying set of fixed redirecting buckets or reversing chambers are cast or welded in one piece. Up to the limit imposed by the circumference of the wheel, any number of these nozzle and bucket sets may be installed. Since the only drop in pressure occurs in the nozzle, this turbine is a single-stage, velocity-compounded, impulse turbine.

This kind of turbine is built only in small units, up to a few hundred horsepower, and is used for driving such auxiliary machinery as pumps and forced draft blowers. It has reasonably high efficiency over a wide range of speeds, and is especially adapted to units requiring large speed variations in normal operation.

PROPULSION STEAM TURBINES

There are several types of turbines installed on naval ships; six major types are:

1. Type I (single-casing unit).—The Type I propulsion unit consists of one or more ahead elements, each contained in a separate casing and identified as a single-casing turbine. Each turbine delivers approximately equal power to a reduction gear or a propulsion generator.

2. Type II-A (straight-through unit).—The Type II-A propulsion unit is a two element straight-through unit, and consists of two ahead elements, known as a high pressure (HP) element and a low pressure (LP) element. The HP and LP elements are contained in a separate casing and are commonly known as the HP and LP turbines, respectively. The HP and LP turbines deliver power to a single shaft by separate coupling to a reduction gear. Steam is admitted to the HP turbine and flows straight through the turbine without bypassing any stages (there is partial bypassing of the first row of blades at high power), and then is exhausted to the LP turbine through a crossover pipe.

3. Type II-B (EXTERNAL bypass unit).—The Type II-B propulsion unit is similar to the type II-A, except that provision is made for bypassing of steam around the first stage or first several stages of the HP turbine at powers above the most economical point of operation. Bypass valves are located in the HP turbine steam chest, with the nozzle control valves.

4. Type II-C (INTERNAL bypass unit).—The Type II-C is similar to the Type II-A, except that provision is made for bypassing steam from the first-stage shell around the next several (one or more) stages of the HP turbine at powers above the most economical point of operation. Bypass valves and steam connections are usually integral with the HP turbine casing; however, some installations have the valves separate, but bolted directly to the casing, with suitable connecting piping between the first-stage shell and valve to the bypass belt.

5. Type III (series-parallel unit).—The Type III propulsion unit consists of three ahead elements, known as the HP element, intermediate pressure (IP) element, and LP element. The HP and IP elements are combined in a single casing and known as the HP-IP turbine. Steam is admitted to the HP-IP turbine and exhausted to the LP turbine by a crossover pipe. For powers up to the most economical point of operation, only the HP element receives inlet steam, with the IP element being supplied in series with steam from the HP element exhaust. At powers above this point of operation, both elements receive inlet steam in a manner similar to that in a double-flow turbine. During ahead operation no ahead blading is bypassed.

6. Type IV (cruising geared and vented unit).—The Type IV propulsion unit consists of a cruising element, HP element, and LP element—each contained in a separate casing. The cruising

turbine is connected in tandem through a cruising reduction gear to the forward end of the HP turbine. The cruising turbine contributes power to the propeller shaft for powers up to the most economical point of operation, and for higher powers it is idled in a partial vacuum and supplied with cooling steam to prevent overheating. It is possible to disconnect the cruising turbine to allow for repair while the HP turbine is operating. For cruising powers, steam is admitted to the cruising turbine and then exhausted to the HP turbine inlet, and thence from the HP turbine exhaust into the LP turbine through a crossover pipe. The arrangement of the HP and LP turbine is identical to the Type II units.

All of these six types of propelling units contain an astern element for backing or reversing. The astern element is located in each exhaust end of the LP turbine casing or in the exhaust end of each single-casing turbine.

Another classification which affects turbine life requirements and construction is:

Class A—Turbines for use in naval submarines.

Class B—Turbines for use in naval surface ships (warships, mine warfare ships and patrol ships).

Class C—Turbines for use in naval ships (amphibious warfare ships and auxiliary ships).

AUXILIARY STEAM TURBINES

Throughout this chapter, we have placed primary (though not exclusive) emphasis on the larger types of turbines used for main propulsion. There are, of course, the ship's service turbine generator set drives and a considerable number of smaller turbines employed in all naval engineering plants for driving auxiliary machinery such as generators, pumps, air compressors, and forced draft blowers. The ship's service generator turbines are multi-stage units with ratings up to 2500 KW. These units are constant speed turbines running at 3600 rpm. Most auxiliary machinery units outside the engineering spaces on naval ships, and many units within these spaces, are driven by electric motors. For example, the usual practice is to duplicate some turbine-driven pumps with electrically driven units to be used at cruising speeds and in port. These motor-driven pumps have a comparatively high efficiency, but on some

ships their capacity is not great enough to meet the demands of the engineering plant at high speeds.

EFFICIENCY OF AUXILIARY TURBINES

Aside from the fact that the turbine driven units (particularly pumps) have a higher capacity than the motor driven units, there are two additional important reasons why turbines are employed to drive the auxiliary machinery:

1. Turbines ensure greater reliability than motor driven units. The possibility of interruption or loss of electric power supply is greater than the possibility of loss of steam supply—especially during action.
2. Turbines improve the overall efficiency of the plant by supplying exhaust steam for such auxiliary machinery units as feed water heaters and evaporators, where low pressure steam is required.

The efficiency of most auxiliary turbines is increased with the use of reduction gears. These turbines are designed to have comparatively few stages (sometimes only one), to conserve space. This results in a large pressure drop in each stage, and a high steam velocity. To obtain maximum efficiency, the blade speed must also be high. Hence, the reduction gears reconcile the two conflicting speed requirements, and increase the general efficiency.

CLASSIFICATION OF AUXILIARY TURBINES

In general, auxiliary turbines in naval use may be classified (in a manner similar to the general turbine type classification) according to the following characteristics:

1. Speed (constant or variable).
2. Exhaust conditions (condensing or noncondensing).
3. Shaft position (horizontal or vertical).
4. Type (impulse or reaction).
5. Steam flow direction (axial, radial, or helical).
6. Stages (single or multiple).
7. Drive (direct or geared).
8. Service (based upon driven auxiliary).
9. Power output capacity and limiting speeds.

Auxiliary turbines are usually impulse turbines of either the helical-flow or axial-flow type. Except for electric generator condensing turbines, they operate against a back pressure of 12 or 15 psig, depending upon the auxiliary exhaust line operating pressure of the ship in which installed. In later ships, this back pressure is 15 psi. Turbines for driving the ship's service generators are ordinarily of the impulse, axial-flow, multistage, geared type.

USES OF AUXILIARY TURBINES

Since the various types of turbines were discussed in the earlier part of this chapter, it is unnecessary to explain in detail the various auxiliary turbines utilized to drive the numerous pumps in the engineering spaces of your ship. The principal pumps driven by these turbines, however, include the main condensate pumps, main condenser circulating pumps, main feed pumps, main feed booster pumps, main fuel oil service pumps, and main lubricating pumps.

Main Condensate Pump Turbines

On many ships the construction of the turbines driving the main condensate, main feed booster, and the lube oil service pumps is identical. The bucket wheels (turbine wheels) and many other parts such as governors, bearings, and turbine and gear casings are interchangeable. Figure 5-15 shows the wheel and blading diagram of a turbine used to drive the main condensate, main feed booster, and lube oil service pumps on a DD-692 class destroyer. These turbines are single pressure stage, radial flow single reentry. Although destroyers and other ships have changed radically since World War II, the basic design of these turbines has changed little. Improved metals are used, however, to withstand the higher pressures and temperatures of steam on the newer class warships.

Main Condenser Circulating Pump Turbine

Figure 5-16 shows a vertically mounted, axial flow, velocity compounded, impulse unit. This turbine is designed to operate on saturated steam and exhaust at 10 psig. (On some new combatant ships, these turbines are driven by superheated steam and exhaust at 15 psig.) The turbine shaft is secured to the vertical shaft of the pump. A thrust bearing, mounted integrally

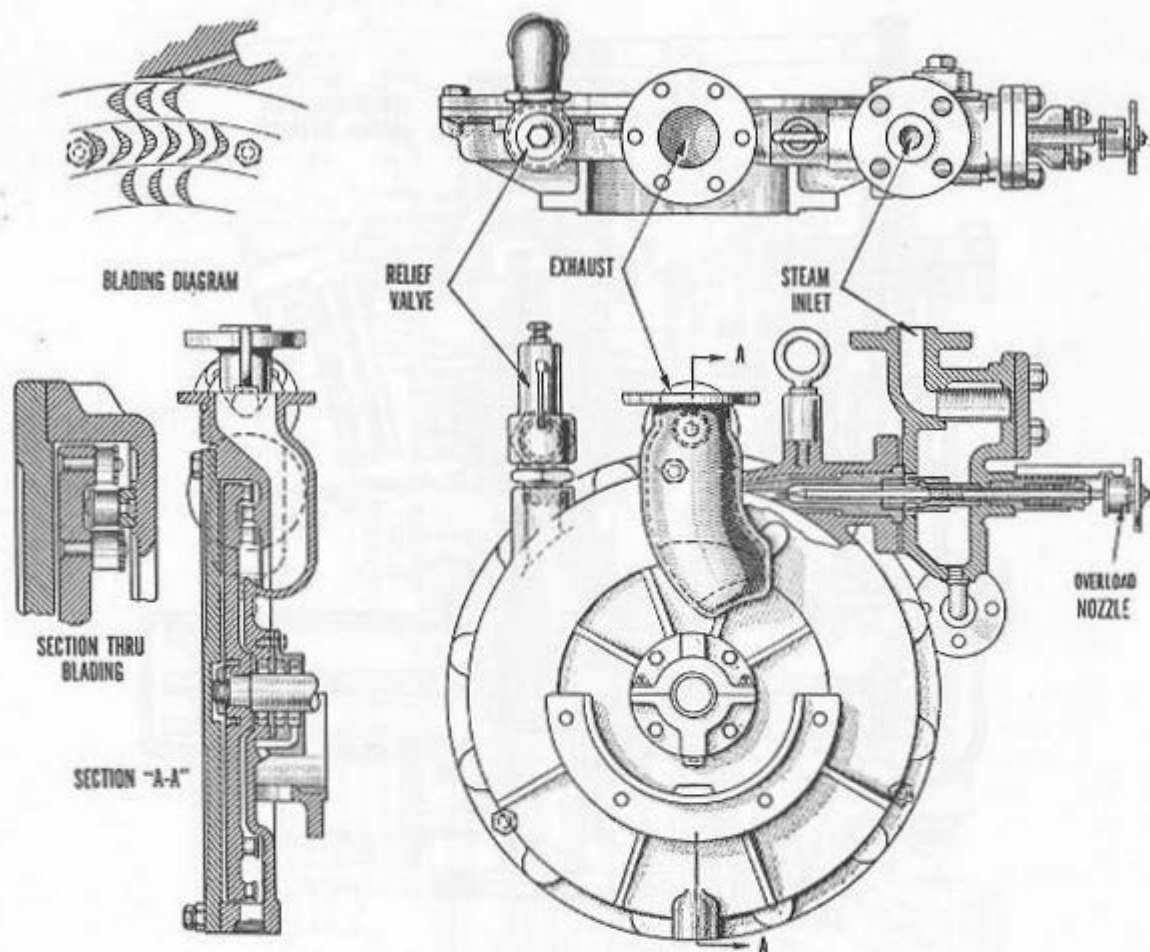


Figure 5-15.—Main lube oil pump turbine.

47.9X

with the upper main bearing, carries the weight of the rotating element, and absorbs any unbalanced downward thrust. A throttle valve and a double-seated balanced inlet valve (normally held wide open by a governor mechanism) allow the steam to flow into the turbine.

Generator Turbines

Figure 5-17 shows a turbine used to drive a 400-kilowatt a-c, 50-kilowatt d-c, generator. The turbine is an axial flow, pressure compounded impulse type. It exhausts to a separate auxiliary condenser having its own circulating and condensate pumps and air ejector. Cooling water for the condenser is provided by the auxiliary circulating pump, through separate injection and overboard valves. In case of casualty

to the auxiliary condenser, the turbine may exhaust to the main condenser, when the main plant is in operation.

A relief valve is always installed on the turbine exhaust casing to relieve excess pressures which would build up within the turbine casing if for some reason the exhaust steam should be inadvertently closed or a loss of vacuum should occur.

The turbine is designed to operate on either saturated or superheated steam at a pressure of 525 psi, and at a maximum temperature of 825° F at the throttle. Provision is made for supplying steam to the turbine from either the main steam line (superheated) while underway, or the auxiliary steam line (saturated) during in-port operation, when the main engines and main steam lines are secured. The steam is

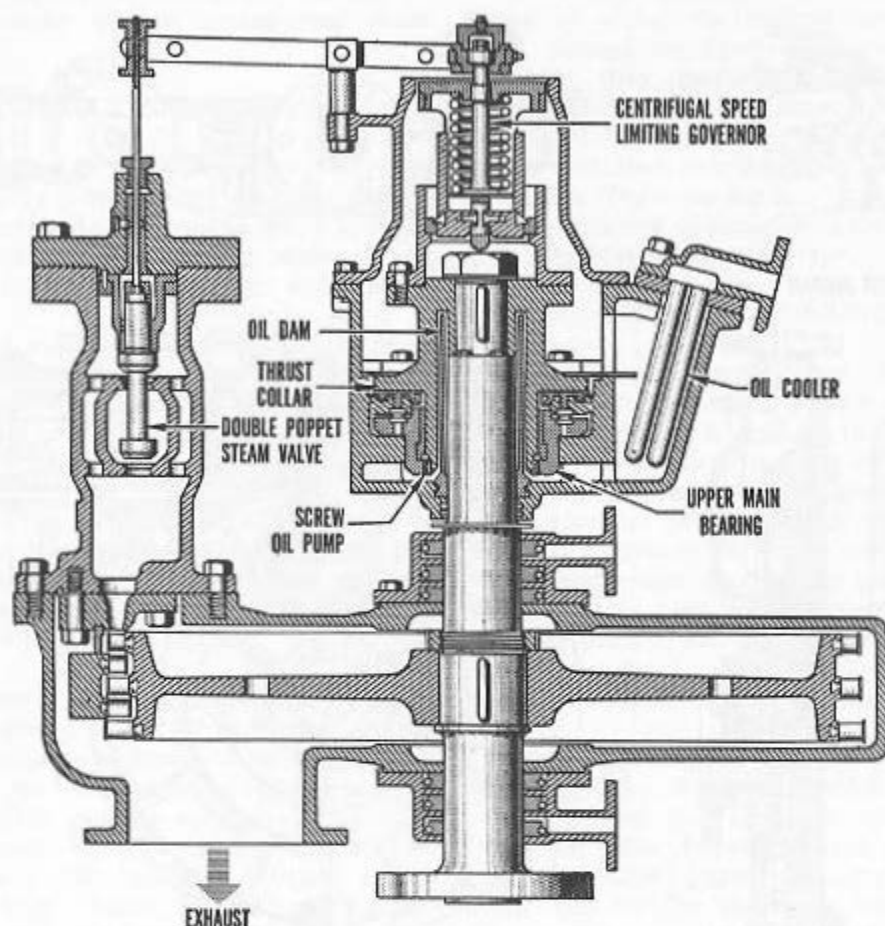


Figure 5-16.—Main condenser circulating pump turbine.

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admitted to the turbine through a throttle trip valve to the steam chest—the speed being regulated by a number of nozzle control valves under the control of a governor.

Generator turbines vary greatly. Detailed information concerning a specific unit can be obtained from the manufacturer's technical manual.

ENGINEROOM OPERATING PROCEDURES

The information in this section deals primarily with operating procedures for steam-driven propulsion machinery fitted with reduction gears and motor-driven turning gear. The steam-driven propulsion installations, in the Navy, vary to such an extent that only general information is given here. Even though the information

which follows can serve only as a general guide, the information will be helpful to you as you learn or review the steps to be followed in operating steam-driven propulsion equipment. In addition to studying the material in this section, you must become familiar with those manufacturers' technical manuals which apply specifically to each main turbine and auxiliary unit installed on your ship, official trial data, and standard operating procedures. From these sources of information, the engineer officer can prepare and issue orders pertaining to the operation of the installation under his charge.

The engine room operating procedures which follow, include the steps usually taken in operating geared turbine installations on ships with two engine rooms.

Information related to certain steps in the procedures will be given later in this chapter.

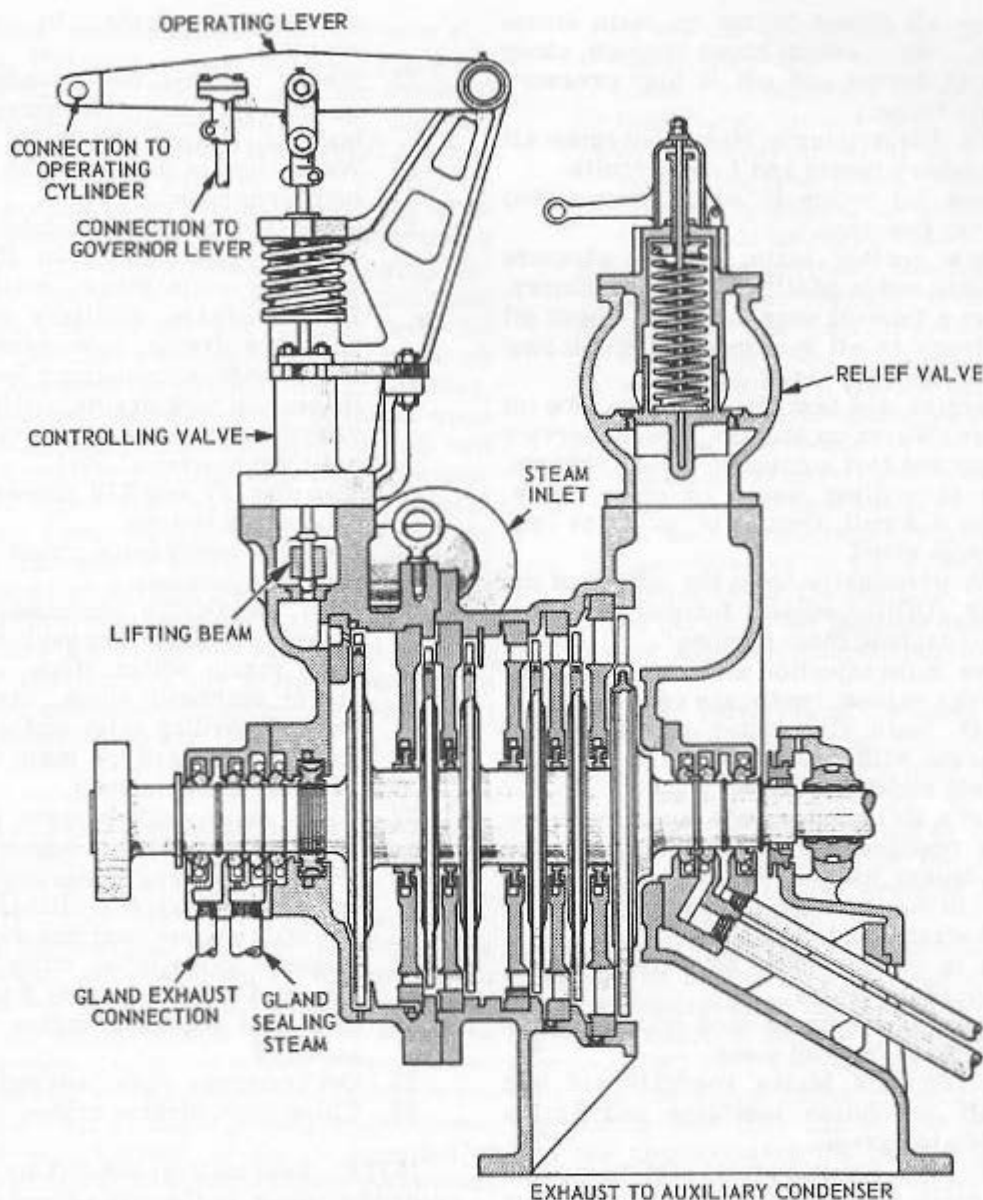


Figure 5-17.—Ship's service generator turbine.

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PREPARATIONS FOR PLACING PLANT IN READINESS FOR GETTING UNDERWAY

A general checkoff sheet or table of instructions to be followed in getting a turbine installation ready for getting underway is usually provided on each ship. These instructions and the specified times of accomplishment of various items will differ from ship to ship in accordance with the type of installation and with the

instructions issued by the engineer officer. The steps included in the following list are representative of those to be taken in placing a geared turbine propulsion plant in readiness for getting underway.

1. Take and record turbine clearances, enter in log specifying cold readings.
2. Back off throttle valves and reseal lightly.
3. Operate hand nozzles.

4. Open all funnel drains on main steam line. (When steam blows through, close funnel drains and cut in high pressure drain traps.)
5. Have Electrician's Mates energize all necessary power and I. C. circuits.
6. Check oil levels in sump, pumps, and spring bearings.
7. Check cooling main, ensure adequate cooling water to all auxiliary machinery.
8. Start a lube oil service pump. Check oil delivery to all bearings and check lube oil system for leaks.
9. Energize and test low pressure lube oil alarm. Warm up standby lube oil service pump and test automatic cut-in devices.
10. Cut in cooling water to stern tubes, allow a small amount of water to leak through gland.
11. With permission from the officer of the deck (OOD), engage turning gear and start jacking main engines.
12. Open main injection and overboard discharge valves, vent main condenser.
13. Start main circulating pump. Do not operate with less than 125 to 150 psig steam chest pressure.
14. Start a main condensate pump, recirculate condensate through the air ejector condenser back to the main condenser.
15. Cut in steam to main turbine gland seal and start gland exhaust fan.
16. Cut in steam slowly to second stage of main air ejectors.
17. Warm up one main feed booster pump and one main feed pump.
18. Electrician's Mates energize and test shaft revolution indicator and engine order telegraph.
19. Shift from emergency (in port) feed pump to main feed pump. (Place emergency feed pump in standby condition.)
20. Open wide the bypasses on the main steam bulkhead stop and main engine guarding valve.
21. Start warming up the main steam line by cracking open the main steam boiler stop valve bypass.
22. Open the drains from the whistle and cut in steam to whistle slowly.
23. When main condenser vacuum reaches 20 inches, shift auxiliary exhaust and low pressure drains to main condenser.
24. Have Electrician's Mates test steering engines and anchor windlass. Report results of tests to main engine control.
25. Warm up and test standby auxiliary machinery: condensate pump, main feed booster pump, and main feed pump.
26. Warm up an additional ship's service turbogenerator.
27. When the required number of boilers are on the line, split the following systems: main steam, auxiliary steam, 150 psi steam, auxiliary exhaust, high pressure drains, low pressure drains, main condensate, makeup feed, firemain, inspection tank drains, and (if applicable) turbogenerator steam. Parallel and then split the electrical load.
28. Man the 1JV and 2JV phones in all main propulsion spaces.
29. Request permission from the OOD to test main engines.
30. With the OOD's permission, stop and disengage the turning gear, open wide the main steam boiler stops, and the main steam bulkhead stops, open the main engine guarding valve and cut steam into the first stage of the main air ejectors.
31. Test the main engines.
32. When main engines have been tested, report engineering department readiness for getting underway to the OOD and to the engineer officer. Open wide the main engine guarding valve.
33. Request permission from the OOD to spin main engines every 3 to 5 minutes.
34. Take and log main engine "hot clearances."
35. Get underway when ordered.
36. Close main turbine drains.

NOTE: Information related to some of the preceding steps in the procedures for warming up the main plant is identified as a step number (step 1), and is given for cross-reference.

For details on taking turbine clearances (step 1), refer to either the manufacturer's technical manual for the specific installation or BuShips Technical Manual, NavShips 250-000.

Steps 6, 8, and 9 deal with lubrication and the main plant lubrication system. This type system (forced-feed) is used for lubrication of main turbines and reduction gears, turbogenerators, feed pumps, and other auxiliary machinery, and in some internal combustion engines.

Each engine room lube oil system is arranged for independent operation, and generally there

is no service connection provided between engine rooms. The main engine lubricating system includes a purifier, whereas smaller systems must be periodically drained of oil (as the crankcase of an automobile is drained) and replenished with new or purified oil.

When preparing to get underway, the first step in connection with lubrication is to check the amount of oil available. A float gage indicates the oil level (in gallons) in the main engine sump. Dip sticks are used to check the oil level in auxiliary machinery sumps and spring bearings. The need for cleanliness, at all times, in the operation of lubricating systems must be constantly kept in mind. Lubricating oil will lose its lubricating qualities if it is contaminated; if the impurities (water or other foreign matter) are removed, the oil can be used over and over. The entire lubrication system must be given constant careful attention to ensure that the oil is kept free of foreign matter.

Each time a lubrication system is put into operation, all parts of the system must be in satisfactory operating condition; to ensure that it is, proceed as follows:

- a. Take and record the oil level. Ensure that 2190 TEP oil is used.
- b. Inspect and clean strainers.
- c. Start a lube oil service pump and maintain the designed pressure throughout the system. Automatic cut-in devices for all lube oil service pumps should be tested. Motor driven pumps should be tested on alternate sources of power. Turbine driven pumps should be operated satisfactorily on their constant pressure governors.
- d. The temperature of the oil supplied to the main engines and reduction gears must be at least 90° F before the unit is turned over. If the oil is below this temperature, it can be heated by use of the purifier heater or by use of the auxiliary exhaust connection to the lube oil cooler, if fitted.
- e. Do not admit cooling water to the lube oil cooler until the oil is 115° F. However, an adequate supply of cooling water must, at all times, be available to the lube oil cooler. When the cooler is put into use, open wide the cooling water inlet valve, open the cooling water vent valves until all air is expelled, then close the vent valves, and regulate the temperature

of the oil by opening or closing down on the cooling water outlet valve.

- f. Inspect all pressure gages and sight flow indicators. Ensure that there is an adequate supply of oil at each bearing and reduction gear spray nozzle. Inspect the lubricating system for leaks. Any trouble found must be corrected.
- g. Test the emergency cooling connections, usually from firemain, if fitted.
- h. Test the low lube oil pressure alarm by decreasing the oil pressure until the alarm sounds. If the alarm does not sound at the proper pressure, remedy the defect at once, and retest.
- i. While underway, draw a sample of oil at least once each watch, from the strainer in use, to determine whether any water has collected in the system. To test the operation of the purifier, draw a sample of oil from the purifier test cock. Check for water or other impurities.

Step 11. Never turn the main engines over without permission from the OOD. A ship's propeller (screw) may hit a boat, barge or some other floating object or a mooring line or wire may be in a position to foul the screw. The OOD will ensure that the area near the screws is clear before granting permission to turn the main engines.

Step 13. When operating in cold water, standing by, or steaming at slow speeds, the cooling water requirements for the main condenser are greatly reduced. However, the main circulating pump **MUST NOT** be operated with less than 125 to 150 psi steam chest pressure. At a steam pressure less than 125 to 150 psig, the speed of the pinion-driven oil pump will not be high enough for the pump to deliver an adequate supply of oil to the lubrication system of the driving unit.

Steps 15 and 16. Never cut in gland sealing steam until the turning gear is engaged and started. The gland exhaustor and the second stage of the main air ejector should be placed in operation just prior to, or simultaneously with, the admission of gland sealing steam. The first stage of the main air ejectors should not be placed in operation until after the turning gear has been disengaged.

Steps 19-21. When the steaming boiler is receiving feed water from the main feed pump, the auxiliary or emergency feed pump may be placed in a standby condition. In the event of

a main feed casualty, the emergency feed pump is ready for immediate use and can prevent a boiler casualty.

Under normal warming-up conditions, the main steam stop bypass valve should not be opened until the main feed pump is feeding the boiler. This reduces the load that would otherwise be put on the emergency feed pump.

The procedure for warming the main steam line will vary from ship to ship. On most combatant ships the procedure is as follows:

- a. Open (1 to 1 1/2 turns) the low pressure (funnel) drain valves.
- b. Open the bypass valves on the main engine guarding valve, the bulkhead or line stop valve(s), and the main steam split-plant valve.
- c. Crack open the bypass valve on the main steam boiler stop valve.
- d. When the pressure in the main steam line reaches 50 psig, cut in the high pressure drain traps and secure the low pressure (funnel) drains.
- e. When the plant is split, secure the bypass on the main steam split plant valve.
- f. When permission has been granted to test main engines, open the main steam boiler stop valve and the line or bulkhead stop or stops. The turning gear must be stopped and disengaged before the main engine guarding valve is opened. Open the guarding valve ONLY 5 TURNS; this serves as a safety measure in the event that a casualty occurs. For example, if a nozzle control valve sticks open while the main engines are being tested, the main engine guarding valve can be closed very quickly from the 5-turn position. After the engines have been tested, and before getting underway, open the guarding valve completely.

Warming Up The Main Turbines

In warming up a turbine it is well to remember that the rotor and the casing must be evenly heated; otherwise, unequal expansion will take place and will produce distortion of the rotor or the casing or both. The results of such distortion are not as noticeable in small turbine installations as in large installations; however, the cumulative effect of distortions due to temperature change and unequal expansion is very noticeable, and unless extreme care is

taken, serious damage, such as rubbing of blades or packing, will result.

If an unusual noise is detected, the turbine should be stopped immediately in order to prevent damage to the installation. No unusual sound is so trivial that it can be neglected. A listening rod will be helpful in detecting faint or indistinct sounds. Additional information concerning unusual noise is covered in the section dealing with casualties.

Two procedures are used in the warming up of a turbine: jacking the turbine; and spinning the turbine. The jacking procedure is used during a normal warming up; the spinning procedure is used when the ship is standing by to get underway and after the turning gear has been disengaged.

JACKING THE MAIN ENGINES.—During warming up or cooling off of the turbine, the rotor must not be permitted to remain at rest for any appreciable time while gland steam is being admitted to the turbine. The turning gear should be put into operation to roll the turbine rotor before steam is admitted to the turbine glands. In an installation equipped with turning gear, the turbine may be turned by steam during an emergency only after sealing steam has been admitted to the turbine glands for at least 15 minutes, and the turning gear has been disengaged.

SPINNING THE MAIN ENGINES.—After the main engines have been tested satisfactorily and while you are waiting to answer bells, the main engines must be turned by steam. The engines are spun astern and then ahead, to prevent putting way on the ship. Spinning the engines by steam not only heats the turbines and their casings, but also prevents the rotors from becoming bowed.

The spinning procedure consists of admitting steam to the turbines by opening the throttle quickly and then closing it immediately. This procedure will start the rotor turning more quickly than will a slight, steady supply of steam; uneven heating of the rotor is less likely to occur. It is preferable to open the astern valve first as any condensate in the piping will be discharged through the large nozzles and fewer rows of astern turbine blading, instead of through the ahead element. Be sure that the main steam line is drained of all condensate before spinning.

After the turbines have been tested astern, repeat the process immediately with the ahead throttle. It is important that sufficient steam

be admitted to start the turbine rolling immediately, without putting way on the ship. For high speed turbines driving double reduction gears, this procedure should be repeated every 3 to 5 minutes, or at more frequent intervals if necessary to properly warm up the turbine.

Procedure Prior to Turning Over

Main Turbines

The main steam line must be warmed up slowly and thoroughly drained to prevent leaks at the joints and to preclude the danger of water hammer. Full boiler-pressure must not be permitted on the main steam lines up to the throttle until the lines have been properly drained and warmed up.

The preferred method of warming up main steam lines consists of warming the line to the bulkhead stop valve. Pressure is then built up in the throttle lines by means of the bulkhead-stop bypass.

An alternate method of warming up the steam lines, not equipped with bypasses, and the throttle lines is to crack the boiler and bulkhead-stop valves, and then permit the pressure to the throttles to build up slowly.

Use of Air Ejectors

The air ejectors should be placed in operation just prior to, or concurrent with, the admission of sealing steam to the turbine glands. The second-stage air ejector should be used during the warming up period. The first stage must be put in operation prior to turning the engines with steam and reporting the department ready for getting underway.

PROCEDURES FOR STANDING BY

When orders are received to stand by, the procedure to be followed will depend on the length of time that the ship is to remain in "standby" condition.

Standing By Indefinitely

When a ship is standing by for an indefinite period of time, the condition of the main propulsion plant will depend upon how much time has been allowed to change from "stand by" condition to "ready to answer bells" condition. The principal variations will be in the number of boilers left on the line, the number of auxiliaries in use, and whether or not the plant will be cross-connected. If the ship is standing by for an hour or more, the following steps may be taken:

1. Close the main engine guarding valve.
2. Secure the first stage of the main air ejectors.
3. Engage and start the turning gear.
4. Cross-connect the main plant and secure all boilers that are not necessary. (On a large ship having four screws, a two-plant setup may be used; the two forward plants cross-connected with one boiler steaming and the two after plants cross-connected with one boiler steaming. In this setup, the systems will remain split between the two forward plants and the two after plants. On a destroyer, or other small ship, only one boiler is necessary.)
5. Use one lube oil service pump in each engineroom, maintain the required lube oil pressure to the bearings and reduction gears.
6. Maintain the required lube oil temperature.
7. Maintain the gland sealing steam at 1/2 to 2 psig.
8. Run the main circulating pump, using the prescribed steam chest pressure.
9. Use one main feed booster pump and one main feed pump to feed the steaming boiler.
10. Close the main steam boiler stop valve on the steaming boiler; open the main steam bypass valve. (If the turbogenerators receive steam from the main steam line, the main steam boiler stop valve will remain open.) Every effort should be made to operate the plant economically, the main feed pump discharge pressure can be lowered to about 75 psig higher than boiler operating pressure. Drain valves from the main steam line and main engines should be cracked open; however, do not open low pressure funnel drains excessively, because this wastes feed water. Causes high fuel oil consumption, and raises the temperature of the engineroom.

Standing By On Thirty-Minute Notice

When a ship is standing by with orders to get underway in thirty minutes, the following steps may be taken:

1. Close the main engine guarding valve.
2. Engage and start the turning gear.
3. Secure the first stage of the main air ejectors.

NOTES ON TURBINE OPERATION

Underway procedures must be carried out in a manner that enables the ship to accomplish its mission with the greatest operating economy possible. Economical and efficient operation of a propulsion plant, under varying conditions and speeds, necessitates the maintenance of a proper vacuum and the proper use of the cruising and maneuvering combinations.

Importance Of Proper Vacuum

In order to attain the greatest operating economy, the vacuum for which the turbine was designed must be maintained. Therefore, you should realize the necessity for the prevention and detection of air leaks in the vacuum system.

When the steam pressure within the turbine is greater than atmospheric pressure, steam tends to leak out of the turbine to the surrounding atmosphere. On the other hand, when the pressure in the turbine is less than that of the atmosphere, air tends to leak into the turbine and impair the vacuum. To prevent air leakage into the turbine and steam leakage from the turbine, steam is led to the glands and the pressure on the glands is maintained slightly greater than that of the atmosphere, generally 1/2 to 2 psig.

To ensure that the proper vacuum will be maintained, care must be taken that the astern throttles do not leak; any leakage of steam past a closed throttle tends to raise the temperature and to increase the pressure within the turbine.

If the following precautions are observed, there will be little difficulty in maintaining the prescribed vacuum:

1. Gland packing must be kept in good condition.
2. A steam pressure between 1/2 and 2 psig must be maintained on the glands when the turbines are in operation.
3. There must be no air leaks in the condenser, exhaust trunks, throttles, lines to air ejectors, gage lines, idle condensate pump packing and valves, and makeup feed lines.
4. Adequate water must be maintained in the feed tank on which the vacuum drag is being taken to replenish feed water.

Cruising Combinations

A combatant ship operates most of the time at speeds far below the maximum; at cruising

speeds, therefore, there is required only a fraction of the power for which the main turbines are designed. Operating economy at these lower speeds is attained (1) by the use of cruising turbines, specially designed to operate at reduced speeds, or (2) by the use of cruising stages in the high pressure turbines, and (3) by arranging the turbines so that they can be run in series. The cruising combinations should be used whenever the standard speed is such that the combination can furnish the required number of revolutions.

Protection Of Cruising Turbines

Protective devices and indicating instruments are required to prevent casualties to cruising turbines. Devices and instruments installed on cruising turbines for this purpose include sentinel valves, relief valves, retard-compound gages, direct reading thermometers, and thermal alarms. When the high pressure turbine combination is in use, cooling steam is supplied from the high pressure turbine to the cruising turbine. The cooling steam prevents the cruising turbine blading from overheating due to the friction of rotation.

When a ship is operating on cruising turbine combination, the following precautionary measures should be taken at frequent intervals to prevent casualties to the cruising turbine.

1. Be sure that the crossover valve is fully shifted to the proper combination.
2. Check the retard-compound gage to be sure that the safe operating pressure is not exceeded.
3. Check the sentinel valve frequently. If there is steam blowing from the sentinel valve, the safe operating pressure is being exceeded.

Turbine Vibration

If a turbine begins to vibrate as its speed is increased, the turbine should be slowed down immediately. If the vibration ceases at a lower speed, maintain that speed for several minutes; then attempt to build up the speed again. If no further vibration is noted, it may be assumed that the trouble was probably due to unequal heating of the rotor. If the vibration does not cease at a lower speed, the turbine must not be used, except in an emergency, and steps must be taken immediately to locate and remedy the trouble. If, after the turbine has been running at a reduced speed for some time, the vibration

again occurs at the higher speed, a speed limit lower than that at which vibration occurs must be set; and this reduced speed must not be exceeded until the trouble has been eliminated.

Use of Nozzles

In most turbine installations, the flow of steam to the cruising and high pressure turbines is controlled by cam-operated nozzles or lifting-beam valves. These valves are mechanically connected so as to open and close in the proper sequence. In some older installations, however, steam flow to the nozzles is controlled by the manual operation of individual control valves.

It is essential that the pressure in the steam chest be kept as high as practicable. This high pressure allows for greater steam expansion and a resulting increase in the useful work obtained from the steam. The fewer the nozzles in use, the higher will be the chest pressure; therefore, it is essential that installations which are fitted with individually operated nozzle valves be operated (at either low or high speeds) with the minimum number of nozzles required to obtain the desired speed. Adjacent nozzles should be used to ensure uniform stresses in the turbine blades, and the nozzle valves in use must be opened wide. The nozzle valves not in use must be tightly closed; otherwise, the resulting steam leakage will reduce turbine efficiency and cause wire drawing to the valve seats.

Turbine Blade Clearance

In an impulse turbine, the axial distance of the moving blades from the casing or the stationary blades is known as the axial blade clearance. This clearance may be determined by means of a finger piece, a rotor-position micrometer, or a clearance indicator.

A ready visual check on the fore-and-aft position of the turbine rotor may be obtained from the FINGER PIECE. In most cases, the finger piece consists of an indicator fastened to a plate which is secured to the turbine case. The indicator extends almost to the shaft. Usually three lines are scribed on the shaft to show the normal position and the maximum positions. In some cases, however, the indicator extends into a groove in the shaft; in these cases, the distance from the indicator to the shaft shoulder may be measured with feelers to determine fore-and-aft clearance.

The axial position of a turbine rotor may be determined with a ROTOR-POSITION MICROMETER. This instrument can be used when the rotor is either revolving or at rest. The micrometer is mounted at the forward end of the turbine shaft, with the spindle in line with the centerline of the shaft. When the micrometer is being used, the spindle contacts the end of the shaft at the center. The reading obtained is compared with established limits to determine if the position of the shaft is satisfactory. Care must be exercised to prevent the end of the micrometer spindle for becoming worn by long or hard contact with the rotating shaft.

In some installations, the axial blade position of a turbine rotor is determined with a ROTOR POSITION INDICATOR. The indicator may be used when the turbine is in operation. The instrument consists of a scale plate and an indicator, mounted within a bracket which is bolted to the turbine casing. The scale plate has scribed lines showing the normal position (midposition) and the maximum and minimum positions. One end of the indicator is made in the shape of a pointer, and a roller or contact surface is mounted on the other end. The indicator operates on a pivot. To take a reading, it is only necessary to press the arm of the indicator so that contact is made between the shaft and the roller, and then note the position of the pointer on the scale.

ROUTINE UNDERWAY INSPECTIONS

Periodic inspections of the propulsion plant must be made if the plant is to be kept operating efficiently. When a ship is underway, the following items should be checked or inspected at frequent intervals during each watch:

1. Check all main engine and reduction gear bearing thermometers to detect signs of overheating.
2. Check oil sight-flow indicators for proper oil flow.
3. Check clearance indicators for proper rotor position.
4. Check all thermometers, pressure gages, and vacuum gages.
5. Check the oil level in the main sump.
6. Maintain the proper water level in the deaerating feed tank.
7. Keep a constant check on salinity indicators.

8. Check the lube oil temperature from the lube oil cooler, maintain oil temperature at 120° F to 130° F.

9. Check the cooling water main for proper pressure.

10. Constantly be on the alert for unusual sounds and vibrations.

11. Each watch, clean lube oil and bilge strainer.

Usually, the first indication of bearing trouble will be a rise in temperature. There is no objection to a bearing running warm, provided the temperature reached is not sufficient to harm the bearing. What must be guarded against is a rapid rise in temperature and an increase over the normal operating temperature. If the bearing temperature increases above normal, the quality and quantity of lubricating oil must be checked. If possible, increase the supply of oil to the bearing and increase the flow of cooling water through the oil cooler. If these measures do not reduce the bearing temperature, the unit must be slowed or stopped.

A sight-flow indicator is fitted in the lube oil line of each main engine bearing and each reduction gear bearing. When a lube oil service pump is in operation each indicator should show a steady flow of lube oil. Frequent inspections of the sight-flow indicators should be made in order to detect any interruption to the flow of lube oil.

Each hour, the rotor-position indicator for each turbine is checked and the rotor position logged to help determine the position of the rotor in respect to the casing. Any abnormal reading must be thoroughly investigated. Should the rotor move sufficiently for the moving blades to strike the stationary blades or nozzles, great damage would result.

One of the first indications of engineroom trouble is an abnormal reading on a thermometer or gage. All thermometers and gages must be checked frequently to detect and prevent casualties. It should never be taken for granted that an abnormal reading is due to the fault of the gage or thermometer. The accuracy of a gage or thermometer may be easily checked by replacing it with one that has been recently calibrated.

Each hour, the oil level in the main engine sump is to be checked and logged in the main engine operating record. However, more frequent checks should be made. An increase in the oil level generally means that water is entering the lube oil system or that the system is gaining

oil in some improper manner. The lube oil purifier may be lined up wrong. A decrease in the oil level of the main engine sump usually indicates a leak in the lube oil system or that the lube oil purifier is discharging oil through the impurity discharge. An increase or a decrease in the main sump oil level should NEVER be neglected. It could result in a temporary loss of a main engine, or even costly repairs to main engine bearings and reduction gears.

For safe efficient operation, the water level in a steaming deaerating feed tank should be kept between the minimum and maximum levels. If the water level is allowed to go above maximum, the deaerating effect is lost. Admitting large quantities of comparatively cold water to the deaerating feed tank will reduce the pressure in the tank. This reduces the main feed booster pressure which may result in casualties to the main feed pump and boiler.

If the water level is below minimum, a sudden demand for feed water for the boilers may empty the deaerating feed tank. This may well result in casualties to the boiler, the main feed booster pump, and the main feed pump.

A salinity indicator is located on or near the throttle board in each engineroom, to detect the entrance of salt water into the condensate system. The indicator must be constantly checked as a small amount of salt in the condensate system will contaminate a steaming boiler beyond allowable limits. An abnormal reading (0.1 ppm or above) must be checked and the source of contamination eliminated. More information on salinity indicators may be found in chapter 9580 (58), BuShips Technical Manual, and in the appropriate manufacturer's technical manuals.

A properly operating main engine and reduction gear installation has a definite sound which trained personnel can recognize. Any abnormal sound should be investigated and the unit operated with caution until the cause is found and remedied.

PREPARATIONS FOR ANCHORING AND SECURING

After the control engineroom has been notified as to the time the ship will enter port, the necessary preparations must be made to secure the main engines. Personnel should be notified and given specific instructions for setting up the inport auxiliary watch. The auxiliary machinery

to be used in port must be placed in operation, the deck machinery used in anchoring must be tested and numerous other tasks must be accomplished.

Setting Sea Detail

On installations where the turbogenerators exhaust to either the auxiliary or the main condenser, the following procedure should be followed in setting sea detail:

1. Man the 1JV and 2JV sound-powered telephone.
2. Put the auxiliary condenser in operation, shift the turbogenerator exhaust from the main condenser to the auxiliary condenser.
3. Start the standby turbogenerator parallel and then split the electrical load.
4. Warm up the main circulator. (Open the turbine exhaust valve, close the turbine casing drain when steam blows through, and drain the steam supply line.)
5. If not already done, split the plant as ordered by the engineer officer. Start the main circulating pump (when necessary).
6. Open turbine drains on the first stop bell.

Securing Main Engines

Each ship has its own detailed form for securing main engines. The following checkoff list (engineroom only) is given as an example.

1. Secure the throttle valves and close the main engine guarding valve. Close the main steam boiler stop valve and drain the main steam line.
2. Secure the first stage of the main air ejector.
3. Engage and start the turning gear.
4. Cross-connect the plant.
5. Shift the electrical load to the generator designated for in-port use and secure the standby generator.
6. Shift the high pressure drains, low pressure drains, and the auxiliary exhaust to the steaming engineroom.
7. Secure the following standby pumps:
 - a. Lube oil service pump.
 - b. Main feed pump.
 - c. Main feed booster pumps.
8. Start the auxiliary feed booster pump (if installed) and the emergency feed pump.
9. Secure the main feed pump and then the main feed booster pump.

10. Shift the auxiliary exhaust and low pressure drains to the auxiliary condenser.

11. Secure the second stage of the main air ejectors.

12. Secure gland sealing steam (when main condenser vacuum drops to 10 inches of mercury).

13. Secure main circulating pump when the exhaust trunk temperature drops to near room ambient temperature. Close the main injection and overboard valves.

14. Stop and disengage turning gear. (Time will depend on type of ship.)

15. Secure lube oil service pump and drain waterside of oil cooler.

16. Close all throttle, root, exhaust, and drain valves not in use. Secure all unnecessary vents and turn out all unnecessary lights.

17. Report main engines secured to the engineering duty officer.

18. Twenty-four hours after securing, close turbine and steam line drains.

As previously stated, operating procedures vary from ship to ship. The information given in this chapter is general. For example, in step 14 of the securing schedule, no specific time can be given for securing the main circulating pump. On a World War II destroyer, the time may be one hour; while on a Forrestal class carrier, the main circulating pump may be run 18 to 24 hours after the main engines are secured. For any particular ship the best sources of information are the ship's warming-up schedule, operating instructions, securing schedule, and specific instructions issued by the engineer officer.

CASUALTIES WITH TURBINE INSTALLATIONS

When a casualty occurs to any part of the main plant or to vital auxiliaries, the importance of continuous operation of the ship's propulsion plant should be the first consideration. Standby machinery must be started before any search is made for the cause of the trouble. The engineering officer of the watch must be notified as soon as practicable; he, in turn, must notify the officer of the deck, if the maneuverability of the ship will be affected by the casualty.

The information which follows is supplementary to that given in the section dealing with engineroom operating procedures.

VIBRATION AND/OR UNUSUAL NOISE IN TURBINE

Abnormal vibration in an operating turbine may usually be traced to one of the following:

1. Water in the turbine.
2. Bearing failure.
3. Bent or broken propeller blades.
4. Broken or missing turbine blades or rubbing of blades.
5. Rubbing of carbon packing, labyrinth packing, or oil seal rings.
6. Bowed rotor.
7. Excessive differential expansion of rotor and casing.

If a rumbling sound is heard from the turbine when it begins to vibrate, the trouble is probably due to water or foreign matter in the turbine. Water in the turbine casing may be caused by either boiler priming or improper casing drainage. The turbine should be immediately slowed down until the abnormal noise disappears. If, after slowing down, correcting boiler operation and checking casing drains, the vibration still exists, the turbine shall be shut down and the interior of the turbine shall be inspected at the earliest opportunity. If a sharp metallic sound is heard after the rumbling noise, it may be assumed that the thrust bearing has failed and part of the blading has been damaged.

When bearing troubles occur, the turbine should be slowed then stopped as soon as practicable to prevent damage to the turbine. The bearings should be inspected, and replaced or repaired as necessary. The cause of the trouble should be determined and appropriate steps should be taken to prevent similar troubles from occurring.

Rubbing of labyrinth or carbon packing or oil seal rings is usually caused by one of the following:

1. Bad bearings.
2. Bowed rotor.
3. Improper installation of packing rings or oil seals.
4. Excessive differential expansion of rotor and casing.

Rubbing of shaft packing or oil seal rings will cause the shaft to overheat in the rubbing area, due to friction; and the shaft will start to show heating discoloration. An immediate inspection should be made to determine the cause of the trouble. If defective bearings are found, they should be replaced. A bowed rotor can be

straightened by operating (heating) the turbine rotor at low speeds. The shaft packing or oil seals may require refitting or renewal to give proper clearances.

It is also possible for the gland sealing system to cause the seal casing to become "egg" shaped and to cause vibration. This occurs when the turbine is operating self-sealing and is slowed to a point where external gland sealing steam is required. When the engine is operating self-sealing, moisture collects in the external gland seal supply piping if it is not draining properly. When the external gland seal supply valve opens, the accumulated condensate is forced into the shaft seal area, causing rapid cooling and distorting this area. The problem can be prevented by proper drainage of the gland seal line.

When rubbing of turbine blading occurs, the cause will probably be a bowed rotor, a defective thrust bearing assembly, a wiped journal bearing, foreign material inside the casing, or differential expansion of turbine rotor and casing. When a rubbing noise in a turbine is heard, the turbine should be stopped immediately and the cause of trouble determined.

When warming up a turbine, or after a turbine has been warmed up, a vacuum shall not be maintained on the turbine unless the glands are properly sealed. Air leaking in along the shaft, particularly when standing still, tends to cause distortion of the shaft and rotor. If the rotor becomes distorted while standing by, close the drains to the condenser and bring the pressure of the gland steam to between 1/2 and 2 psi above atmospheric pressure, and spin the rotor alternately astern and ahead.

Foreign matter may enter a turbine casing through a defective steam strainer, or because of improper protection of a turbine that has been opened for inspection or repair. When any part of a turbine has been opened, the greatest care shall be exercised to prevent the entry of foreign matter. Inspection plates shall not be left off overnight, or for any length of time unless the openings are well covered. Before reassembling a turbine after it has been opened, a very careful examination shall be made of the rotor and interior of the casing for any articles left behind. An examination shall be made before the rotor is lowered in place, and another examination made before the casing cover is lowered in place.

Another cause of vibration in the turbine is bent or broken propeller blades. Normally, this condition is first indicated by excessive

vibration of the main shaft and by a lesser vibration in the main reduction gears. When these conditions exist, the main turbines should be slowed until the noise and vibration stops or is within safe limits. An immediate inspection should be made to determine the cause of vibration.

If vibration of the turbine is caused by bent or failed turbine blading, the turbine should not be used until effective repairs can be made by experienced personnel.

LUBRICATING OIL FAILURE

Even a momentary loss of lubricating oil flow will result in localized overheating; it may result in wiping of one or more bearings. Continued operation with wiped bearings can cause serious derangement to the shaft packing, the oil seals, and the turbine blading.

Loss of lubricating oil pressure may be caused by:

1. Failure of the lubricating oil system, including the main lubricating oil pumps.

2. Failure of the power supply to the main lubricating oil pumps.

Failure of the system may be caused by the presence of dirt, rags, or other foreign material; by a piping failure; or by failure of the operating pump, coupled with failure of the standby pump to start.

Standby lubricating oil pumps should be maintained in a ready-to-start condition, at all times. When automatic starting devices are not provided, steam driven pumps should be lined up so that the opening of the throttle valve is the only action required to start the pump. Steam-supply lines to the pump should be kept thoroughly drained. When operating installations which are equipped with electrical pumps, personnel should be thoroughly familiar with the alternate sources of power.

A loss of steam pressure, due to an operational casualty or to battle damage, may be unavoidable. Complete loss of steam pressure, however, can usually be prevented by prompt action on the part of the throttlesman. The throttles must be closed promptly so that the available steam will be conserved for the lubricating oil pumps.

The following general procedure should be followed when a loss of lubricating oil pressure is indicated:

1. If steam pressure is available, close the throttle in use and stop the shaft by means of

the throttle for the opposite direction. Engage the jacking gear and apply the jacking gear brake. If the ship is operating at high speed it may be necessary to reduce the speed before the affected shaft can be stopped. Endeavor to locate the source of any unusual sounds.

2. When steam pressure is lost in the engine room, during split-plant operation, the way should be taken off the ship by backing the other engines, if the tactical situation permits.

3. Concurrently with the action described in the preceding two paragraphs, make every effort to regain lubricating oil pressure. The lubricating oil pumps should be started, if they are not in operation. The oil-sump level should be checked; the strainers should be shifted. Any oil leaks should be located and repaired.

4. Secure the gland sealing steam and the main air ejectors to minimize distortion of the turbine rotors.

After lubricating oil pressure has been regained, the lubricating oil should be circulated until the bearings are sufficiently cool for inspection; circulation should be continued while the shaft is locked, except during the time that bearings are open.

The following should be accomplished prior to operation of the turbine:

1. Reduction gear bearings of the turbine and of the cruising turbine should be thoroughly inspected. Bearing caps should be raised; the shells should be rolled out for inspection.

2. Main reduction gear bearings, accessible without lifting the gear casing, should be thoroughly inspected.

3. Reduction gear bearing thermometers should be removed in order that a check may be made for oil flow from the wells. An absence of oil flow from a thermometer well indicates that the oil passage to the thermometer has been closed.

4. Inaccessible reduction gear bearings should be examined, through the inspection openings, for a flow of babbitt along the shaft.

5. The oil-strainer basket in use should be examined for the presence of babbitt flakes.

6. If the examination of the main reduction gear bearings produces no indications of wiping and only one of the turbine-or cruising-gear bearings is found to be wiped, it may be assumed that the main reduction gear bearings are undamaged.

7. If several of the turbine or cruising-gear bearings are found to be wiped, it is probable that some of the main reduction-gear bearings

are also wiped. Under these circumstances, the shaft should not be operated until such time as a complete inspection of all bearings can be made and the necessary repairs accomplished.

The procedure described in the preceding paragraphs applies when the lubricating oil pressure is lost on an entire system. It does not apply when a local loss of oil, involving one or two bearings, occurs.

Most ships are equipped with turning-gear brakes, or clamps. The following procedure must be followed when it becomes necessary to lock a shaft of an installation which is equipped with turning-gear brakes:

1. Slow ship's speed to one-half power or less. When a limiting speed has been designated by the Naval Ship Systems Command, the ship must be slowed below that limiting speed.

2. Close the ahead throttle; open the astern throttle until the shaft is stopped. Record the astern steam-chest pressure on the stopped-shaft, and the revolutions per minute on all operating shafts.

3. Engage the turning gear; immediately clamp the turning-gear brake.

4. Close the astern throttle slowly.

5. Reduce the superheat to the affected turbine.

The following procedure must be followed when it is desired to unlock the shaft:

1. Bring all operating shafts to the speed which was recorded when the locked shaft was stopped.

2. Open the astern throttle of the locked turbine until the astern steam-chest pressure equals that which was recorded when the locked shaft was stopped.

3. Apply a steady, disengaging force to the clutch lever of the turning gear. Open the astern throttle slowly, until the clutch disengages.

4. Close the astern throttle slowly when the turning gear is disengaged. Release the turning-gear brake.

5. Open the ahead throttle and continue operation. If the shaft has been locked for an appreciable length of time, the turbine rotor may have become bowed; the procedure previously described for straightening bowed rotors should then be followed.

Reduction ratios as high as 20,000:1 are used between the propeller and the turning-gear motor. If the propeller is permitted to turn while the turning gear is connected, the motor will be overspeeded and seriously damaged.

LOSS OF VACUUM

A loss of vacuum may be caused by loss of the gland-sealing medium, insufficient cooling water in the main condenser, air leaks, or improper operation of the air ejectors or the condensate pumps. When the cause is determined, corrective action should be taken without delay.

JAMMED THROTTLE

A balanced throttle valve of the type that is fitted with a pilot valve integral with the main disk may jam if it is opened too rapidly. If the disk is unseated carefully, the valve may then be opened as rapidly as desired. If a main-throttle valve jams or sticks open, either the guarding valve or the bulkhead stop should be closed immediately.

PUMP FAILURE

If a main circulating pump fails, the condenser cooling systems should be cross-connected. In ships fitted with scoop injection, the affected turbines may be warmed up and placed in operation without the main circulator, when the ship's speed is above five knots.

LARGE LOSS OF OIL

If the oil supply begins to fail, all bearings, lines, and tanks, should be examined for leakage. The oil supply should be replenished by striking down oil from the settling tanks. If repairs cannot be accomplished, the affected unit must be secured.

SALTING UP

Condensers are the most common source of saltwater leakage into the feed-water system. In most installations, the condensate normally contains not more than 0.05 ppm of chloride. Any consistent increase above this value is an indication of a leak. A leak should be stopped as soon after it has been detected as operating conditions will permit dismantling the affected unit. The procedures for testing condensers and for repairing leaks will be discussed in chapter 10 of this text.

Whenever the condensate from any condenser contains excessive quantities of chloride, the

quality of the steam from the boilers should be tested. This may be accomplished by testing a sample of water from one of the steam drains. The results of the steam-condensate analysis will indicate carryover of boiler water in sufficient quantity to affect the chloride content of the condenser condensate.

HOT BEARING

Generally a hot bearing may be traced to one of the following causes:

- 1 Improper or insufficient lubrication.
2. Grit or dirt in the lubricant.
3. Bearing out of alignment.
4. Bearing improperly fitted.
- 5 Poor condition of bearing or journal surface.
6. Obstruction in the oil lines.

If the temperature of a bearing increases above its normal running temperature, the quality and quantity of the lubricant supplied to that bearing should be checked immediately. If the trouble is due to improper or insufficient lubrication, and is discovered before the metal has wiped, an abundant supply of lubricant should gradually bring the bearing back to its normal operating temperature. Should the trouble be caused by grit or dirt in the bearing, an increased supply of lubricant may flush out the impurities sufficiently to permit continued operation. The supply of oil should be increased by opening the needle valve, if a needle valve is provided, or by increasing the delivery pressure of the oil pumps, where practicable. The lubricant should be further cooled by increasing the flow of circulating water through the oil cooler. If these measures are not effective, the speed of the unit should be reduced or stopped. Spraying water on a bearing should not be resorted to except in an emergency, as cold

water causes contraction of the bearing, further reducing the clearance.

If the bearings are out of alignment, improperly fitted, or bearings and journals are not in proper condition, the only effective treatment is to operate the turbine at low speed until such time as the proper adjustments or repairs can be made.

The most effective treatment of a hot bearing will probably be the operation of the turbine at low or moderate power. Usually an abnormal temperature in a bearing can be lowered by decreasing the amount of work of the bearing. The temperature of a bearing should never be allowed to exceed 180° F, since the babbitt will become soft and the bearing will wipe.

If bearing temperature reaches 180° F, the turbine should be immediately slowed down. The turbine should be kept turning at a minimum speed to prevent the molten metal from adhering to the journal. When the temperature drops below 180° F, the turbine should be stopped, the main shaft locked, and the lubrication system kept in operation.

Bearing depth gage readings should be taken to determine if any wear of the bearing has occurred. If the readings indicate no wear of the bearing, operation of the turbine at low speeds can be attempted, or the bearing can be disassembled for a complete inspection. Operation of a wiped bearing can result in serious damage to the turbine.

When a bearing overheats, the lube oil strainers should be carefully checked for traces of babbitt. The lube oil should be inspected and the purifier started.

In recent years, the pivoted-shoe bearing has been adapted to journal bearings. If the shoes are properly pivoted, they will have a freedom of motion which permits them to automatically align themselves to the shaft, and yet hold the shaft to a smaller amount of motion than do sleeve bearings.

CHAPTER 6

TURBINE MAINTENANCE

The maintenance of maximum operational reliability and efficiency of steam propulsion turbines requires a carefully planned and executed program of inspections and preventive maintenance, in addition to strict adherence to prescribed operating instructions and safety precautions. If proper maintenance procedures are followed, abnormal conditions may be prevented.

This chapter presents selected information (supplementary to that given in ch. 5) on the general care, maintenance, and repair of the most common types of main turbines. Additional information can be obtained from the manufacturers technical manuals, detail drawings for specific installations, and BuShips Technical Manual for all installations.

GENERAL CARE AND MAINTENANCE OF TURBINES

When not under steam and not in drydock, main engines shall be jacked over daily at least 1-1/4 revolutions. Care must be taken not to bring the turbine rotor to rest in the same position for 2 consecutive days. The procedure prevents freezing of bearings, bowing and spot corrosion of the rotor, and permits lubrication of all gear teeth.

When the propulsion machinery is not in use, lubricating oil that is free from impurities should be circulated through the entire system for at least 15 minutes each day. It is essential that an oil film be maintained in all bearings while the turbines are being jacked.

Corrosion and rusting of the turbines may be almost entirely prevented by continuing the operation of the second-stage air ejector to dry the machines after they have been shut down, and while they are still hot.

After a turbine has been warmed up, a vacuum shall NOT be maintained on the turbine

unless the glands are properly sealed. Therefore, it is best to perform the following procedure:

1. Secure steam to the second stage.
2. Secure the condensate pump.
3. When the vacuum has dropped to 10 inches, secure the gland seal and break the vacuum through the air ejector suction. This would allow maximum normal cooling time and put most of the incoming air through the condenser vice the turbines.

The interior of main turbines shall be inspected quarterly if practicable, or more frequently if necessary. During this inspection, the effectiveness of the procedures in keeping the turbine dry and free from corrosion should be noted.

The turbine inspections and checks listed in Table 6-1 should be made and appropriate entries made in the Engineering Log.

MAINTENANCE OF PROPER VACUUM

When turbines and associated condensing equipment are operated at other than design vacuum, inefficiencies occur which result in a high fuel rate, lowered turbine performance, and incorrect heat transfer. The design vacuum recommended by the turbine manufacturer and condenser manufacturer may be found in their respective technical manuals and in shipbuilder furnished operating guides. Turbine plants are designed for best and most economical operation at or near 29-30 inches Hg. vacuum.

Cold turbines should be warmed up with reduced vacuum with optimum (or design) vacuum withheld until these conditions have permitted a thorough and uniform turbine warm up. This can be accomplished by not cutting in

Table 6-1.—Turbine Checks and Inspections

When	What	Why
Daily	Jack turbines 1-1/4 turns.	To prevent freezing of bearings, bowing and spot corrosion of rotor and to lubricate all gear teeth.
Daily	Circulate lube oil through system.	To prevent accumulation of water and sediment in pockets and to form oil film jacking.
Daily	Run air ejector 1/2 hour.	To dry out turbines.
Daily	Operate lube oil purifier.	To remove water and impurities from lube oil.
Weekly	Check the valves, cocks, and joints of steam, exhaust, and drain lines.	For tightness.
Weekly	Operate and lubricate throttle control gear. NOTE: Do not place any lubricant on steam valve stems.	To prevent sticking.
Weekly	Operate all valves not normally used.	To ensure proper operation when needed.
Weekly	Inspect exterior fittings of the installation.	To detect oil leaks and corrosion.
Quarterly	Inspect exhaust trunk and last stages of LP turbine through manhole plate.	To detect corrosion or other defects.
Quarterly	Sound with hammer-holddown bolts, ties, and chocks of turbines.	To detect signs of loosening turbine fastening.
Quarterly	Remove turbine inspection plates.	To determine existence of missing or loose blades or shrouding, and to check for corrosion.
Quarterly	Clean steam strainers.	To remove foreign matter and to ensure integrity of the steam strainers.
Quarterly	Inspect shoes of thrust bearings for clearance, and condition of bearing surfaces.	To ensure proper position of the rotor.
Quarterly	Inspect exhaust trunk.	For tightness, evidence of corrosion, and loose bolts.

Table 6-1.—Turbine Checks and Inspections—Continued

When	What	Why
Quarterly	Test and set relief and sentinel valves.	To ensure proper protection against excessive pressures.
Quarterly	Check location and tightness of rotor balance weights through inspection openings if provided.	To detect loose or missing balance weights.
Quarterly	Inspect nozzle control valves.	For leaking valves.
Semi-annually	Inspect gland packing (where examination can be made without lifting turbine casing).	To ensure efficient seal being maintained.
Annually	Inspect propulsion turbines lower casing.	For signs of corrosion and continuously wet insulation.
Annually	Inspect condenser expansion joint.	To detect deterioration.
Annually	Calibrate gages.	To ensure correct readings.
Overhaul cycle	Check main bearings for clearance.	To ensure correct clearances.

the first stage air ejector until 30 minutes prior to getting underway. This procedure is in accordance with instructions in applicable technical manuals, which counsel operators to observe preferred practices. After the turbine is warmed up, the plant vacuum should be gradually increased to the underway design value and maintained at that value after reporting "ready to answer all bells."

PRECAUTIONS TO PREVENT ENTRY OF FOREIGN MATTER

When any part of a turbine is open, every precaution must be taken to prevent the entry of foreign substances. Turbine inspection plates should not be left off overnight, or for any considerable length of time, unless the openings are completely covered. While the inspection plates are off, the openings should not be left unattended. All objects should be removed from the pockets of any person making an inspection of turbine interiors. Inspecting personnel entering casing should use masking tape on buttons, collar devices, and eyeglasses. A final inspection

must be made by the engineer officer or his authorized representative officer, immediately prior to the replacement of the inspection plates. An entry pertaining to the inspection should be made in the Engineering Log; this entry should include the name of the inspecting officer.

LUBRICATION OF TURBINES

One of the more important factors in the operation and maintenance of propulsion turbines is an adequate supply of the correct lubricating oil (2190 TEP) having the correct physical and chemical qualities. Turbines are provided with either (a) NEEDLE VALVES that permit adjustment of the oil flow to all journal and thrust bearings, (b) NONADJUSTABLE ORIFICES in the oil supply lines to each journal bearing, (c) a NONADJUSTABLE ORIFICE in the inlet to or discharge from each thrust bearing, or (d) a BEARING so constructed that the oil clearance around the journal acts as an orifice. The needle valves are adjustable but the setting should never be changed except

in an emergency, and then only by experienced personnel. These valves are so constructed that they cannot fully cut off the flow of oil to the bearing. With the needle valves properly set, the oil flow to the bearings is such as to provide adequate lubrication, but if a bearing is wiped to such an extent that the oil flows freely out of the sides of the bearing, its needle valve will not permit the damaged bearing to take an excessive amount of oil away from the others.

Under normal operating conditions, the temperature of the oil leaving the lube oil cooler should be between 115° F and 130° F. The temperature of the oil leaving the bearing should be between 140° and 160° F but never greater than 180° F. The maximum operating temperature rise allowable in the bearing is 50° F, even though such a rise may cause a final temperature of lower than 180° F.

Various means are provided for maintaining a continuous check on the supply of oil to the bearings, and on the bearing temperatures as indicated by the temperature of oil flowing from the bearings. On some older installations, a pressure gage is connected to the oil supply line to each bearing, or a spinner-type flow indicator is connected in the supply line. A thermometer is fitted in each bearing as near as possible to the point from which the oil drains from the bearing shell. On some naval ships, journal bearings and thrust bearings have four types of temperature indicators presently being used: the mercury bulb thermometer, the bimetallic thermometer, the thermocouple, and the resistance thermometer element (RTE).

The bimetallic thermometer uses the principle of two dissimilar metals expanding due to heat, and indicates the temperature on a calibrated gage. The bimetallic thermometer can be used to replace the mercury bulb thermometer for direct reading.

Thermocouples have been installed in the bearings to indicate the temperature of the oil film. The thermocouples are monitored automatically by an electrical scanning device or monitor, briefly described as follows: The thermocouples are connected to lamps and an alarm in the scanner through contacts. These contacts are made and broken by a rotary stepping switch pulsing circuit which provides the power pulses to operate the rotary stepping switch so that all thermocouple channels can be scanned within 10 seconds. If the temperature on any bearing exceeds 250° F, the lamp corresponding to the

bearing will light and the alarm will sound. The alarm may be reset manually, but the light will remain on until the temperature returns to normal. (NOTE: Under normal conditions, the maintenance of alarms will be performed by Electrician's Mates.) Provision is also made for a meter in the scanner which can be connected to read the actual temperature on any one bearing at a given time.

It should be understood that there will generally be some difference between the temperatures as indicated by the mercury bulb or bimetallic thermometers (where installed) and the scanner meter. These differences, however, are due primarily to the difference in position of the sensing elements for the bearing. If the temperature (as read by the thermometer or scanner), should suddenly rise without a change in speed, there may be a distressed bearing, and the speed should be reduced, if possible, and the cause ascertained.

The RTE, and electrical resistance type thermometer installed within the bearing, is used to measure the temperature of the babbitt material. The RTE uses the same type monitoring system as the thermocouple.

The bearings and gears of warships require a high grade mineral oil (2190 TEP). The oil must be kept free from water and impurities by means of the purifier and the settling tank. In keeping a continuous check on the condition of the lubricating oil, a routine procedure of taking oil samples should be followed. The oils should also be tested at regular intervals whenever testing facilities are available, to determine the neutralization number, flash point, viscosity, and other physical or chemical properties which govern the effectiveness of the oil as a lubricant.

MAJOR ADJUSTMENTS OF A TURBINE

In all propulsion turbines installed on ships in the Navy, there are two major adjustments: the fixing of the proper radial and axial positions of the rotor. The radial position of the rotor is maintained by the main bearings, and the axial position by the thrust bearings.

The major reason for maintaining a turbine rotor in its proper position is to prevent damage to the turbine and to maintain the proper clearances between the rotor and the turbine casing. This is an important factor in connection with the efficiency of the turbine. If the rotor touches the casing any any time, because

of failure of the thrust or journal bearings while the turbine is in operation, damage will result and it will be necessary to lift the turbine casing for repairs. The turbine parts that are particularly subject to damage, because of close clearances involved, are the rotor blading, diaphragm packing rings, shaft packing rings, and oil deflector or oil seal rings.

Radial Position of the Rotor

The quickest means of detecting any change in the radial position of the rotor, resulting from bearing wear, is by using the depth gage micrometer. When the turbines were installed originally, depth gage readings were taken and recorded. Any difference between the original and the new readings will be the amount of bearing wear.

To take new readings (see fig. 6-1) a depth gage spindle is inserted into the depth gage well until the bridge of the gage rests evenly on the reference boss; the knurled handle of the micrometer is then turned until the spindle touches the journal. Read the micrometer and compare the new and the original readings.

Another means of checking bearing wear is by measuring the crown thickness with an outside micrometer. When the turbine bearings were installed originally, the radial position of

the turbine rotor was set, and by using a micrometer the combined thickness of the bearing shells and liners (at designated places) was measured and stamped on the bearing shell. To take new readings: the bearing cap must be removed, the top half of the bearing lifted off, and the lower half of the bearing rolled out. Radial lines are scribed on one end of each bearing to indicate the measurement points which are always 1 1/4 inches from the end of the bearing. Any difference between the ship-board and the factory measurements will be the amount of bearing wear.

Another way of measuring bearing wear is by using an inside micrometer to measure the inside diameter of the bearing and an outside micrometer to measure the outside diameter of the journal. The difference between the readings will be the oil clearance. The difference between the old and the new oil clearances will be the amount of bearing wear.

Axial Position of the Rotor

The axial position of a turbine rotor is maintained by means of a thrust bearing, usually of the pivoted segmental or Kingsbury type. With this type bearing, the axial position of the rotor is adjusted by machining from the filler piece, or by adding shims.

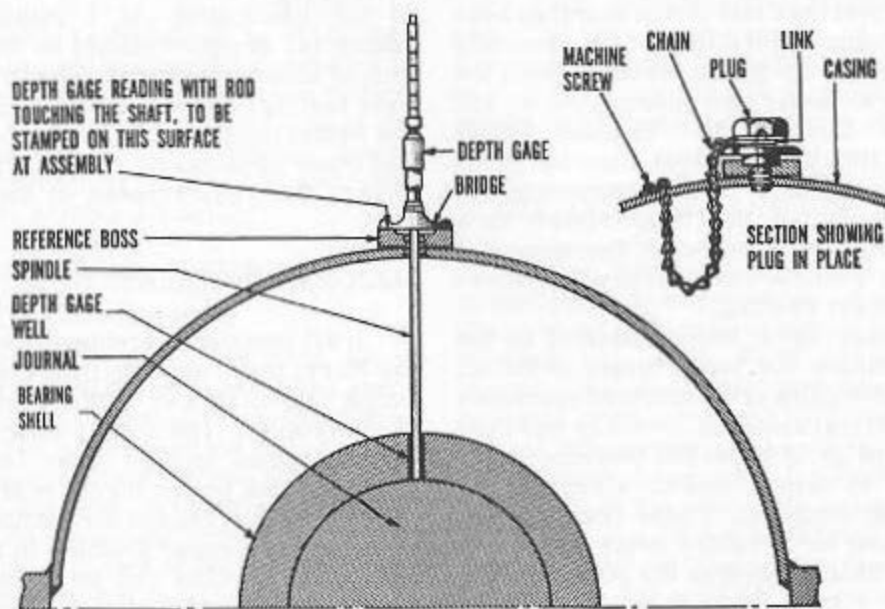


Figure 6-1.—Bearing wear micrometer depth gage.

The axial clearance instruments consist of the rotor position micrometer and the axial clearance micrometer. The rotor position micrometer is shown in figure 6-2. It is used on some turbines, while they are in operation, to determine the axial position of the rotor and the amount of thrust bearing wear.

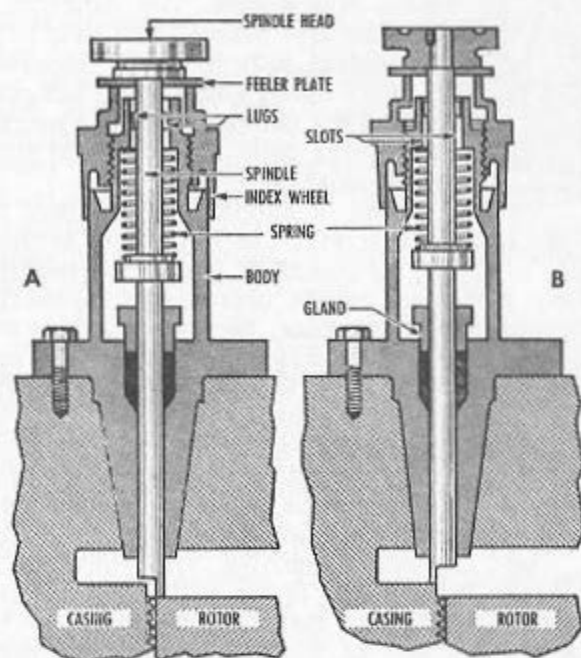
The principal parts of the rotor position micrometer are: (1) the spindle, with spindle head attached; (2) the body, attached directly to the turbine casing; (3) the index wheel, which is threaded to the body and graduated to read axial movement in thousandths of an inch; (4) the feeler plate; and (5) the spring. The spindle is cut away at the end, leaving only a half-section.

Readings are carefully taken and recorded just after the turbine is installed, and after each overhaul period. (At any future time, readings can be taken and compared with those on record.) Any difference between the readings taken at installation, or at overhauls, indicates thrust bearing wear, which should be checked as soon as possible. The normal oil clearance in the thrust bearing should be given consideration; it should not be mistaken for excessive wear.

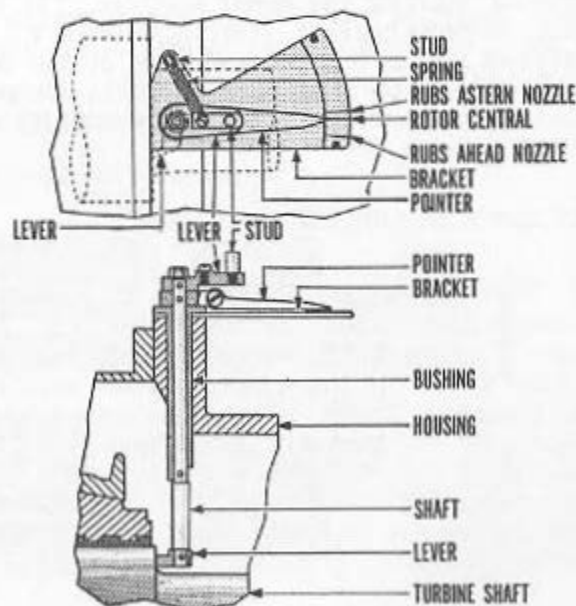
Sometimes the rotor position micrometer is installed so that readings can be taken from the dummy piston and cylinder; it may then be referred to as a dummy micrometer.

Some propulsion turbines are equipped with a different type of micrometer which is mounted on the forward end of the turbine shaft, with its spindle in line with the centerline of the shaft. The linear speed of any point on the shaft approaches zero as the point nears the center of the shaft. Thus, when the micrometer spindle touches the center of the shaft, it will suffer negligible wear. Therefore, in taking one reading, instead of two, and comparing that reading with the predetermined safe limits, the axial position of the shaft can be readily determined. This type of rotor position micrometer has an additional advantage in that it does not pass through the casing of the turbine, and therefore does not require a stuffing box and packing gland.

Many propulsion turbine installations are equipped with axial clearance indicators. An axial clearance indicator of the type installed on the low pressure turbine of a destroyer is shown in figure 6-3. The indicator is located at the forward end of the turbine and provides an easy means of obtaining a check on the axial position of the rotor. When not in use, the lever is held out of contact with the shoulder on the



47.23X
Figure 6-2.—Rotor position micrometer.



47.24X
Figure 6-3.—Axial clearance indicator.

shaft by means of a spring. The indicator is used by moving the stud manually so as to bring the lever in contact with the shaft shoulder. The pointer, at its initial adjustment, indicates rotor center; and the indicator plate is marked to indicate the danger point of deviation (at which point adjustment must be made).

Another means of determining whether the rotor is operating within safe limits is to check the total oil clearance of the thrust bearing. This clearance can be obtained by measuring the end play of the rotor. Methods of taking this measurement for various installations may differ but the basic principle is the same. With

the thrust bearing completely assembled, the rotor is moved as far as it will go, first in one direction and then in the opposite direction. The length of travel is measured with a precision instrument, such as a dial indicator.

One method of moving the rotor is as follows: Remove the upper half of the coupling guard and attach the dial indicator to the flanged surface of the bearing cap. To move the rotor forward, apply a bar between the after face of the coupling flange and the face of the adjacent cover. To move the rotor aft, the bar is applied between the forward face of the coupling flange and the face of the bearing cap. In each case a wooden block is used to prevent marring the metal surfaces. The end play (thrust bearing clearance or float) is obtained from the two readings of the dial indicator. If the end play is within designed limits, the rotor is operating within its allowable limits.

TURBINE BEARING MAINTENANCE

When a bearing is opened, it should be carefully inspected for ridges, scores, and amount of wear. It should be noted whether or not the babbit lining has remained anchored to the shell. If the bearing is only slightly wiped, it can probably be scraped to a good surface and restored to service. In this case the clearance reading of the reconditioned bearing should be fairly close to its original value.

Thrust Bearing Repairs

When trouble occurs or is suspected in a thrust bearing, the oil clearance in the bearing

should be measured before the bearing is disassembled. If the readings are beyond allowable tolerances, there is no doubt that the bearings should be disassembled for inspection.

When it is necessary to disassemble a thrust bearing, a careful inspection should be made of all parts. If there is slight rusting of the collar surfaces, the rust can be removed with a fine oilstone. The work should be done slowly and carefully by experienced personnel. When thrust shoes are reconditioned and reinstalled, check whether too much bearing metal has been removed during reconditioning. Renew the shoes if wear is evident and it exceeds allowable limits. The manufacturer supplies a spare thrust collar and 12 spare shoes to the ship. There should be no problem encountered in using the manufacturer's spare thrust shoes since they are accurately machined and surfaced to the proper dimensions. Whenever taking measurements of the shoes, consult the detail drawing for the place and design value of such a measurement.

If thrust shoes are damaged and require rebabbiting and machining, the detailed measurements can be found by referring to the applicable blueprints. Damaged thrust shoes which cannot be reconditioned by the ship's force are sent to a repair activity to be rebabbitted and machined. The radial edges of the shoes should be slightly rounded, otherwise the sharp edges will tend to scrape the oil film off the thrust collar.

Frequently a set of shoes is slightly burnished or partially worn. If this happens when no spares are available, shift the astern shoes to the ahead side (if they are interchangeable). Stone any ridges cut in the collar (the greatest care must be taken here as to the thickness; tolerance is only 0.005 inch). Spot in the worn shoes and install on the astern side. After the bearing is reassembled, check for any change in thrust clearance.

If a thrust collar is found to be badly scored or if deep rust pits are present, the collar should be removed for repairs. On most turbines the thrust collar can be removed without lifting the casing and without disturbing the lower half of the forward journal bearing.

The propulsion turbine thrust collars on older ships are keyed to the shaft and held in place by a thrust nut threaded on the end of the shaft. To prevent the thrust nut from loosening and backing off, a lockwasher is placed between

the thrust nut and the keyed sleeve. The lock-washer ears must be bent squarely into the thrust nut notches to prevent the thrust nut from backing off. On modern installations, the collar is held in place by checknuts.

From a study of figure 6-4, it is apparent that the lower half of the inner casing will have to be removed before the thrust collar (runner) can be removed from the shaft. The lower inner casing, together with the thrust bearing, is shown in figure 6-5. The lower inner casing is removed from the outer thrust bearing housing by rotating it 180°, and lifting it from the journal. This is accomplished much the same as is removing the lower half of a journal bearing.

When a thrust collar is to be remachined, the bore should be exactly square with the faces. The faces should be machined flat and smooth, and the thickness should be exactly uniform all around. The marks left by machining or grinding must be removed by lapping.

When the thrust bearing has been reassembled and the oil clearance taken, the thickness of the shim to be added should be computed. Take, for example, a thrust bearing that has the following clearances: designed clearance 0.010 inch; maximum clearance 0.020 inch; minimum clearance 0.007 inch. If a reading of 0.025 inch was obtained, a shim of 0.015 inch should be installed. Never more than one shim shall be used to obtain the proper oil clearance.

Bearing Journal Repairs

Bearing journals should be smooth, even, and free from rust at all times. With the increased emphasis on noise reduction in the Navy today, it is impossible to maintain, by hand methods of reconditioning, the roundness required for satisfactory operation. Any journal showing rust, ridges, or sharp edges should be sent to a repair activity for machining.

FITTING OF BEARINGS.—A bearing should have sufficient bearing area of fit in order to withstand maximum designed load. If the bearing area is reduced by any considerable amount, more heat than the metal can withstand will be generated in the bearing; and extreme measures will have to be taken to keep the bearing cool and prevent it from wiping.

Modern bearings are usually finish bored to a diameter equal to that of the journal plus the desired oil clearance, and little or no fitting should be necessary. However, where hand fitting is required, a mandrel should be used; the mandrel should have a diameter equal to that of the journal plus the oil clearance.

General practice is to finish the hole to a standard size, within the limit of the accuracy desired. Therefore, a 3/4-inch standard hole would ordinarily be within a tolerance of one-half thousandth of an inch above or below the

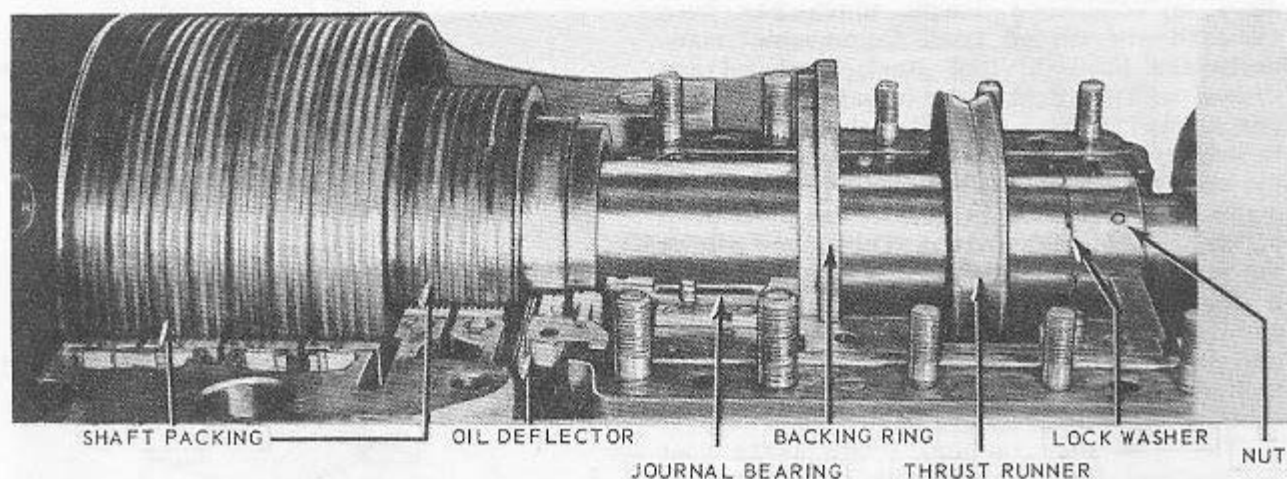
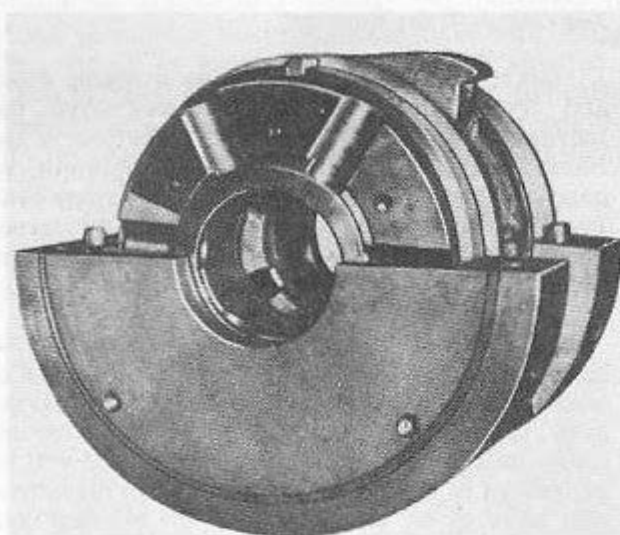


Figure 6-4.—Forward end of a high pressure turbine (base rings, leveling plates, and thrust shoes removed).

96.1X



96.2X

Figure 6-5.—Thrust bearing (assembled) and lower inner casing.

true standard size of exactly 0.750 inch. First the hole is drilled or bored to within a few thousandths of an inch of the finished size; then the remainder of the material is removed with a machine reamer, followed with a hand reamer if the limits are extremely close.

The bearing is then pressed on a mandrel tight enough so the work will not slip while being machined and a dog is clamped on the mandrel which is mounted between centers.

A mandrel is simply a round piece of steel of convenient length which has been centered and turned true. Commercial mandrels are made of tool steel, hardened and ground with a slight taper (usually 0.0005 inch per inch). On sizes up to 1 inch the small end is usually one-half thousandth of an inch under the standard size of the mandrel, while on larger sizes this dimension is usually one thousandth of an inch under standard. This taper allows the standard hole in the work to vary according to the usual shop practice, and still provides a drive to the work when the mandrel is pressed into the hole. The taper is not great enough to distort the hole in the work. The countersunk centers of the mandrel are lapped for accuracy.

The first step in hard fitting is to coat the mandrel with a compound such as Prussian blue. One half of the bearing is placed on the mandrel and turned slightly with a light pressure to cause the coloring on the mandrel to adhere to the high spots on the bearing. These

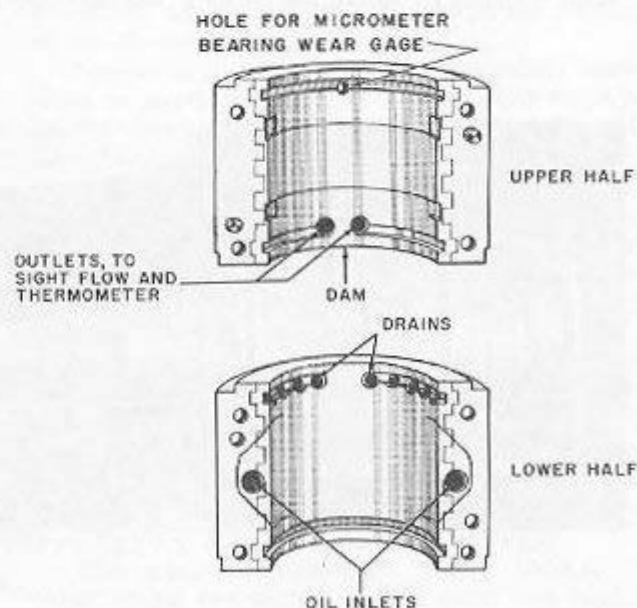
high spots should be removed with a scraper and the fitting operation repeated until the coloring matter is uniformly distributed over the bearing surface, which indicates that all of the bearing surface is in contact with the journal. When no mandrel is used, contact with the journal should be limited to a small area, about 30°, in the bottom of the bearing.

In scraping a bearing, care must be taken to see that the lining is kept concentric with the shell, and that taper runout is avoided.

REPLACEMENT OF JOURNAL BEARINGS.

—When a bearing surface is found to be scored, uneven, considerably worn, wiped, or burned out, or if the metal is loose, the bearing must be rebabbitted or replaced. The detailed procedure for replacing turbine bearings will vary somewhat for different sizes and types of turbines. Care must be taken to properly mark all parts, while the bearing is being disassembled. A bearing improperly installed, will not receive adequate lubrication. A typical turbine bearing is shown in figure 6-6.

When a spare bearing is being readied for installation, it should be carefully cleaned and inspected. The two bearing halves should be bolted or clamped together and the inside diameter of the bearing measured with an inside micrometer. The inside diameter of the bearing



96.3X

Figure 6-6.—A typical propulsion turbine journal bearing.

should equal the outside diameter of the journal plus the designed oil clearance. The dimensions for a bearing may be found by checking the manufacturer's technical manual or the applicable blueprints. Ensure that a bearing which has been rebabbitted complies with dimensional specifications. Thermal distortion from heating and cooling the bearing shells during babbitting often results in dimensional variations of the spherical contour.

After the bearing cap and the upper half of the bearing have been removed, the weight of the rotor is lifted by a jacking device (fig. 6-7). Lift the rotor only enough to permit the lower half of the bearing to be rolled out. Lifting the rotor excessively will damage the shaft packing, and the bearing half might bind. Before removing the lower half bearing, ensure that the thermocouples are removed (if applicable). When the lower half of the spare bearing is installed, the jack is removed and the bearing reassembled.

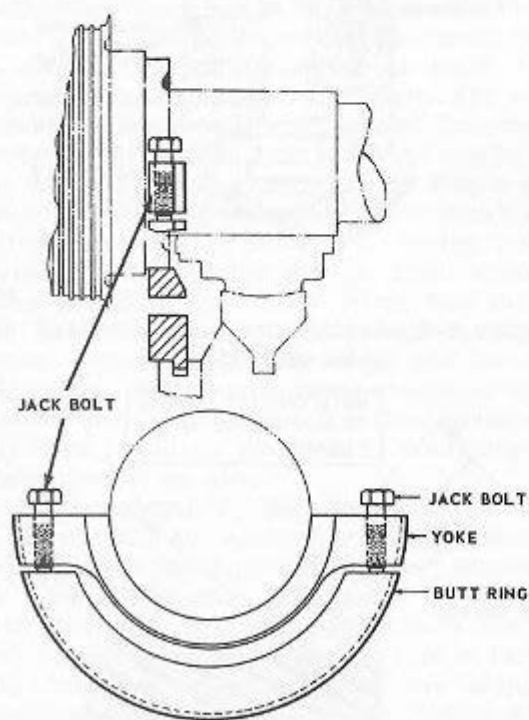
A bearing being used for the first time should be used at low speed; and the oil temperature should be checked at frequent

intervals. A temperature rise of more than 1° F per minute usually indicates that the rubbing surfaces have been scored. An interval of 10 minutes is usually sufficient to determine the rate of temperature change.

When a defective bearing has been replaced by a spare, the old bearing should be rebabbitted as soon as possible if it is a reusable type. The usual procedure is to have a repair ship or shipyard rebabbitt and machine the bearing. The appropriate blueprints or manufacturer's technical manual will have to be furnished to the repair activity, for the necessary detailed information concerning the bearing dimensions.

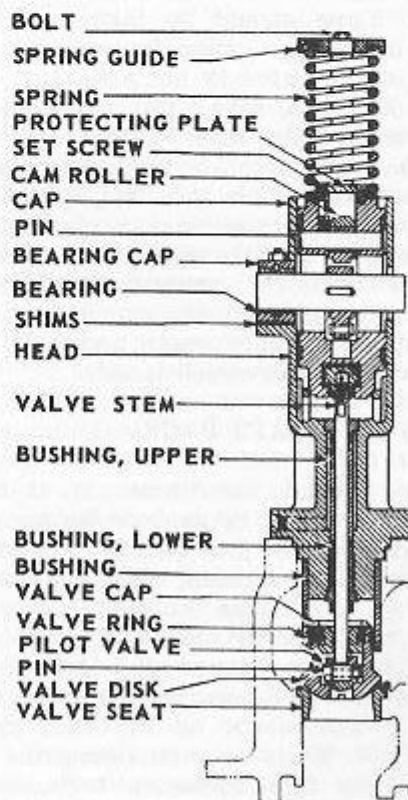
NOZZLE CONTROL VALVE REPAIRS

The nozzle control valves (fig. 6-8) for the main high pressure turbine normally will operate for a long period of time without maintenance or repairs. However, the nozzle control valves are subjected to high steam pressures and temperatures, and in time they will require repairs.



96.4X

Figure 6-7.—Special jack used for removing lower half of a journal bearing.



96.5X

Figure 6-8.—A turbine nozzle control valve.

One of the more common troubles that may occur to nozzle control valves is the leakage of steam between the valve seat and disk. On modern ships, the complete disassembly of the operating mechanism is not necessary. The steam chest cover is lifted and carefully placed on wooden blocks to prevent damage to the valves. The contact area of a valve with its seat should be checked by bluing the valve. If the valve does not make a good contact with its seat, do not lap the valve and seat as this makes a flat spot on both the valve and seat and destroys the spherical surface of the valve.

Figure 6-9 shows a enlarged section of a nozzle control valve.

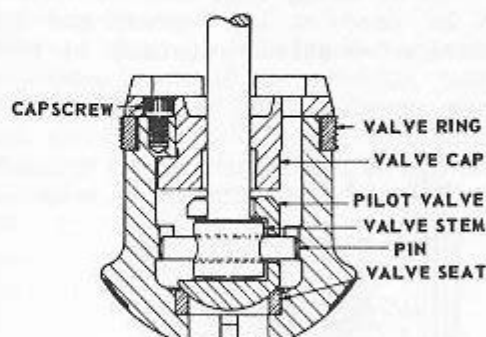
All valve seats have flat angular surfaces at the line of contact with the spherical surfaces of the valve disks. In order to resurface the valve seat, the following method is suggested: Turn a cast-iron cone with an angle the same as the valve seat angle. Leave a tip on the upper end of the cone so that it can be held in, and driven by, an air motor or electrical drill. With this cone and some grinding compound, the flat angle of the valve seat may be resurfaced. Care should be taken not to grind off any more metal than is necessary. If the surface of the valve is not spherical because of pits or wear, place the valve in a lathe and polish it with emery cloth and oil until the surface is smooth and there is less than a 0.0005-inch runout. In this way the valve disk will maintain a spherical surface and seat tightly even if slightly out of line. The manufacturer's technical manual should be consulted for the correct disassembly procedure. Badly cut or damaged seats and disks are replaced rather than reconditioned.

RENEWAL OF SHAFT PACKING

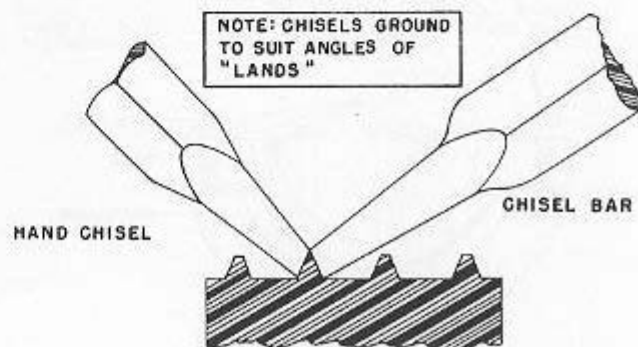
Under normal conditions, if it becomes necessary to repair or replace the main engine shaft packing, the job will be done during a routine shipyard overhaul. When necessary, the outer rings of packing for most high pressure turbines can be replaced by the ship's force, since this can be accomplished by removing the upper half of the packing casing. The inner packing rings cannot be replaced by ship's force, as it would require lifting the turbine casing. Some high pressure turbines in the Navy have only labyrinth packing. Other high pressure turbines have carbon packing in the low pressure end only.

On low pressure main turbines in which only labyrinth packing is used, usually the inner and outer packing is accessible when the upper half of the packing housing is removed. On low pressure main turbines where carbon packing is used, this packing can be replaced by the ship's force.

Worn labyrinth packing may be repaired in an emergency by using a chisel bar and a hand chisel as shown in figure 6-10. These tools are placed as indicated in the figure, the chisel is struck with a hammer, and then advanced around the periphery of the packing a trifle less than the tool's width. Care must be taken that each new position of the chisel overlaps the preceding position. This procedure expands the "tooth" in height and draws it out to its original featheredge. The drawing out of the "teeth" must be continued to give the packing clearance specified on manufacturer's drawings or in manufacturer's technical manuals. If the clearance is not



96.6X
Figure 6-9.—Section of a nozzle control valve (pilot valve details).



96.7
Figure 6-10.—Method of expanding lands of worn labyrinth packing.

available from plans or instructions, the drawings of "teeth" should be continued until they come within 0.005 inch of touching the shaft.

When it becomes necessary for the ship's force to overhaul carbon packing, it is recommended that the removed segments be placed in a box in such a manner that adjacent segments of a ring will be next to each other. Each segment of carbon packing is marked on each end with the number of the ring of which it is a part. As each segment is removed, an examination should be made for scores, grooves, and wear in general. The rings can be refitted or renewed, whichever is necessary.

The retainer springs must be carefully inspected and tested. If they are weak or corroded; they must be renewed.

LIFTING THE TURBINE CASING AND ROTOR

Although shipyard personnel are responsible for lifting turbine casings and rotors, you should have a good understanding of the procedures involved. Before a turbine casing is lifted, preliminary work has to be done. All the turbine lifting gear, special tools, and equipment should be inventoried and inspected at least 1 day before the actual work is to begin. The manufacturer's technical manuals and Coordinated Shipboard Allowance List (COSAL) can be used for inventory of the lifting gear. Ship's force should be ready (if necessary) to furnish turbine lifting gear which includes: casing guides, casing supports, rotor guides, rotor supports, lifting brackets, and other items that the ship will have aboard. On some ships the turbine lifting gear has been removed, and therefore will be available only in naval shipyards and on tenders and repair ships. The ship's blueprints will have listed on them all of the lifting gear placed aboard the ship.

The decision as to when casings should be lifted will be made by BuShips when so requested by the type commander; otherwise, the type commander will make the decision. This decision will be based upon the past performances of the particular type of turbine, data furnished by the CO of the ship, and recommendations made by the forces afloat. In an emergency, turbine casings may be lifted before permission is granted, but a detailed report must be promptly submitted to the Naval Ship Systems Command.

Regulations for Lifting Turbines

Three months prior to each regular overhaul, a report by the CO of the ship on the condition of each propulsion turbine he thinks should be lifted is submitted to the type commander. Copies of the report are sent to the Naval Ship Systems Command and to the repair activity concerned. BuShips Technical Manual, chapter 9410 (41), should be consulted for the information required to be contained in the report.

Any comments from the Naval Ship Systems Command concerning a recommendation to disassemble the casing or to perform additional tests or inspections will be directed to the type commander with copies to the reporting ship, the planned overhaul activity, Ships Parts Control Center (SPCC), Naval Boiler and Turbine Laboratory (NBTL), and any other activities concerned. Final authority for disassembling the casing is the responsibility of the activity (usually the type commander) controlling the operating schedule and overhaul funds of the ship.

Lifting Casing and Rotor

Whenever turbine casings are lifted for any purpose, advantage should be taken of the opportunity to observe the condition of all nozzles, blading, packing rings, and other internal parts. When practicable, such examinations should be made when adequate facilities are available for necessary repairs which are beyond the capacity of the ship's force.

All turbine measurements and clearances should be taken before and after repairs; a permanent record of these measurements should be maintained. (Fig. 6-11 shows the method of checking the rotor position with a taper gage.) Tip clearances may be omitted, if they are considered unnecessary by the repair agency. The record must also include the material condition revealed when the turbine is opened and after repairs are made. A report of the above facts must be forwarded to the Naval Ship Systems Command with copies to the ship concerned and to her home yard.

Some preliminary work must be completed before the casing can be lifted. The covers over the flexible couplings, between the turbines and the reduction gears, must be removed. If a cruising turbine rotor is to be lifted, the cruising turbine reduction gear also

must be disassembled, as the pinion is part of the turbine shaft. Sections of the main steam lines are disconnected and removed. The cross-over line between the high pressure turbine and the low pressure turbine must be removed. Drain lines and gland seal lines may be removed if necessary. In some turbine installations, obstructions to lifting, such as steam lines and ventilation ducts, may have to be removed, and it may be necessary to remove some of the insulation from the turbine.

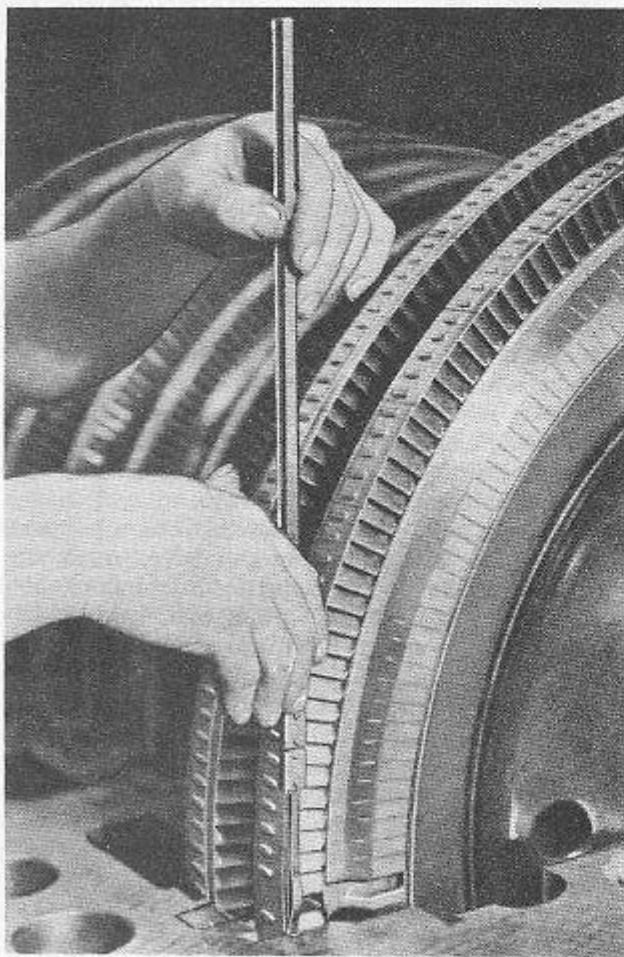
Proper temporary stowage of the piping, valves, nuts, bolts, tools and other necessary materials must be provided, either in or out of the engineroom. Passageways and working areas must be kept free of tools and materials being used or disassembled. Avoid damage to the

piping, gages, gage lines, lagging, and other material.

After the preliminary work has been completed, the turbine casing horizontal joint bolts are removed. As a rule, the vertical joint bolts on the high pressure turbine are not removed, except where repairs require the joint to be opened. Most inspection covers have caution plates which call attention to internal bolts or fittings which must be removed. The upper housing and upper halves of main turbine bearings must be removed. When removing turbine casing bolts that were tightened by heat, it is important that heat be applied when loosening these bolts; the heat will prevent galling the threads. If there is a tendency for the joint to spring open at disassembly, it is good practice to loosen the first few bolts, then tighten them lightly; these bolts can be removed last. After all the bolts have been removed, the joint can be broken loose by means of jack bolts, if necessary.

When a ship is built, padeyes are welded in the overhead of the engineroom for attaching chain falls for lifting heavy objects. The manufacturer's technical manual and the ship's blueprints will give detailed information on the arrangement, number and size of the chain falls, wire slings, and shackles to be used to lift any particular piece of machinery. The lifting arrangement for a turbine casing will allow the four corners of the upper casing to be lifted in a plane parallel to the flange of the lower casing. Four upper casing guide pins are installed. If there is a scale on a guide pin, this scale should face outboard where it can be readily seen. The location of the upper casing guide pins is shown in figure 6-12. The guide pins are used to prevent any damage to the turbine blading and shaft packing. As the turbine casing is raised or lowered, it should be handled in a manner to prevent tilting or swaying so as not to strike the turbine blading or shaft packing.

When the turbine casing is ready to be lifted, men are assigned to the various jobs and stations. It usually requires 10 or 12 men to raise or lower a main turbine casing. (Four men operate the chain falls. Four men, one at each corner of the turbine casing, take measurement readings from the guide pins. Usually an observer is stationed at each side of the turbine, and one man will supervise the entire operation.)



96.8X

Figure 6-11.—Using a taper gage to check the position of a rotor.

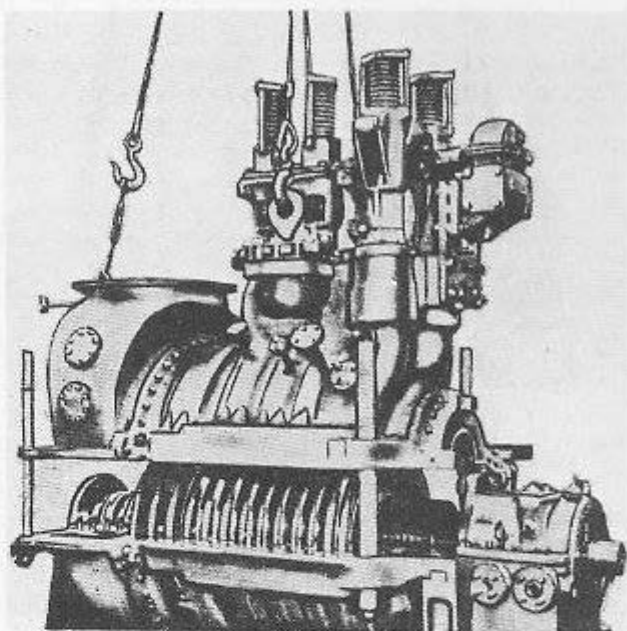
The casing is slowly raised, keeping uniform heights at the graduated guide pins to ensure that the casing is level and not tilted. The usual procedure is to slowly raise the casing about one inch at a time until the upper casing is clear of the rotor. As a safety precaution, blocks are inserted under the upper casing flange as the casing is raised. When the casing is clear of the rotor, it can be either swung clear of the turbine, or secured in a position above it as shown in figure 6-13.

After the casing has been raised to the desired height (not higher than the guide pins), and if it is not to be swung clear, the four upper casing supports are installed, as shown in figure 6-13. Applicable blueprints should be on hand to show the exact location for installing the various turbine supports and guide pieces. The upper casing support pieces are bolted to the upper and lower casing flanges. Figure 6-13 shows a turbine opened for inspection.

A similar procedure is used for lifting a turbine rotor as is used in lifting the upper casing. Four rotor guides are attached to the lower casing of the turbine, as shown in figure 6-14. There are different methods of attaching the wire slings to the turbine rotor. One method, shown in figure 6-14, is used for a small turbine rotor. Another method uses a special lifting yoke and a lifting plate to raise the rotor. The lifting yoke, a form of clamp, is attached to the forward end of the rotor. The lifting plate, a padeye welded to a plate, is attached to lifting devices so that chain hoists may be used in lifting the rotor.

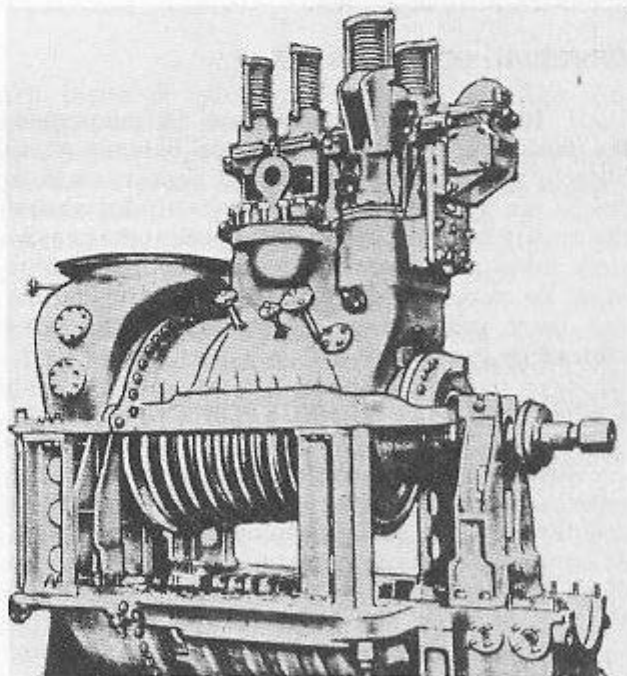
The rotor guide pieces perform two functions: when the rotor is being raised, the guide pieces keep it in a vertical plane passing through the centerline of the rotor shaft; machined surface on the inside corners of the rotor guide pieces prevent the rotor from moving forward or aft. The machined surfaces bear with a small clearance against shoulders on the forward and after ends of the shaft. In many cases, special bushings are attached to the rotor shaft. These bushings are located on the sections of the shaft between the pairs of rotor guide pieces.

After all preliminary work has been completed, the turbine rotor is slowly lifted from the lower casing. The rotor is lifted approximately one inch at a time and measurements taken at each end to ensure that both ends have been raised evenly. Adjustments in height are made as necessary. This procedure is repeated until the rotor has cleared the lower



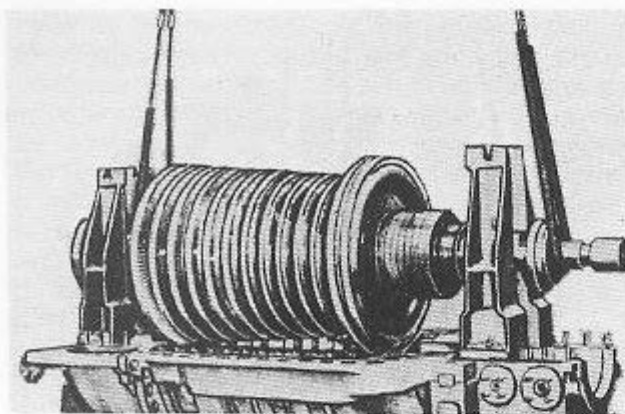
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Figure 6-12.—Lifting or lowering upper casing of a high pressure turbine.



96.10

Figure 6-13.—Upper casing and rotor resting on supports.



96.11

Figure 6-14.—Lifting a high pressure rotor.

casing. A rotor that has been lifted clear of the casing is shown in figure 6-14.

When a turbine rotor is to be placed in its raised position, special securing devices such as rotor guide saddles, rotor supporting bars, rotor guide tie brackets, and rotor guide spacer bolts are used. These attachments are secured in place so as to properly support the weight of the rotor. The same procedures are used to lift and support the high pressure and the low pressure turbine rotors.

CHECKING ROTOR BALANCE

If turbine rotor unbalance is suspected, the rotor should be checked for balance while still in the casing. The normal procedure is to notify the type commander who will determine the repair activity which will conduct the necessary tests and inspections. All turbine rotors must be rebalanced when any of their blading has been renewed or their balance has been altered by repairs.

MAJOR OVERHAUL CHECKPOINTS

When a turbine casing has been lifted for repair, there are several tests and inspections required by the Naval Ship Systems Command. A complete turbine repair guide list can be found in chapter 9410 (41) of BuShips Technical Manual. Some of the important points (see fig. 6-15, a through h) to be checked are as follows:

1. High pressure buckets (a).—Scale may be found here. It may usually be removed by washing with water; however, several other

methods are employed for hard-to-remove deposits. It is not recommended to use chemical solvents in removing scale.

2. Low pressure buckets (b).—Steam entering the low pressure turbine, having lost heat in the high pressure turbine, may contain water. The water may cut the bucket tips, especially near the entrance edge. If the bucket tips are deeply eroded, it will probably be necessary to renew the buckets. If the buckets are not replaced, the amount of erosion can be measured by using a feeler gage and a straightedge.

3. Water drainage orifices (c).—If the blading has eroded, the drain orifices will probably be plugged. The orifices will always be cleaned out so that normal drainage can take place.

4. Diaphragm joints (d).—Flow marks will be evident if there is leakage across the diaphragm joints. This leakage indicates that the joint is not properly seated. To correct severe leakage, welding and machining may be necessary or the diaphragm supports may be adjusted.

5. Rotor axial clearance (e).—The rotor axial clearance should be measured and compared with the designed clearance. If adjustments are necessary, the axial clearance can be adjusted, using the procedures explained in this chapter.

6. Journal bearing clearances (f).—If journal bearing clearances are beyond allowable limits, the bearings must be rebabbitted or replaced.

7. Shaft packing rings (g).—If the clearance of the shaft packing is beyond the manufacturer's specified tolerance, the packing rings should be renewed or reconditioned.

8. Casing interiors (h).—If erosion is found here, it may be necessary to make repairs to the eroded parts. In most instances, the casing can be welded to restore the surface.

REASSEMBLING A TURBINE

When a turbine is opened for a major overhaul, the repair guide list in BuShips Technical Manual, the type commander's instructions, the manufacturer's technical manual, and the instructions issued by the Shipyard Commander should be checked—and followed where applicable—before the turbine is reassembled.

Before reassembly of a turbine that has been opened, a very careful examination should be made of the rotor and the interior of the casing for any articles left behind. This examination should be made before the rotor is lowered into place and again before the upper

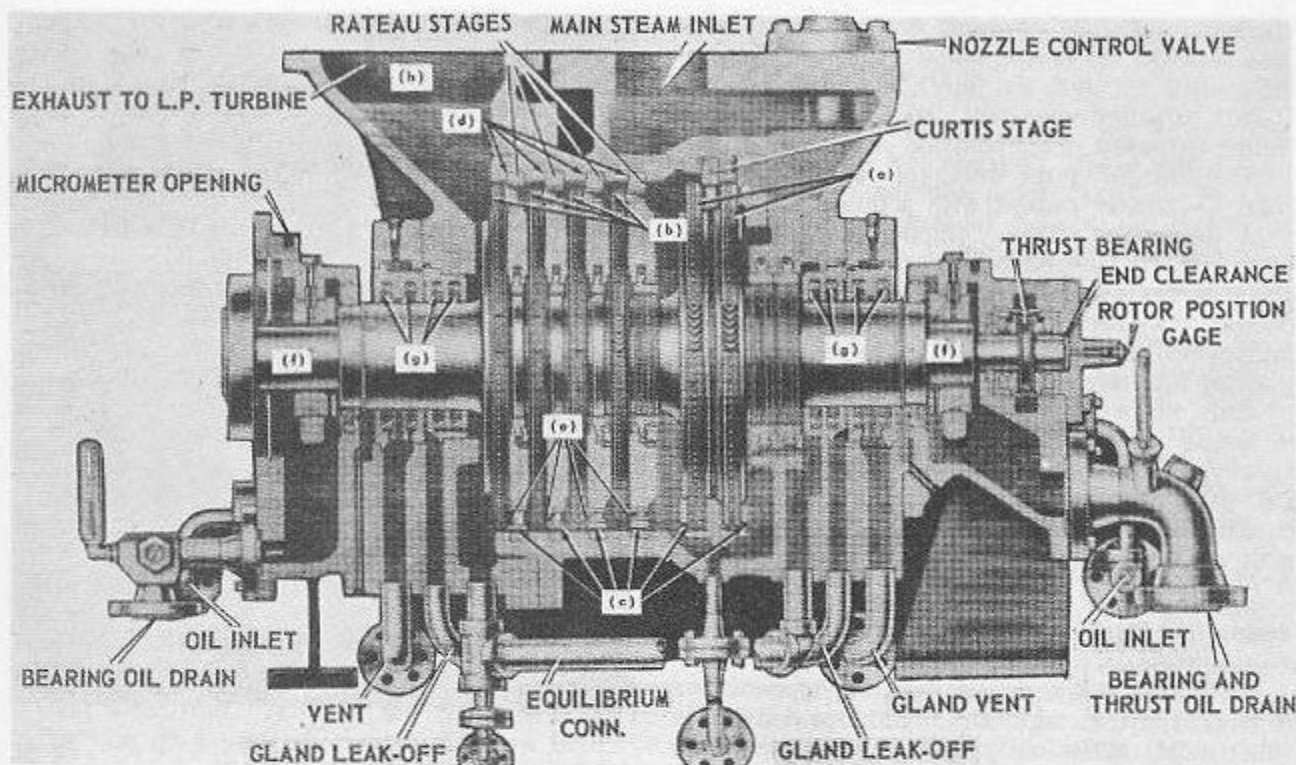


Figure 6-15.—Required overhaul checks.

47.4

casing is lowered and secured in place. This examination should be made by an authorized officer of the engineering department of the ship. If the work is being done by a naval repair activity, an engineering officer from the repair activity will also make an inspection. An entry, including the names of both officers, is to be made in the Engineering Log.

Sealing Turbine Flange Joints

Before the upper half of the turbine casing is lowered into place, the horizontal joints should be cleaned with a solvent. If the solvent fails to clean the flange, mechanical cleaning methods may be necessary. DO NOT use belt sanders or files. Use only mild scraping or a crocus cloth.

Apply a thin film of Prussian blue to the joint on the upper half casing and to the horizontal joint of internal stationary parts assembled in the upper half casing. Carefully reassemble the upper half casing on the lower half. Install all joint studs; lubricate threads

and faces of nuts and all washers, and assemble nuts. Cold tighten all studs to approximately one-half the normal operating stud stress in order to obtain a proper joint check. Disassemble joint nuts and studs and carefully raise the upper half casing and observe the blue contact on the joint of the lower half casing.

If the blue check indicates a poor contact due to local high areas, these areas should be either scraped or stoned so as to obtain a proper blue check in this area when using a surface plate not over 6 inches in diameter. In some cases, the joint may contain eroded areas and grooves caused by steam leakage. To seal these areas and grooves and prevent subsequent leakage, it may be necessary to apply a small amount of weld. The welding should be done under the supervision of a capable welding engineer.

When the joints on both the upper and lower halves of the casing show at least a continuous (approximately 85 percent) contact on the surface between the bore of the turbine casings and the bolt holes and also an intermittent

(approximately 50 percent) contact on the surface between the bolt holes and the outer edge of the casing flanges, the joints should be cleaned of all foreign material and the upper half casing lowered into position for assembling.

The entire joint surface on each casing shall be lightly coated with a thin even film of joint compound. This compound should be a triple boiled linseed oil or an approved compound in accordance with MIL-S-15204. (Sealing compounds are presently being tested for high temperatures in use today.) The use of sheet packing for flange joints is prohibited.

The main horizontal and vertical joints in some turbine casings have a system of grooves in the joint faces for pressure pumping with sealing compound during emergency repairs. These grooves shall not be filled with sealing compound during routine overhaul.

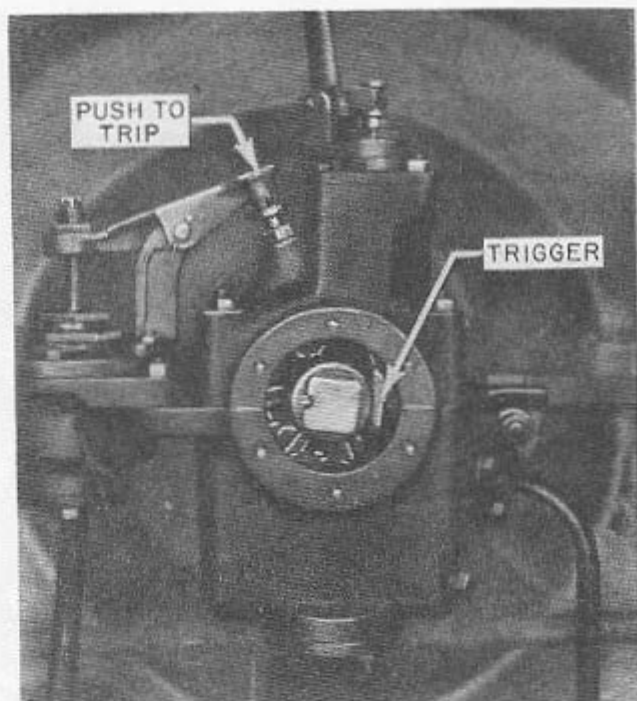
Tightening Turbine Flange Joints

With high steam pressures and temperatures it is difficult to make the turbine casing joints (when cold) sufficiently tight by using sledges or extension wrenches. Bolts are given and additional stress by tightening after heating. The heating is usually done with an acetylene torch or with electric heating elements; because acetylene torches are available on most ships, they are more commonly used. Almost all horizontal joint bolts of cruising and high pressure turbines are drilled their full length for the application of heat. In applying the heat, a standard acetylene torch is fitted with an attachment which is provided with a 1/16-inch orifice. For complete details on applying the heat and tightening the bolts, refer to the manufacturer's technical manual and BuShips Technical Manual.

SETTING OVERSPEED TRIPS

As far as turbogenerator installations are concerned, the tests, inspections, maintenance, and repairs are carried out similarly as those for main propulsion turbines. However, you should be familiar with information concerning the setting of overspeed trips.

The overspeed trip (fig. 6-16) is a device which stops the turbine, by tripping the throttle valve and shutting off the steam to the turbine, in the event of overspeed that is not checked by the constant speed governor.



96.24

Figure 6-16.—Overspeed trip mechanism.

Under normal operating conditions, the constant speed governor will not allow the speed of the unit to go beyond 100 percent of rated speed. If, because of some abnormal condition, the speed of the unit should increase to 110 ± 2 percent of rated speed, the overspeed trip will function and shut off the flow of steam to the turbine. The overspeed trip operates independently of the constant speed governor.

Overspeed trips are set at the factory and no additional adjustments should be necessary. No adjustments should be made without first having checked to make sure that all parts are clean and in proper operating condition, and then only if it has been determined by several successive trials that the tripping speed is incorrect.

If the overspeed trip should fail to function at 10 ± 2 percent of operating speed, or should it stop the generator at less than this speed, the necessary adjustments can be made as follows:

1. Remove the manual trip lever.
2. Disconnect the reset lever.
3. Remove the end plate from the turbine bearing.

4. Remove the top half of the bearing cap.
5. Turn the turbine rotor, if necessary, so that the lock screw is accessible.
6. Remove the lock screw.
7. If the overspeed trip functions at too low a speed, increase the spring tension by turning the bushing clockwise.
8. If the overspeed trip functions at too high a speed, decrease the spring tension by turning the bushing counterclockwise.

The new setting of the overspeed trip can be tested by reassembling the unit, and then starting in accordance with prescribed procedures. When the turbine is properly warmed up and up to normal operating speed, a portable tachometer may be held against the generator shaft and the speed of the unit increased until the overspeed trip functions, or 115 percent of the rated speed is reached. Repeat the operation several times because the overspeed trip tends to function at a lower speed after the first actuation. Then, if the trip continues to function at a speed greater or less than 110 ± 2 percent of normal operating speed, the trip will have to be reset. This process may have to be repeated several times in order to obtain the proper setting.

Additional information on control and safety devices may be obtained from either manufacturer's technical manuals or BuShips Technical Manual.

DOCK TRIALS

When a main propulsion turbine has been opened for inspection and repair, the work is not considered complete until a DOCK TRIAL and a POST REPAIR TRIAL have been satisfactorily completed and any deficiencies found have been corrected.

The engineer officer of each ship may issue instructions for operating the plant during a dock or post repair trial; however, the general procedure will be as follows:

Before oil is circulated through the lube oil system, muslin bags are fitted in the lube oil strainers. The muslin bags, available at naval shipyards, will prevent very FINE particles of dirt from entering the bearings and gears. A lube oil pump is started and oil is circulated through the system. The muslin bags must be

changed often (the interval of time between changes is usually set by the engineer officer). When dirt or other foreign matter is no longer found in the muslin bags, the turning gear should then be engaged. Personnel will be stationed at various points around the turbine to listen for unusual noises. If no abnormal conditions are detected, the turbine can be considered ready for a dock trial.

During a dock trial, the ship will remain tied to a pier and the engines turned by steam. The commanding officer usually determines the maximum number of rpm the engines will be permitted to turn. On a ship having two engines, one engine should turn in the ahead direction and the other engine must turn in the astern direction; then the engines should be reversed.

The main plants are warmed up in accordance with the engineer officer's instructions. When the engines are ready to be tested, the special sea detail should be stationed. The officer of the deck will shift his watch from the quarter deck to the bridge and personnel will be stationed around the turbines to detect unusual noises or other abnormalities. When all stations are manned and the engineering plant is ready, the engineer officer will request permission from the bridge to test main engines. When the OOD is certain that the area around the fantail is clear of boats, mooring lines, etc., he will grant permission to test main engines. When the main engines have been tested and found satisfactory, the engineer officer will report to the bridge that the main engines are ready for dock trial. One main engine will then be designated to go in the ahead direction and the other main engine will be designated to go in the astern direction. The appropriate orders will be rung up on the engine order telegraph and the required rpm will be indicated on the engine order telegraph. When these orders are received in the engine-room, the engine itself will be turned, by steam, at the indicated rpm. If no abnormal conditions are found, the engineer officer will request an increase in speed. The OOD will order the rpm increased (about 5 rpm each change) until the maximum allowable rpm is reached. If no abnormal conditions are detected, the main engines may be considered ready for a post repair trial.

Information on Post Repair Trials is given in BuShips Technical Manual and in Engineering Administration, NavPers 10858-C.

SAFETY PRECAUTIONS FOR TURBINES

Turbine installations in the Navy vary to such an extent that detailed safety precautions for each type cannot be covered in this training course. The following general safety precautions are prescribed by the Naval Ship Systems Command and should be observed:

1. Be sure that the lubrication system is operating properly before turning over the main engines.
2. Keep the rotors turning over continuously while the main engines are being warmed up.
3. Never fail to investigate any unusual noise coming from a turbine.
4. Do not put way on the ship when turning over the main engines during warmup.

5. If a turbine vibrates, slow it down, investigate and locate the cause.

6. Except in an emergency, do not admit steam to the astern turbine until steam to the ahead turbine is secured, and vice versa.

7. Before getting under way, be sure that all steam lines are drained properly.

8. When steam pressure drops, do not open the throttle to such an extent that the operating pressure of the steam drops to a dangerously low point.

9. Stop the engines immediately if the oil supply fails.

10. If the throttle valve sticks, close the guarding valve as soon as possible. In an emergency, the guarding valve can be used as a throttle.

11. Exercise care to prevent the entry of foreign matter into a turbine when it is opened for inspection.

CHAPTER 7

REDUCTION GEARS AND RELATED EQUIPMENT

In order to understand the care and operation of propulsion reduction gears, the engineer officer should be familiar with the general principles of gear design. The manufacturers of the different gears in use in the naval service have issued technical manuals, which should be thoroughly studied. The engineer officer should also be thoroughly familiar with the detailed plans of the gears which may be included in the engineering drawings furnished the ship. It is the responsibility of the engineer officer to ascertain that the required manuals and drawings for the specific equipment are on board.

This chapter contains information on the operation, care, and maintenance of reduction gears found on Navy ships. It also includes information on related equipment such as bearings and shafting. Additional details concerning a specific reduction gear installation can be obtained from the manufacturer's technical manual.

REDUCTION GEARS

Figure 7-1 illustrates some of the more common types of gears found in various shipboard machinery. Probably one of the simplest types of reduction gearing is the worm gear, found in auxiliary machinery. Single and double helical gears are found on ships with more complicated types of propulsion machinery.

Steam turbines must operate in a relatively high rpm range for greatest efficiency while propellers operate most efficiently in a relatively low rpm range. One means of accomplishing the necessary stepdown from high turbine shaft rpm to lower propeller shaft rpm is by use of an electric drive. The most common means of obtaining the required propeller rpm for ship propulsion is by use of reduction gears.

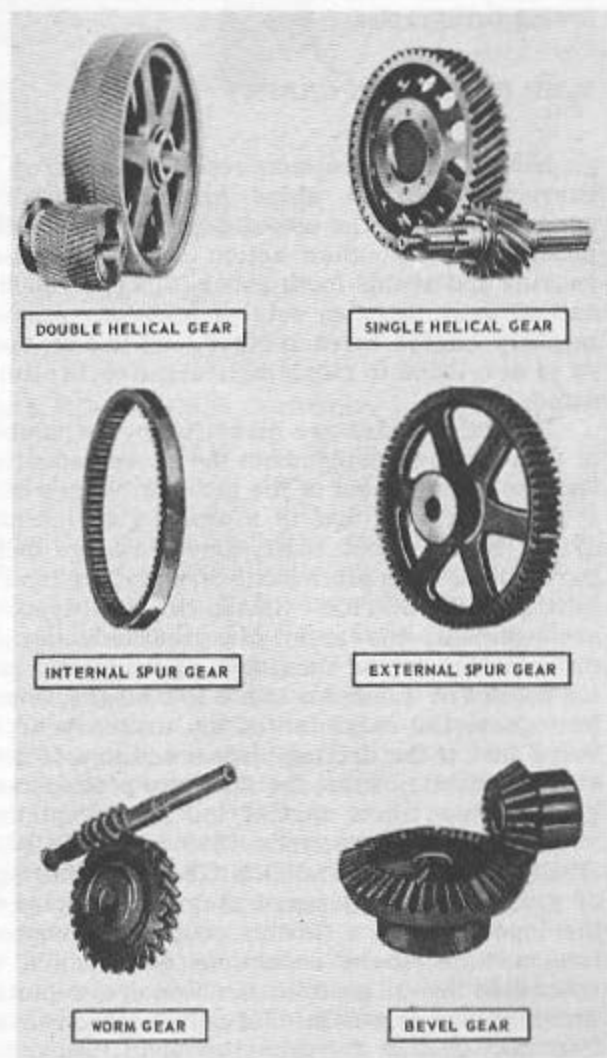


Figure 7-1.—Types of gears found in shipboard machinery.

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The use of reduction gears is by no means limited to ship propulsion. Other steam turbine-driven machinery such as ship's service generators, air compressors, and various pumps also have reduction gears. In these, as in ship propulsion units, turbine operating efficiency requires a higher rpm range than that suitable for the driven unit.

The construction, operation, and minor maintenance of main reduction gears, used with propulsion turbines and reduction gears used on auxiliary turbines, will be discussed in the following paragraphs.

MAIN REDUCTION GEARS

Most main propulsion reduction gearing in current combatant ships has double helical gears (fig. 7-1). The use of double helical gears produces a smoother action of the reduction gearing and avoids tooth shock. Since the double helical gear has two sets of teeth at complementary angles to each other, end thrust, such as is developed in single helical gears, is eliminated.

Reduction gears are classified by the number of steps used to bring about the speed reduction and the arrangement of the gearing. Where only a pair of gears, that is a small gear (pinion) driven by the input shaft, drives a large (bull) gear on the propeller shaft directly, we have a SINGLE REDUCTION GEAR. In this type of arrangement, the ratio of speed reduction is proportional to the diameter of the pinion and the gear. For example, in a 2 to 1 single reduction gear, the diameter of the driven gear is twice that of the driving pinion; and in a 10 to 1 single reduction gear, the diameter of the driven gear is ten times that of the driving pinion.

Most ships built since 1935 have DOUBLE REDUCTION PROPULSIONS GEARS. In this type of gear set, a high speed pinion, connected to the input shaft by a flexible coupling, drives an intermediate (first reduction) gear which is connected by a shaft to the low speed pinion which in turn drives the bull gear (second reduction) mounted on the propeller shaft. Thus, for example, a 20 to 1 speed reduction might be accomplished by having a ratio of 2 to 1 between the high speed pinion and the first reduction gear, and a ratio of 10 to 1 between the low speed pinion on the first reduction shaft and the second reduction gear on the propeller shaft ($6000 \div 2 = 3000 \div 10 = 300$).

For a typical example of a double reduction gear application, consider the main reduction gear installation on a DD-692 class destroyer:

The cruising turbine is connected to the high pressure turbine through a single reduction gear. The cruising turbine rotor is solidly attached to a pinion which drives the cruising bull gear; the cruising bull gear is connected to the high pressure turbine shaft by a flexible coupling. The cruising turbine rotor and pinion are supported by three bearings, one at the forward end of the turbine and one on each end of the pinion in the cruising reduction gear case.

The high pressure and low pressure turbines are connected to the propeller shaft through a locked train type of double reduction gear (fig. 7-2). First reduction pinions are connected by flexible couplings to the turbines. Each of the first reduction pinions drives two first reduction gears. Attached to each of the first reduction gears by a quill shaft and flexible couplings is a second reduction (slow speed) pinion. These four pinions drive the second reduction (or bull) gear which is attached to the propeller shaft.

Types of Double Reduction Gears

The DD-692 class destroyers have a LOCKED TRAIN GEARING. There are two other arrangements of double reduction gearing in use—the ARTICULATED GEARING and the NESTED GEARING.

ARTICULATED.—Typical articulated propulsion reduction gears (fig. 7-3) have two first reduction pinions (high speed), two first reduction gears, two second reduction pinions (slow speed), and a main gear. The first reduction pinions are connected to their respective turbines by flexible couplings. The first reduction gears are usually connected to the second reduction pinions by a shaft which passes through the bores of the pinions and gears and is coupled, at one or both ends, by a flexible coupling.

The articulated type of gearing generally has more bearings and occupies more longitudinal space in a ship than the nested or locked train double reduction gearing.

NESTED.—The nested gearing is the simplest of all double reduction gears. Nested double reduction gearing employs no quill shafts and uses a minimum number of bearings and flexible

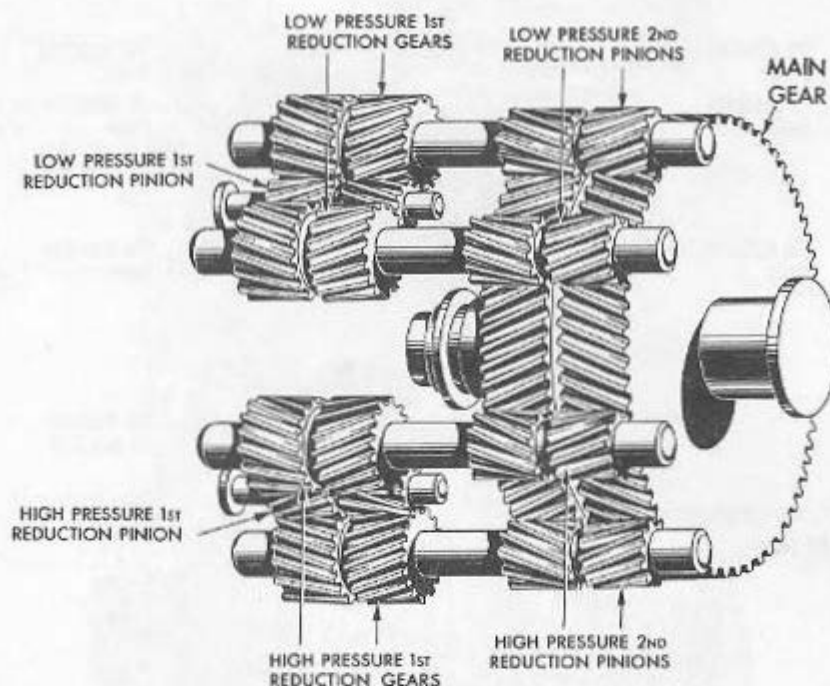


Figure 7-2.—Double reduction gear of a DD-692 class destroyer.

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couplings. Figure 7-4 shows two different types of nested reduction gears. Note that in part B of Figure 7-4, the helixes of the first reduction gear wheels are on separate wheels, and these wheels straddle the second reduction gear wheel.

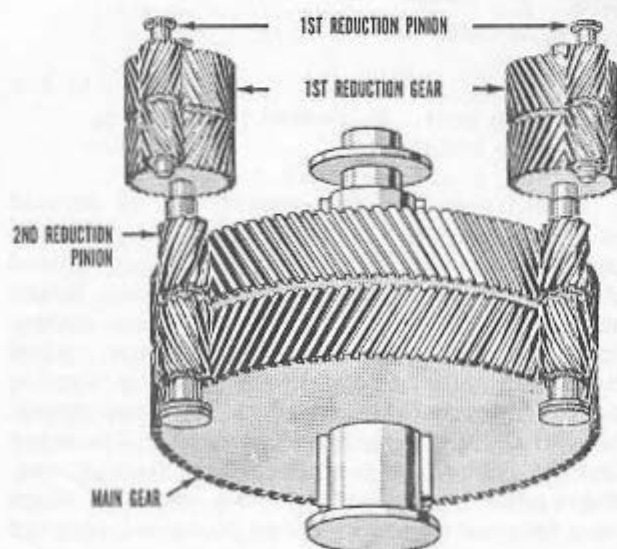


Figure 7-3.—Articulated type of double reduction gearing.

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LOCKED TRAIN.—In the locked train type of double reduction gearing (fig. 7-2), each high speed pinion meshes with, or drives, two first reduction gears and thus transmits power to two second reduction pinions. Since the power path between each first reduction pinion and the main gear is split two ways instead of one way, the load on the gear teeth under a given power condition can be designed to be considerably less than it is in other types of main reduction gearing of equivalent dimensions. For a particular power rating, locked train reduction gear units can therefore be made more compact than any of the other types of reduction gears. For this reason, high powered ships, currently used by the Navy, are equipped with locked train reduction gears.

Figure 7-5 illustrates a turbine and reduction gear installation in a DD-692 class destroyer. Most ships do not have cruising turbines and cruising reduction gears, so details will vary; but most propulsion reduction gears used on destroyer type ships follow the same general pattern. Note the size of the locked train double reduction gearing for the main turbines as compared with the size of the single reduction gearing for the cruising turbine.

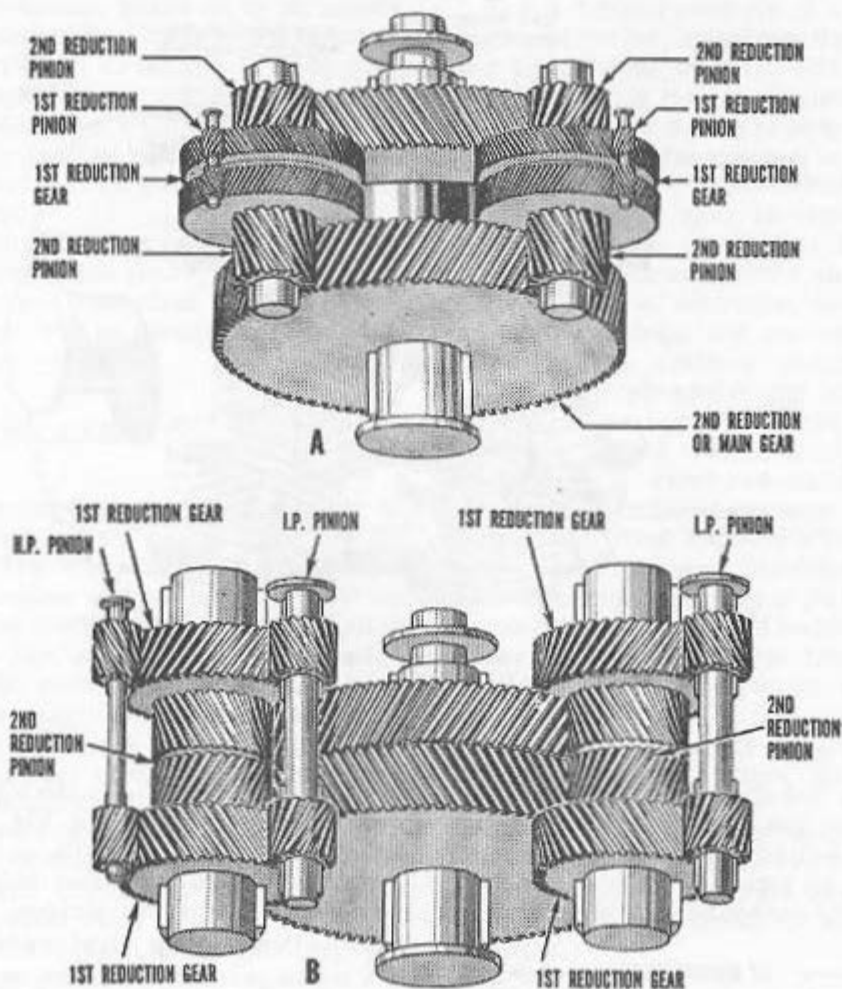


Figure 7-4.—A. Nested type gearing, with divided main gear. B. Nested type gearing with divided first reduction pinion and gear.

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Construction of Main Reduction Gears

The gears in a main reduction gear unit operate at high rotational speed and must be capable of transmitting tremendous power loads. Since even very slight unevenness of tooth contour and tooth spacing would cause the gears to operate noisily or even to fail, special precautions are taken to manufacture the gears to very close limits. The gears are cut in rooms in which the temperature and humidity are kept constant. Expansion and contraction of the gear-blank, during machining, are negligible; oxidizing, due to moisture in the air, is virtually eliminated. In addition, all gears are carefully checked for errors.

CASINGS.—The gear casing can be divided into three parts. The lower part is called the base section, or the lower case. It is used to support the bull gear, the main thrust bearing, and the upper parts of the main reduction gear. The intermediate section, called the upper case, supports the bearing housing for the intermediate speed pinions and gears, as well as the high speed pinions. The other part of the gear casing is the main cover. The cover is divided into two sections which have inspection ports. These ports are covered by easily operated hinged plates and so located that the teeth of any pinion or gear can be examined without the necessity of lifting the main cover sections.

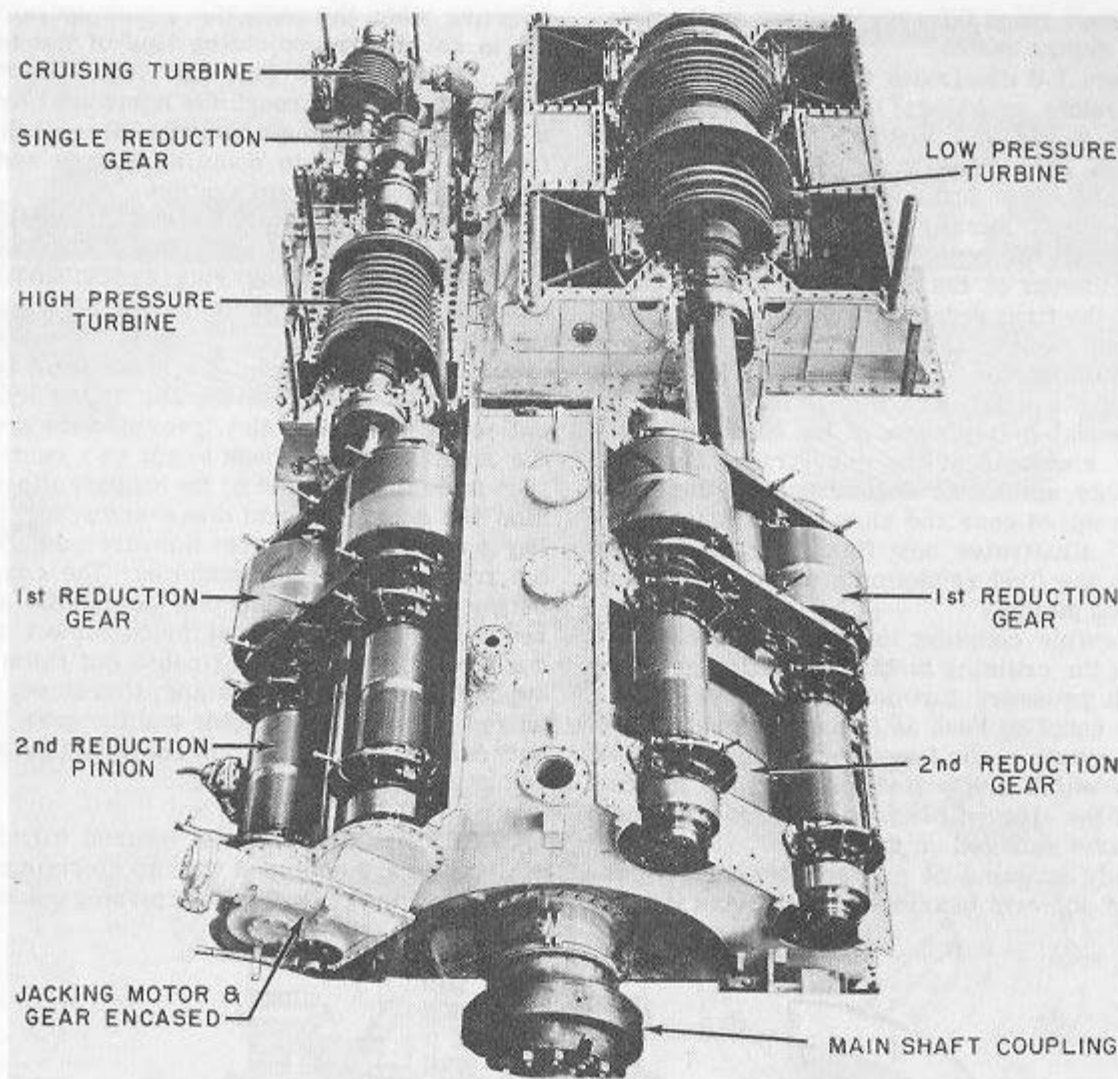


Figure 7-5.—Turbine and locked train double reduction gearing installed on a DD-692 class destroyer.

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GEARS.—Double helical type gears are capable of transmitting large power loads smoothly, and do not impart axial thrust to either the driving member or the driven member.

In most reduction gears, all pinions are completely machined out of specially heat-treated nickel-steel forgings. The gear wheels are generally of built-up construction, with the teeth cut in forged steel bands which are welded to steel webs. The first reduction gears are generally welded on their respective shafts. The bull gear is usually pressed on the shaft against a locating shaft shoulder, secured by one or

more keys and locked, with a locknut, on the shaft.

FLEXIBLE COUPLINGS.—Flexible couplings provide longitudinal and radial flexibility between the input shaft and the pinion. This permits each shaft to be adjusted axially and radially to its proper position without imposing excessive forces.

In most installations the flexible couplings are of the gear type. Power is transmitted through a floating intermediate member with external teeth that mesh with the internal teeth

of the shaft rings (sleeve) mounted on the driving and driven shafts.

Figure 7-6 illustrates the design of the gear type flexible couplings that connect the main turbines to the high speed pinions of the main reduction gear. The couplings also allow for expansion of the turbine shafts, and take care of any slight misalignment between the main turbines and the reduction gears.

The design of the flexible couplings, which connect the first reduction gears and the second reduction pinion, is shown in figure 7-7. In these couplings, a quill shaft on high torsional flexibility is used, as the floating member, to obtain equal distribution of the load among the several elements of the gear train. The quill shaft runs inside the hollow bore of the intermediate speed gear and slow speed pinion. Figure 7-7 illustrates how flexibility is obtained between the first reduction gear and the second reduction pinion.

A flexible coupling is installed in the shaft between the cruising turbine reduction gear and the high pressure turbine. Figure 7-8 shows a flexible coupling such as is used on destroyers. In this coupling, the floating member is the two sleeves which are bolted together; the internal teeth of the sleeves mesh with the external teeth of the hubs mounted on the shaft.

Steady streams of oil from the supply passages of adjacent bearings are directed into the

coupling when the reduction gears operate. The oil is caught by projecting lips of the turbine and pinion flanges (see fig. 7-6). Centrifugal action forces oil through the horizontal holes in the flanges to the coupling teeth. Oil is discharged from the teeth into coupling guards and then flows into the oil drain system.

In order to ensure a flooded oil condition in the area of the coupling teeth a "snap in" type of oil dam and retaining ring is provided in most couplings. Referring to figure 7-6 this dam would be placed in the shaft rings at the end of the teeth at the oil outlet. This dam provides for oil flooded coupling teeth, but it also acts as a collecting point for dirt, provided the speed of the shaft is high enough to act as a centrifuge. Dirt is centrifuged out of the oil and collects behind the dam. Frequent disassembly and cleaning is required to prevent this dirt from limiting the free action of the coupling. The couplings between the first reduction gears and second reduction pinions run at much slower speed; consequently, the dirt is flushed out rather than deposited. Frequent cleaning, therefore, is required between the turbine and the gear but not between the first reduction gears and the second reduction pinions.

TURNING GEARS.—All geared turbine installations are equipped with an electric motor-driven turning gear. A typical turning mechanism

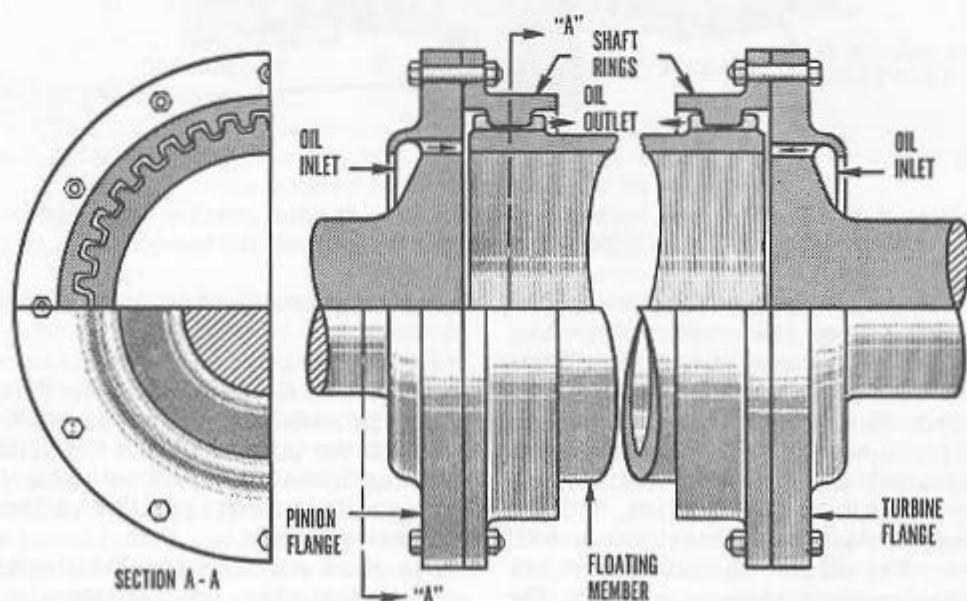


Figure 7-6.—Gear type of flexible coupling.

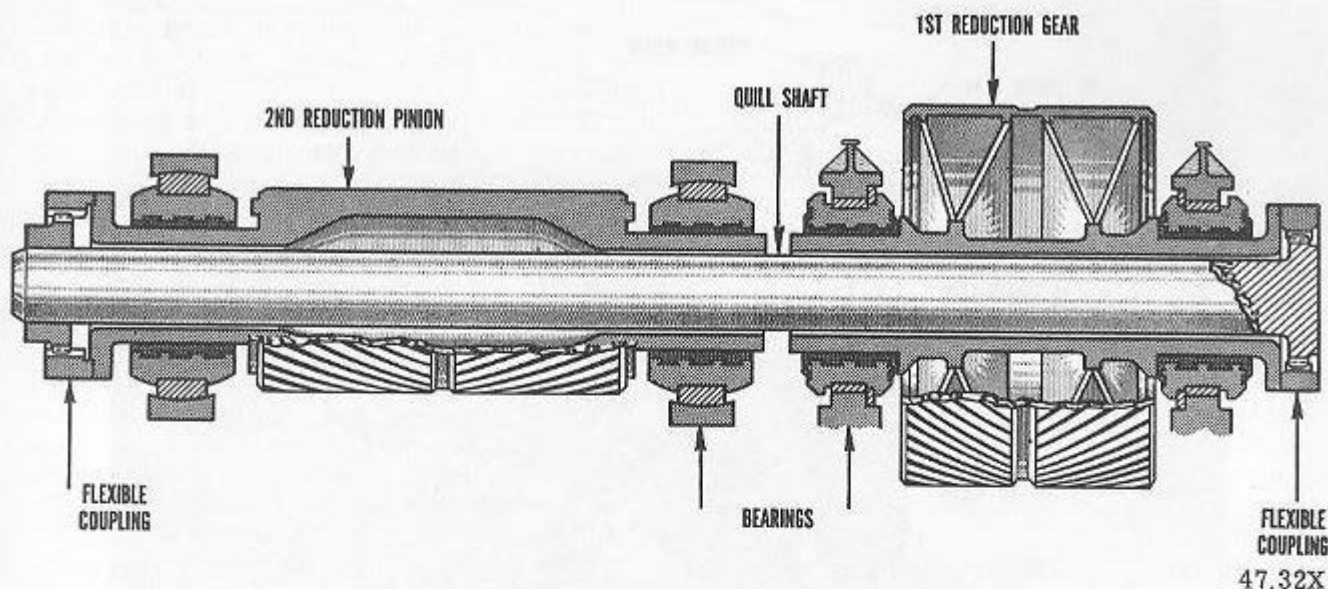


Figure 7-7.—Quill shaft assembly.

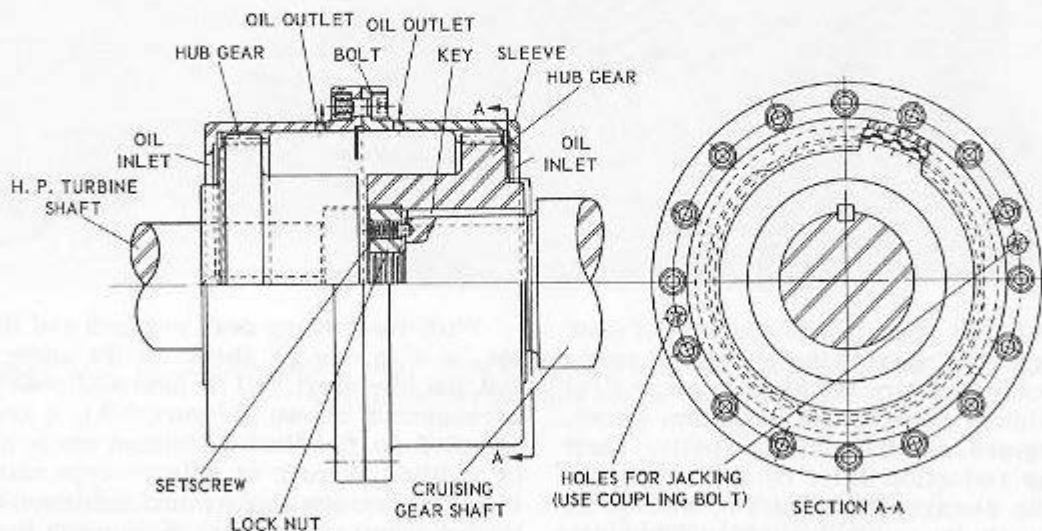
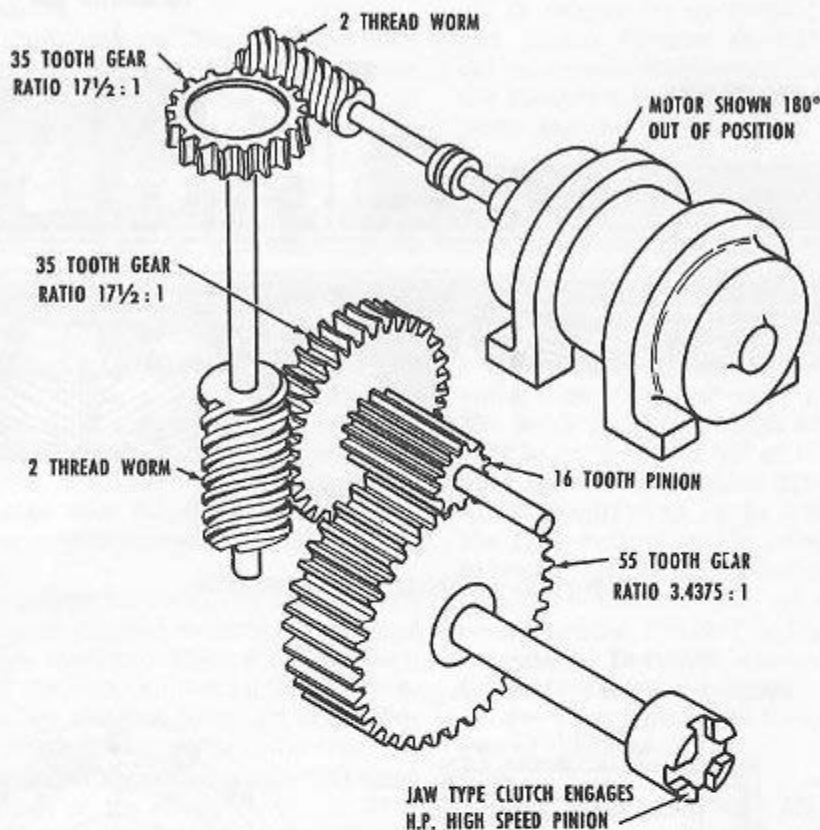


Figure 7-8.—Flexible coupling between the cruising gear and the high pressure turbine.

is illustrated in figure 7-9. The unit is used for turning the main engine during warming-up and securing periods so that the turbine rotor may heat or cool evenly. (The rotor of a hot turbine or of one that is in the process of being warmed up, with gland sealing steam cut in, will become bowed or distorted if left stationary even for a few minutes.) The turning gear is used for other routine purposes such as for turning the engine in order to bring the reduction gear teeth into view during routine inspection. In addition, the

turning gear is used for the required daily jacking of the main engines.

The turning gear (fig. 7-9) is mounted on top and at the after end of the reduction gear casing. A shaft, extending from the end of the high pressure first reduction pinion over the bull gear to the after end of the reduction gear casing, connects to the turning gear by means of a manually operated jaw clutch. Engaging this clutch connects the pinion to an electric motor, through a train of gears, which usually



47.34

Figure 7-9.—Turning gear mechanism.

consist of a set of worm gears and sets of spur or helical gears. Engaging the clutch and operating the motor will turn the high pressure first reduction pinion, causing the reduction gears, the main engines, and the main (propeller) shaft to turn. The reduction ratio between the main shaft and the electric motor may be as high as 16,000 to 1; with the motor turning and the turning gear engaged, the main shaft will make one turn in approximately 10 minutes. Because of this high ratio, if the shaft was allowed to turn at 1 rpm, the motor would overspeed and be seriously damaged.

The turning gear is equipped with a propeller locking device (fig. 7-10) which is used when it becomes necessary to lock a propeller against rotation while underway. A friction brake is generally installed on the first reduction worm shaft. Either a brake drum is mounted on the worm shaft or the shaft coupling serves as a drum. (NOTE: Many locking arrangements don't have a brake on the worm shaft.)

With the turning gear engaged and the brake set, a ship can go ahead on its other engines and the idle shaft will be held stationary. In the arrangement shown in figure 7-11, a drum (1) is mounted on the first reduction worm shaft (2). In addition, a pair of scissor-type clamp jaws (3 and 4) are mounted around the drum; they are hinged together by a pin (5) through the anchor support block (6). An adjustable screw (7) is arranged below the lower clamp jaw (4) to support it in such a position that, when released, the jaw will not drag on the drum. A screw shaft (8) has threads at its lower end which screw into the lower clamp jaw (4). When the crank handle (9) is turned in a clockwise direction, the screw shaft draws the upper clamp jaw toward the lower clamp jaw and tightens the jaws around the drum. This brake stops the rotation of the worm gear shaft. A spring (10) is mounted between the clamp jaws so that when the screw (8) is released, the clamp jaws are forced open; this action lifts the upper jaw and drops the lower

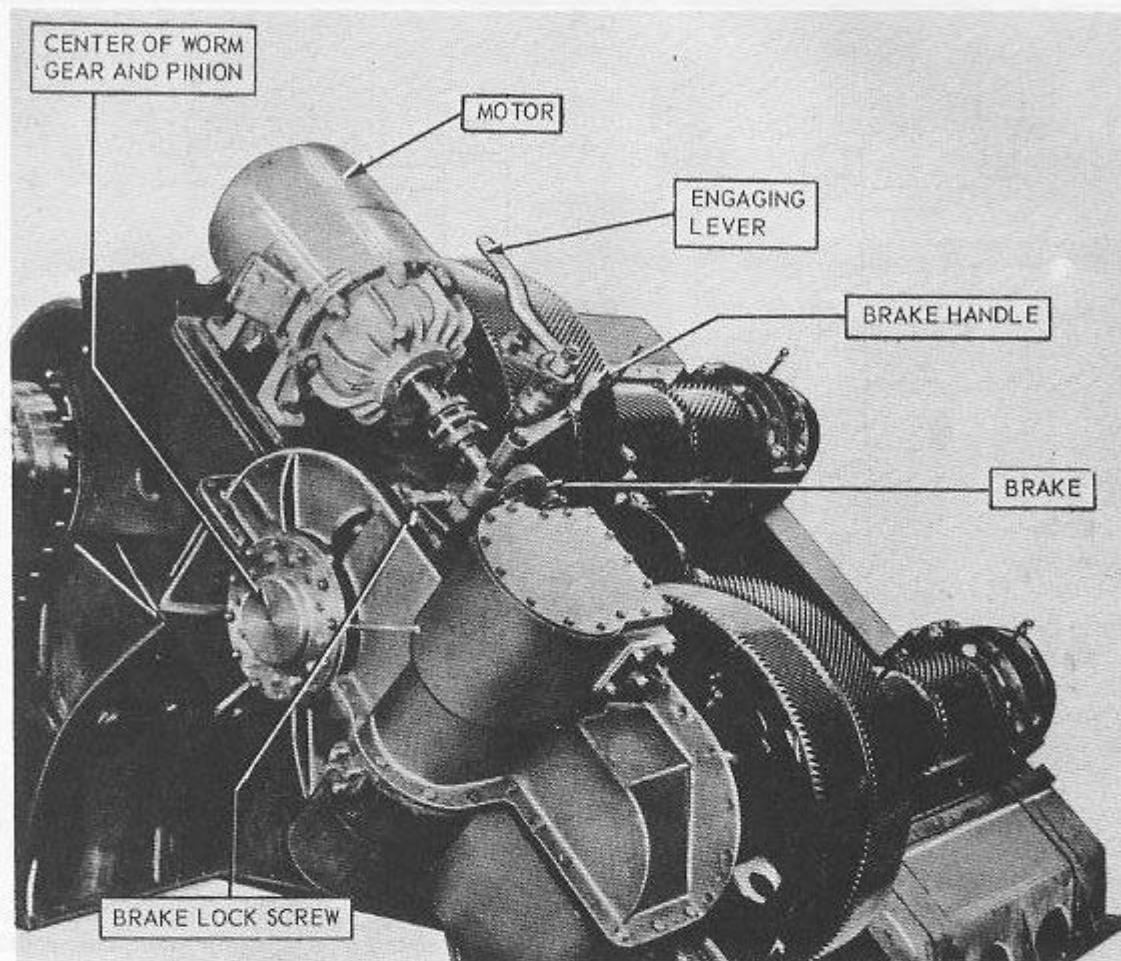


Figure 7-10.—Main reduction gear after end, high pressure side, showing turning gear and propeller locking mechanism.

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jaw free from the drum. Another screw (11) is provided to clamp the screw (8) in either the locked or unlocked position so that accidental engaging or disengaging of the brake jaws cannot occur.

In order to engage the turning gear clutch it is necessary to first stop the shaft, either by stopping the ship or by using the astern turbine to stop and then hold the shaft stationary. The turning gear must never be engaged with the shaft turning. Regardless of how slow the shaft movement may be, damage to the motor or gears, or both, will occur. While the ship is moving the clutch should never be engaged without using the brake and continuing oil circulation to the main engine and reduction gear bearings.

REDUCTION GEARS FOR AUXILIARY MACHINERY

In the previous section of this chapter, main reduction gears of the double helix, double reduction type, were discussed. In smaller units of engineroom machinery, such as turbogenerators and turbine-driven pumps, there are different types of reduction gears.

Turbogenerators

Most ship's service turbogenerators use a single reduction, single helix type of reduction gearing. An example of this type is found on the DD-692 class destroyers. A gear ratio of 8.3825 reduces the turbine speed of 10,059 rpm to the

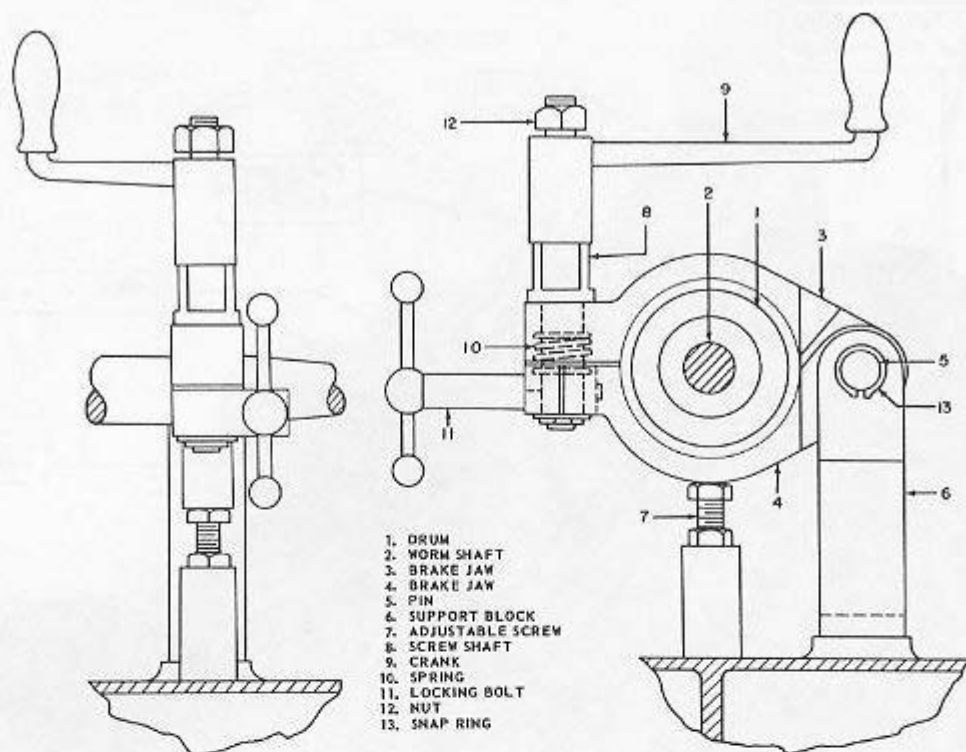


Figure 7-11.—Propeller shaft locking device.

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generator speed of 1200 rpm. The pinion is forged integral with the shaft. One end of the pinion shaft is flanged and bolted rigidly to the turbine shaft. On the other end, a high speed thrust bearing is mounted to maintain the axial position of the pinion and turbine rotor. The gear wheel is a steel forging pressed and keyed on its shaft. One end of the shaft is coupled solidly to the generator shaft, the turbine end is extended to carry the gear that drives the oil pump and governor.

Main Circulating Pumps

Turbine-driven main circulating pumps employ another type of helical gear (fig. 7-12). Single reduction, double helical gears with a ratio of about 8 to 1 reduce the turbine speed of approximately 5000 rpm to the pump speed of 600 rpm. Lubrication of the reduction gear is provided by a gear type pump mounted on the lower end of the pinion shaft. Oil is sprayed through an orifice into the space between the gear teeth.

The weight of the combined rotating element of the pump and the driving unit is carried on a

Kingsbury-type thrust bearing which supports a collar mounted at the upper end of the reduction gear shaft. The weight of the turbine rotor and pinion shaft is transmitted to the Kingsbury thrust bearing through the teeth of the double helical reduction gear.

The pinion is a solid forging, while the gear is constructed by welding a forged hub, forged rim, and plate sidewalls. The gear hub is bolted to a spider which is keyed to the gear shaft and held in place by the thrust collar which screws on to the shaft and locks with a setscrew.

Main Condensate Pumps

In the reduction gears used on a turbine-drive main condensate pump, shown in figure 7-13, a worm shaft and worm wheel reduce the turbine speed of 5534 rpm to the pump speed of 1145 rpm. The worm is cut in a solid, low carbon, nickel-steel forging. It is carried in two babbitt-lined split sleeve bearings and is located axially by a collar type thrust element. One end is tapered for mounting the turbine wheel while the other is squared for the application of a turning wrench.

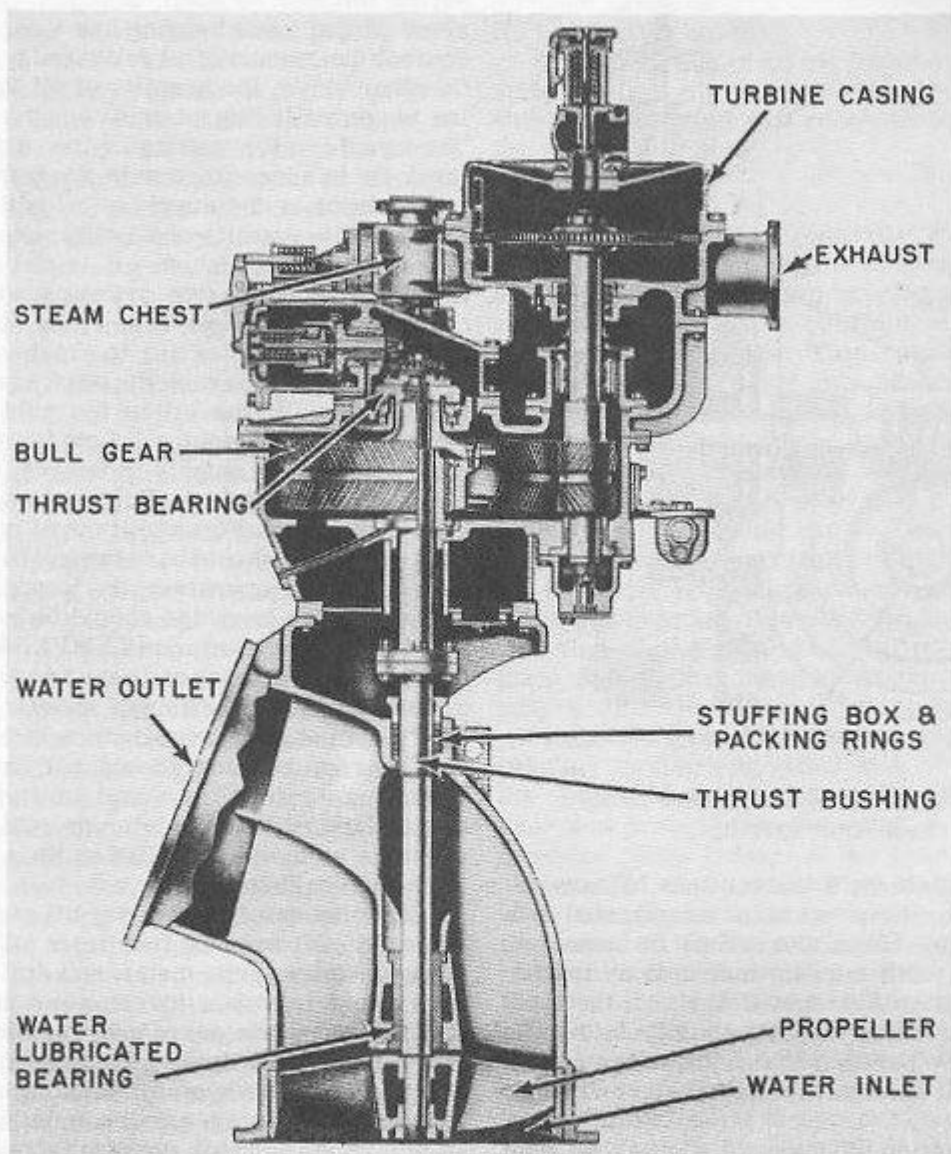


Figure 7-12.—Main condenser circulating pump (showing reduction gearing).

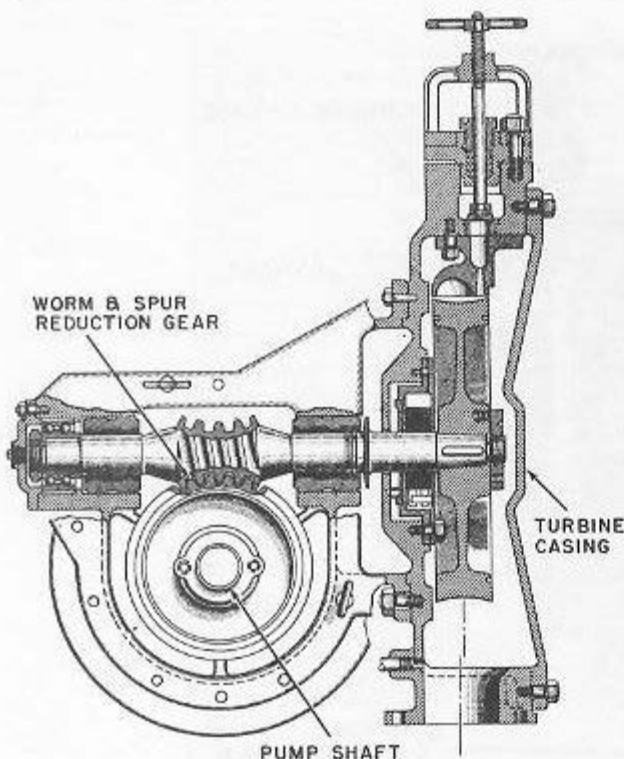
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The worm wheel is a solid, nickel-bronze casting; it is pressed on a forged steel shaft which carries the drive pinion for the speed limiting governor and the driving half of the main pump coupling. The gear casing is cast steel, specially designed to form a rigid support for the rotating elements. The gear case is of rugged construction to ensure proper alignment of the driving and driven elements, and is split horizontally to allow assembly and disassembly. The gear unit has a separate, closed pressure

oil system; the bottom half of the gear casing serves as the oil sump.

CARE AND OPERATION OF REDUCTION GEARS

Some things are essential for the proper operation of reduction gears. Proper lubrication includes supplying the required amount of oil to the gears and bearings, plus keeping the oil clean and at the proper temperature. Locking and unlocking the shaft must be done in accordance



47.38

Figure 7-13.—Main condensate pump reduction gearing.

with the manufacturer's instructions. Abnormal noises and vibrations must be investigated and corrective action taken. Gears must be inspected in accordance with current instructions issued by the Naval Ship Systems Command, the type commander, or other proper authority. Information given in the sections which follow is supplementary to that given in the chapters on turbines.

Proper Lubrication of Gears

Proper lubrication of reduction gears and bearings is of the utmost importance. The correct quantity and quality of lubricating oil must, at all times be available in the main sump. The oil must be **CLEAN**; and it must be supplied to the gears and bearings at the pressure specified by the manufacturer. (With clean, pure oil supplied at the designed pressure and temperature, reduction gears may operate successfully for several years.)

In order to accomplish this, several conditions must be met. The lube oil service pump must deliver the proper discharge pressure. All relief valves in the lube oil system must be

set to function at their designed pressure. On some ships, each bearing has a needle valve to control the amount of oil delivered to the bearing. On other ships, the quantity of oil to each bearing is controlled by an orifice in the supply line. The needle valve setting or the orifice opening must be in accordance with the manufacturer's instructions or the supply of oil will be affected. Too small a quantity of oil will cause the bearing to run hot. If too much oil is delivered to the bearing, the excessive pressure will cause the oil to leak at the oil seal rings. Too much oil may also cause a bearing to overheat.

Lube oil must reach the bearing at the proper temperature. If the oil is too cold, one of the effects is insufficient oil flow for cooling purposes. If the oil supply is too hot, some lubricating capacity is lost. For most main reduction gears, the normal temperature of oil leaving the lube oil cooler should be between 120°F and 130°F. For full power operation, the temperature of the oil leaving the bearings should be between 140°F and 160°F. The maximum **TEMPERATURE RISE** of oil passing through any gear or bearing, under any operating conditions, should not exceed 50°F; and the final temperature of the oil leaving the gear or bearing should not exceed 180°F. This temperature rise and limitation may be determined by thermometer or resistance temperature elements installed in the oil discharge from the bearings.

Cleanliness of lubricating oil cannot be overstressed. Oil must be free from all impurities, such as water, grit, metal, and dirt. Particular care must be taken to clean out metal flakes and dirt when new gears are wearing in or when gears have been opened for inspection. Lint or dirt, if left in the system, will clog the oil spray nozzles. The spray nozzles must be kept open at all times. Spray nozzles should never be altered without the authorization of the Naval Ship Systems Command.

The lube oil strainers perform satisfactorily under normal operating conditions, but they cannot trap particles of metal and dirt which are fine enough to pass through the mesh. These fine particles can become embedded in the bearing metal and cause wear on the bearings and journals. These fine abrasive particles passing through the gear teeth act like a lapping compound and remove metal from the teeth.

Effects Of Acid And Water In Oil

Water and acid in oil are extremely dangerous. The oil must be tested frequently for water

and at regular periods for acid. Even a small amount of water in oil can cause pitting and rusting. Fresh water can accumulate, due to leaking turbine packing glands or from condensation. Where main sump tanks are located at the skin of the ship, salt water may leak into the lube oil. Salt water may also enter through leaks in the lube oil cooler. When salt water is found in a lube oil system, corrective steps must be taken. The source of the salt water must be found and sealed off. The contaminated oil must be removed from the system by adequate flushing with clean oil.

When oil is contaminated with fresh water, adequate purification will prevent an accumulation of water in the oil but the source of water must be found and eliminated. Under normal operating conditions, operating the lube oil purifier 12 hours a day, while underway, will be sufficient; however, if the presence of fresh water is noted, the purifier will have to be operated until there is no visual indication of water in the oil and no water is discharged from the purifier. If, with additional purifier operating time, the oil does not clear up, the purifier should be checked for improper operation. The presence of salt water or fresh water in lube oil should never be ignored. The system should be checked immediately and the source of contamination should be eliminated.

When the turbines are secured, a lube oil pump should be kept running and the turning gear should be engaged and kept turning until the turbines have reached approximately room temperature (ambient). While oil is circulating, the lube oil cooler should be left in use and the purifier should be operated. Circulating oil will carry away the heat from the turbines which might otherwise reach the bearings. Operating the purifier will eliminate water caused by condensation on the interior of the reduction gear casing.

Ships should take advantage of every opportunity to have laboratory tests made of the lube oil. Samples should be tested for water, acid, and sediment content. When the neutralization number exceeds 0.50 the lube oil should be replaced.

Oil Emulsion

With continuous use, the lube oil will increase in acidity, and the free fatty acids will form mineral soaps which can form a stable oil and water emulsion. Once the emulsion has formed, the removal of water becomes more

difficult, and of more importance, the oil loses its lubricating quality.

The formation of an oil film becomes impossible and the oil must be renovated. Operating with emulsified oil will result in wiped bearings and worn gear teeth.

Main Sump Oil Level

Lubricating oil is generally supplied to the gears from the main engine lubrication system, with a connection to each bearing and with nozzles located so that a constant spray of oil is directed to the gears. This constant spray of oil over the gears, not only lubricates but also cools the gears. For reduction gears, where the maximum oil level in the sump may reach the bottom of the bull gear, positive means are taken to ensure that the bull gear does not dip into the oil. An oil excluding pan is fitted around the bottom of the bull gear to prevent oil from reaching it, during normal operation.

If the gear is allowed to dip into the oil, the churning action of the gear will cause the oil to foam and to heat up. Under normal conditions, only a small quantity of oil comes in contact with the bull gear, therefore no dangerous vibration and no churning effect will occur. Oil from the gears is swept out of the pan by the bull gear and drained into the sump. A drain hole is provided on the bottom of the pan so located that drainage of any accumulated water is assured when the ship is on an even keel. When there is too much oil in the sump, the gear will churn and aerate the oil, causing a sudden increase in temperature. If this occurs, the engines must be slowed or stopped until the excess oil can be removed and normal conditions restored. Routine checks should be made to see that the lubricating oil is maintained at the proper level. Any sudden loss or gain in the amount of oil, in the main sump, should be immediately investigated.

Noises and Vibration

On steam turbine-driven ships, some noises may occur at low speeds or when maneuvering, or when passing through shallow water, which do not result from any defect in the propulsion machinery and will not occur during normal operation. A rumbling sound which occurs at low shaft rpm is generally due to the low pressure turbine gearing floating through its backlash. This condition has also been experienced with cruising reduction gears. The rumbling and thumping noises which may occur during maneuvering or during operation in shallow

water, are caused by a torsional vibration initiated by the propeller. These noises referred to are characteristic only of some ships and should be regarded as normal sounds for these units. These sounds will disappear with a change of propeller rpm or when the other causes mentioned are no longer present. These noises can usually be noticed in destroyers when the ship is backing, especially in choppy seas or in ground swells.

UNUSUAL NOISES.—A properly operating reduction gear has a definite sound. At different speeds and under various operating conditions, the operator should be familiar with the normal operating sound of the reduction gears on his ship.

If any abnormal sounds occur, an investigation should be made immediately. In making an investigation, much will depend on how the operator interprets the sound or noise.

The lube oil temperature and pressure may or may not help an operator determine the reasons for the abnormal sounds. A badly wiped bearing may be indicated by a rapid rise in oil temperature for the individual bearing. A certain sound or noise may indicate misalignment or improper meshing of the gears. If unusual sounds are caused by misalignment of gears or foreign matter passing through the gear teeth, the shaft should be stopped and a thorough investigation should be made before the gears are operated again.

VIBRATION.—The most common causes of vibration in a main reduction gear installation are: faulty alignment, bent shafting, damaged propellers, and improper balance.

A gradual vibration in a main reduction gear that has been operating satisfactorily for a long period of time can usually be traced to a cause outside of the reduction gears. The turbine rotors, rather than the gears, are more likely to be out of balance.

When reduction gears are built, the gears are carefully balanced (both statically and dynamically). A small amount of unbalance in the gears will cause unusual noise, vibration, and abnormal wear of bearings.

When the ship has been damaged, vibration of the main reduction gear installation may result from misalignment of the turbine, the main shafting, the main shaft bearings, or the main reduction gear foundation. When vibration occurs within the main reduction gears, damage to the propeller should be one of the first things to be

considered. The vulnerable position of the propellers makes them more liable to damage than other parts of the plant. Bent or broken propeller blades will transmit vibration to the main reduction gears. Propellers can also become fouled with line or cable which will cause the gears to vibrate. No reduction gear vibration is too trivial to overlook. A complete investigation should be made, preferably by a naval shipyard.

MAINTENANCE OF MAIN REDUCTION GEARS

The main reduction gear is one of the largest and most expensive units of machinery found in the engineering department. Main reduction gears that are installed properly and operated properly will give years of satisfactory service. However, a serious casualty to main reduction gears, will either put the ship out of commission or force it to operate at reduced speed. Main reduction gear repairs can be very expensive as repairs usually have to be made at a shipyard. The sections which follow deal with gear teeth. Bearings are covered in a separate section.

The importance of proper gear tooth contact cannot be overemphasized. Any abnormal condition which may be revealed by operational sounds or by inspections should be corrected as soon as possible. Any abnormal condition which is not corrected will cause excessive wear which may result in general disintegration of the tooth surfaces.

If proper tooth contact is obtained when the gears are installed, little wear of teeth will occur. Excessive wear cannot take place without metallic contact. Proper clearances and adequate lubrication will prevent most gear tooth trouble.

WEAR-IN OF GEAR TEETH.—Gears which have been realigned and new gears should be given a wearing-in period at low power before being subjected to the maximum tooth pressure at full power.

TOOTH CONTACT.—For proper operation of the gears, it is essential that the total tooth pressure be uniformly distributed over the total area of the tooth faces. This uniform pressure is accomplished by accurate alignment and adherence to the designed clearance.

The designed center-to-center distance of the axes of the rotating elements should be maintained as accurately as practicable but the axes

of pinions and gear shafts must always be parallel. If the shafts are not parallel, the load is concentrated on one end of a helix; the result may be flaking, galling, pitting, feathered edges on teeth, deformation of tooth contour, or breakage of tooth ends.

TOOTH CONTOUR.—The designed tooth contour must be maintained. A lack of it can cause load concentrations with consequent scoring.

BACKLASH.—Backlash is the play between the unloaded surfaces of the teeth in mesh on the pitch circle. Backlash increases with wear, and can increase considerably without causing trouble.

TOOTH SURFACE WEAR.—If proper contact is obtained when the gears are installed, the initial wearing, which takes place under conditions of normal load and adequate lubrication, will smooth out rough and uneven places on the gear teeth. This initial wearing-in is referred to as **NORMAL WEAR** or **RUNNING IN**. As long as operating conditions remain normal, no further wear will occur.

Small shallow pits starting near the pitch line, will frequently form during the initial stage of operation; this process is called **INITIAL PITTING**. Often the pits (about the size of a pinhead or even smaller) can be seen only under a magnifying glass. These pits are not detrimental and usually disappear in the course of normal wear.

Pitting which is progressive and continues at an increasing rate is known as **DESTRUCTIVE PITTING**. The pits are fairly large and are relatively deep. Destructive pitting is not likely to occur under proper operating conditions, but could be caused by excessive loading, too soft material, or improper lubrication. It is usually found that this type of pitting is due to misalignment or to improper lubrication.

The condition in which groups of scratches appear on the teeth (from the bottom to the top of the tooth) is termed **abrasion**, or **scratching**. It may be caused by inadequate lubrication, or by the presence of foreign matter in the lubricating oil. When abrasion or scratching is noted, the lubricating system and the gear spray fixtures should immediately be examined. If it is found that dirty oil is responsible, the system must be thoroughly cleaned and the whole charge of oil centrifuged.

The term "scoring" denotes a general roughening of the whole tooth surface. Scoring

marks are deeper and more pronounced than scratching and they cover an area of the tooth, instead of occurring haphazardly, as in scratching or abrasion. Small areas of scoring may occur in the same position on all teeth. Scoring which occurs with proper alignment and operation, usually results from inadequate lubrication, and is intensified by the use of dirty oil. If these conditions are not corrected, continued operation will result in a general disintegration of the tooth surfaces.

ROOT CLEARANCE.—The designated root clearance with gear and pinion operating on their designed centers can be obtained from the manufacturer's blueprints. The actual clearance can be found by taking leads or by inserting a long feeler gage or wedge. The actual clearance should check with the designed clearance. If the root clearance is considerably different at the two ends, the pinion and gear shaft will not be parallel. Provided there is still sufficient backlash, and the teeth are not meshed so closely that lubrication is adversely affected or that clearance is reduced below specified limits, the tolerance will be satisfactory.

CHECKING TOOTH CONTACT.—The length of tooth contact across the face of the pinion is the means of determining if reduction gear alignment is satisfactory. To check the length of tooth contact, the teeth of one gear should be coated lightly with prussian blue (machinist's dye) and the teeth of the other gear with yellow chromate or red lead pigment, and the gears rolled (with the turning gear) with sufficient torque to cause metal contact between the meshing teeth.

Either copper sulphate or blue or red Dykem is used to determine tooth contact for operating conditions. Dykem should be used for dock trials as it will show markings for light load conditions. Copper sulphate markings will remain visible after longer and higher power operations than will Dykem markings. Lubricating oil must be removed from the gear teeth by an approved cleaning agent, before the compound is applied; several bands should be coated on all gear elements. After the tooth contact is determined, the compound must be removed from the gear teeth to prevent possible contamination of the lubricating oil.

It should be noted that some gear teeth are cut with a very slight taper to offset the effects of torsional twist and bending. In such gearing, full contact across the teeth will not be obtained at light loads.

SPOTTING GEAR TEETH.—Rough gear teeth should be stoned smooth if it is certain that the roughening was caused by the passage of some foreign matter. Any tooth deterioration which cannot be traced to a casualty should be investigated, giving special attention to the condition of the bearing, to lubrication, and to the possibility of a change in the supporting structure, which has disturbed the parallelism of the rotors.

To spot-in surfaces of reduction gear teeth, the pinion teeth are coated lightly with prussian blue. Then the gear is turned in its ahead direction by using the turning gear. As the gear teeth come in contact with the marked pinion teeth, an impression is left on the high part of the gear tooth. After the gear is turned 1/4 turn, or is in a convenient position for stoning, all high spots indicated by the marks are removed with a small handstone. It will be necessary to replace the bluing on the pinion teeth repeatedly, but if the bluing is applied too thickly, false impressions will be left on the teeth.

It is permissible to hand stone gear teeth, with a small oil stone, to remove a local hump or deformation, however, hand stoning of gear teeth to obtain contact is not permitted. Hand stoning to obtain contact, cannot be done without the approval of the Naval Ship Systems Command.

MAINTENANCE OF CRUISING TURBINE REDUCTION GEARS

Many destroyers, as well as other type ships, have cruising turbines and cruising turbine reduction gears. These gears differ primarily from main reduction gears in that they are single reduction. This type reduction gear (fig. 7-14) consists of one pinion and one reduction gear enclosed in a housing and fitted with the necessary bearings, thermometers, oil lines, and other fittings. Detailed information concerning the construction of cruising turbine reduction gears can be obtained from the manufacturer's technical manual for the specific installation.

Maintenance for cruising reduction gear installations is basically the same as for main reduction gears. Repair work for a cruising gear may be easier because there are fewer bearings in a cruising gear, which may mean less work if the bearings need replacing. Having only one pinion and one gear, cruising

gears do not have to be timed as do main reduction gears. The casing of a cruising reduction gear is easier to lift than a main gear casing.

Bearing Maintenance

In some cruising reduction gear installations, the bearing shells are very thin and are not suitable for rebabbiting. Such bearings, if damaged, must be replaced with new bearings.

To replace cruising gear bearings, it is necessary to proceed as follows: Remove the bolts in the horizontal and vertical joints of the coupling guards. Remove the upper half of the coupling guards; the alignment bearing (centering ring) may raise with the low speed coupling guard. Remove the bolts in the vertical joint, between the disconnect lever housing and the gear casing. Remove the nuts from the bearing cap studs, these studs extend through the upper half of the gear casing. Remove all bolts from the horizontal joint of the gear casing. Lift the upper half of the gear casing; then the bearings can be removed for inspection.

Gear Tooth Maintenance

As with main reduction gear teeth, cruising gear teeth must be kept in correct alignment at all times. Uniform distribution of wear over the entire length of the gear and pinion teeth is an indication of correct contact. Any evidence of poor tooth contact is an indication of worn bearings or misalignment of the gears.

The pinion should not be removed from the assembly unless it is necessary to replace it. The pinion can be lifted by the following procedure: Remove the upper half of the reduction gear casing. Place the support yoke under the after end of the cruising turbine shaft and remove the bolts from the cruising turbine coupling. Remove the upper half of the pinion bearings. The use of hydraulic pressure, rather than pneumatic, is recommended for removing such fitted parts. However, an air fitting is installed in the cruising turbine coupling, through which air pressure can be applied to force the tapered part out of position. The pinion can now be removed. (NOTE: Extreme caution should be taken when using pneumatic pressure.)

In order to remove the gear from the assembly, it is necessary to remove the disconnect device and the coupling at the same time. After the gear has been removed from

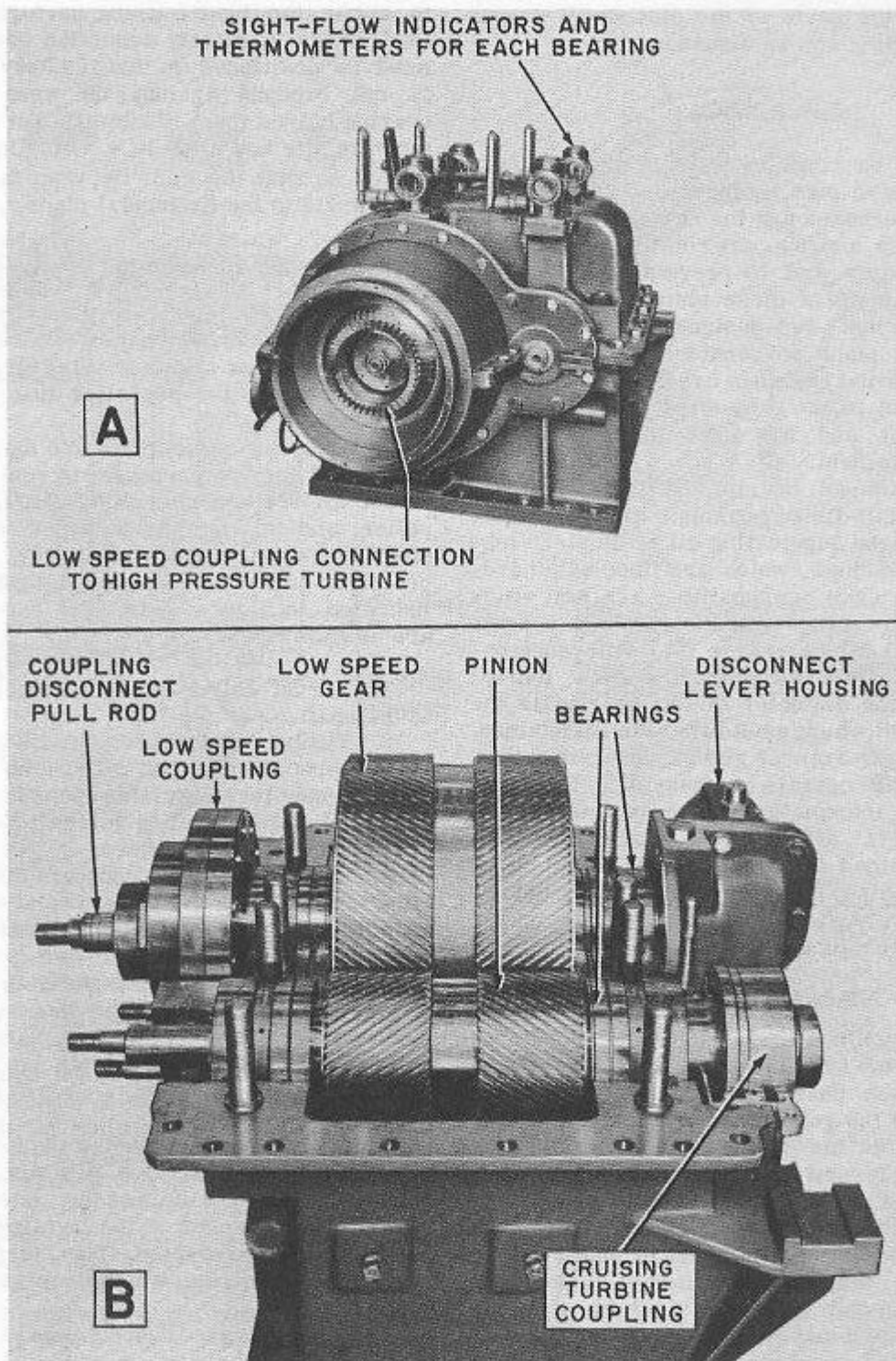


Figure 7-14.—A. Assembled cruising gear, after end, showing the disconnect coupling.
B. Cruising gear, cover off, showing bearings, pinions, and gear.

the casing, the parts of the disconnect device and the coupling can be disassembled.

BEARINGS

Although bearings in main propulsion units vary greatly in size, composition and lubrication, their purposes are the same. Bearings are used to guide and support rotating or reciprocating elements and to prevent free axial or radial movement of these elements. Radial or journal bearings are designed to carry loads applied in a plane perpendicular to the axis of the shaft. Thrust bearings are designed to carry loads applied in the same direction as the axis of the shaft and are used to prevent free endwise movement.

Lubrication of bearings differs. For example, babbitt-lined bearings are lubricated by an approved lubricating oil while stern tube and strut bearings, which are lined with hardwood or a rubber composition, are salt water lubricated. Bearings are designed to operate with a small oil clearance (the difference between the outside diameter of the journal and the inside diameter of the bearing is the oil clearance) which must always be maintained. With proper clearances and proper lubrication, bearings may operate successfully for many years. The information given in this section is of a general nature. Additional information may be obtained from chapter 9430 (43) of the Bureau of Ships Technical Manual. For details concerning a particular unit, consult the manufacturer's technical manual.

MAIN REDUCTION GEAR BEARINGS

Many propulsion gears have roller and ball bearings; some have spherical seated bearings. Reduction gear bearings must not only support the weight of the gears and their shafts, but they must also hold the shafts in place against the tremendous forces exerted by the shafts and gears when they are transmitting power from the turbine shaft to the propeller shaft. Like other radial sleeve bearings in main engine installations, these bearings are of the babbitt-lined split type; however, instead of being spherical seated and self-aligning, the reduction gear bearings are rigidly mounted, and doweled into the bearing housings. The angular direction of the forces acting upon a main reduction gear bearing changes with the amount of propulsion power being transmitted by the gear. In order

to obtain the best bearing performance when load is the greatest, reduction gear bearings must be positioned so that the heavy shaft load is not brought against the area where the bearing halves meet (the split). For this reason most of the bearings in a reduction gear are placed so that the split between the halves is at an angle to the horizontal plane.

MAIN THRUST BEARINGS

The main thrust bearing is located either at the forward or after end of the main reduction bull gear or in the propeller line shafting aft of the gear.

Axial or thrust bearings are mounted on the main shaft for two purposes: to resist any axial thrust or force exerted on the shaft by the propeller, and to limit the axial movement of the shaft to a small running clearance. Main thrust bearings are pivoted-segmental shoe type as indicated in figure 7-15. The essential parts are as follows:

1. Thrust collar—made of steel and keyed to the shaft.
2. Tilting segments, or shoes—made of aluminum-bronze and faced with babbitt.
3. Upper leveling plates upon which the shoes rest, and lower leveling plates to equalize the thrust load among the shoes.
4. Base ring—which supports the lower leveling plates, holds the plates in place, and transmits the thrust on the plates to the ship's structure.
5. Shoe supports (hardened steel buttons or pivots)—forming part of the shoes and pivoting them against the upper leveling plates in such a manner that the shoe segments can assume the correct angle.

Pins and dowels hold the upper and lower leveling plates in position, allowing ample play between the base ring and the plates to ensure freedom of movement of the leveling plates. The base ring is prevented from turning by its notched construction, which secures the ring to its housing.

The stationary bearing element is divided into six or more segments or shoes. These shoes are supported so that they are free to pivot slightly under the load.

The rotating bearing element or collar (fig. 7-15) is attached to and turns with the main shaft.

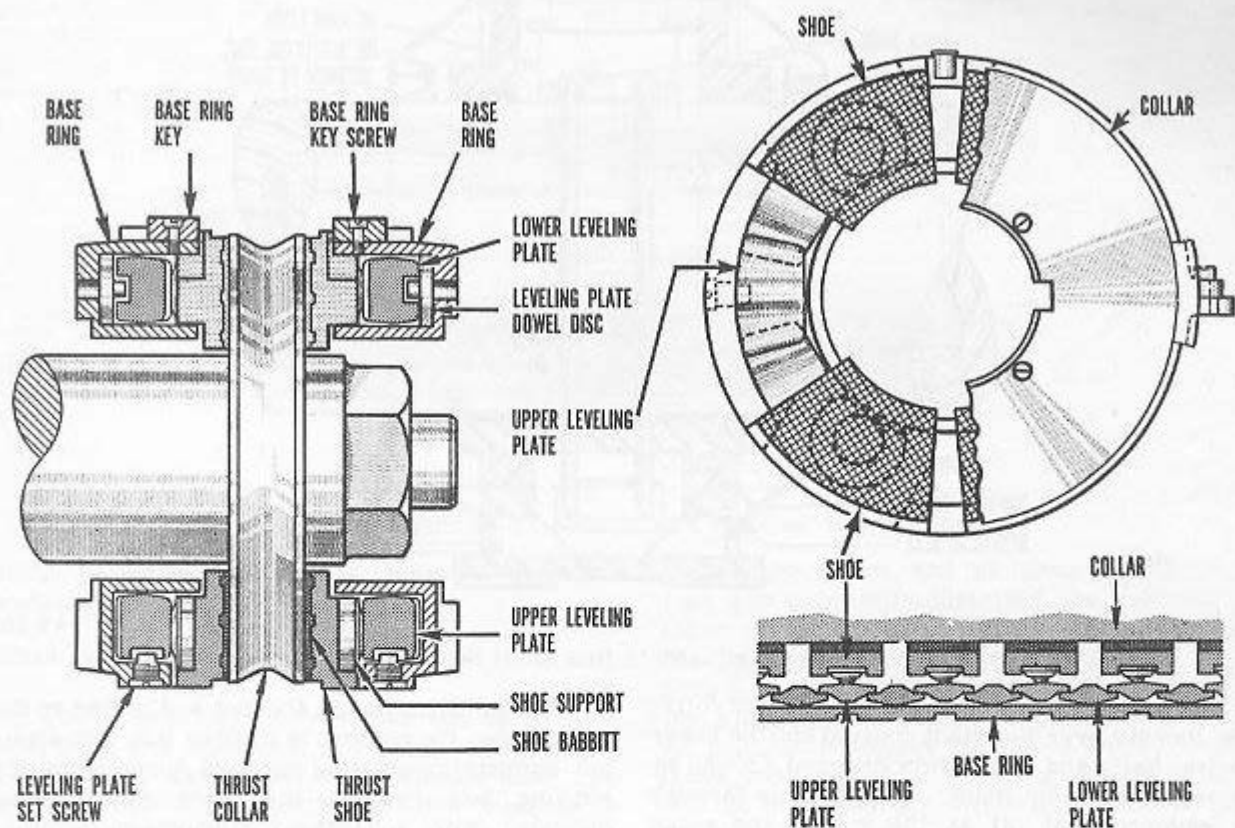


Figure 7-15.—Kingsbury pivoted-shoe thrust bearing.

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The entire assembly is submerged in oil, some of which is dragged in between the collar and each shoe as the shaft rotates.

Lubrication of the main thrust bearing is provided by the same system which furnishes oil to the turbine bearings, reduction gears, and flexible couplings—if located in with the reduction gear. If the main thrust bearing is located in the shaft alley, then lubrication of the bearing differs. The bearing will have its own oil sump, oil system, oil cooler, and pumps. While turning the engines by jacking gear, backing down, or going ahead slow, oil is supplied by an electric-driven gear pump. When the shaft speed is increased sufficiently, a shaft-driven gear pump supplies oil to the bearing and the electric-driven pump is secured. The shaft speed at which the shaft-driven pump can be secured will vary with the type of ship. For additional information, consult the manufacturer's technical manual for the specific unit or equipment.

MAIN PROPULSION SHAFT BEARINGS

The bearings which support and hold the propulsion shafting in alignment are divided into two general groups: the main line shaft bearings or spring bearings, and the stern tube bearings and the strut bearing.

Main Line Shaft Bearings or Spring Bearings

These bearings are of the ring-oiled, babbitt-faced, spherical seat, shell type. This bearing (see fig. 7-16) is designed primarily to align itself to support the weight of the shafting. On some low powered ships, the bearing is not of the self-aligning type and consists only of a bottom half. The upper half of the assembly consists only of a cap or cover (not in contact with the shaft) to protect the shaft journal from dirt. The spring bearings of most naval ships, however, are provided with both upper and lower self-aligning bearing halves.

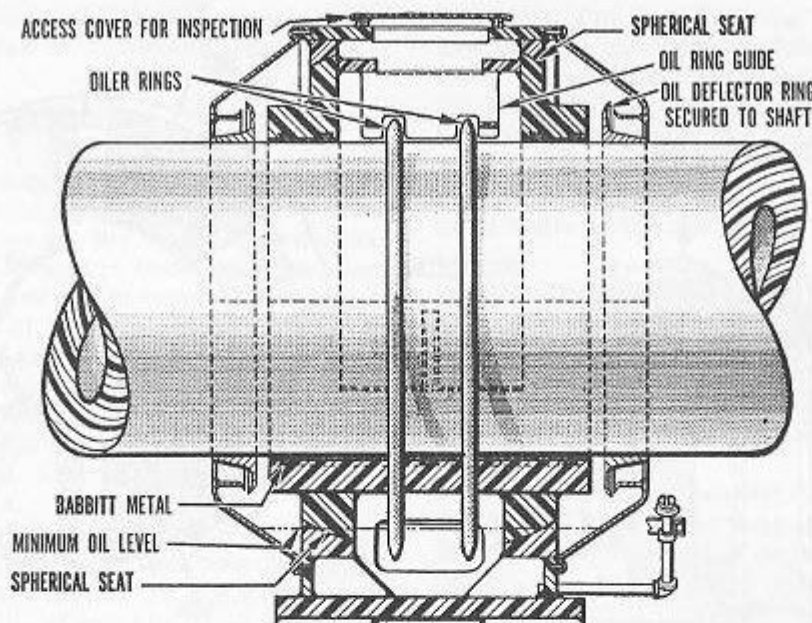


Figure 7-16.—Main line shaft bearing.

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The brass oiler rings, shown in figure 7-16, hang loosely over the shaft journal and the lower bearing half, and are slowly dragged around by the rotation of the shaft. As they glide through the reservoir of oil at the bottom the rings carry some of the oil along to the top of the shaft journal. The upper bearing half is grooved to accommodate the rings.

Spring bearing temperatures and oil levels should be checked hourly while underway. At the overhaul cycle the bearings should be inspected, clearances taken, and defects corrected.

Stern Tube and Stern Tube Bearings

The hold in the hull structure for accommodating the propeller shaft to the outside of the hull is called the stern tube. The propeller shaft is supported in the stern by two stern tube bearings—one at the inner end and one at the outer end of the stern tube. At the inner end of the stern tube is a stuffing box packing gland (fig. 7-17) generally referred to as the stern tube gland. The stern tube gland seals the area between the shaft and stern tube and yet allows the shaft to rotate. Construction of the stern tube bearings is similar to that of the strut bearings. (See the next section of this chapter.)

The stuffing box is flanged and bolted to the stern tube. Its casting is divided into two annular compartments—the forward space being the stuffing box proper, the after space being provided with a flushing connection for providing a positive flow of water through the stern tube for lubricating, cooling, and flushing. This flushing connection is supplied by the firemain. A DRAIN CONNECTION or a leakoff past the packing (on natural pressure circulation systems) is provided both for testing the presence of cooling water in the bearing, and for permitting sea water to flow through the stern tube and cool the bearing when the ship is underway, where natural sea water circulation is employed.

The gland for the stuffing box is divided longitudinally into two parts. The gland bolts are long enough to support the gland when the latter is withdrawn at least 1 inch clear of the stuffing box. This permits the addition of a ring of new packing, when needed, while the ship is waterborne. Either braided flax packing or special semimetallic packing is used (ship's engineering drawings show the proper type of packing). This gland is usually tightened up to eliminate leakage when the ship is in port, and loosened just enough to permit a slight trickle of water for cooling purposes, when the ship is underway. (NOTE: On anchoring, the glands of natural pressure circulation systems should

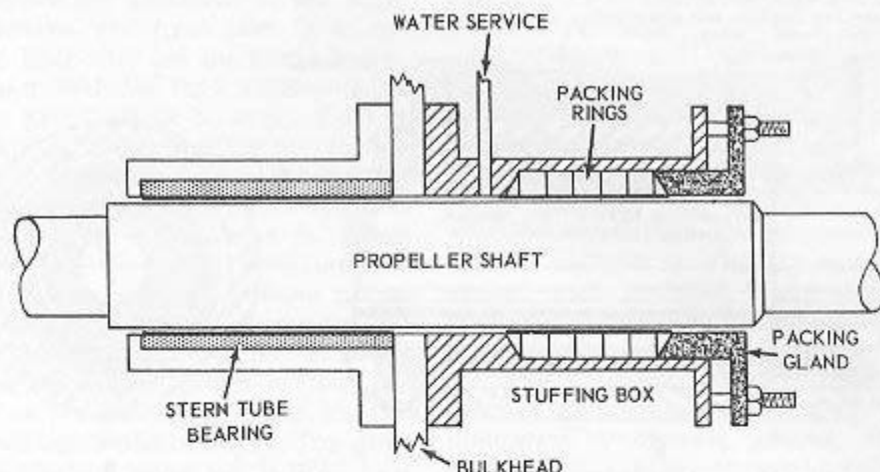


Figure 7-17.—Stern tube stuffing box and gland.

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NOT be disturbed unless leakage becomes excessive.)

Strut Bearings

These bearings, as well as the stern tube bearings, are equipped with composition bushings which are split longitudinally into two halves. The outer surface of the bushing is machined with steps to bear on matching landings in the bore of the strut. One end is bolted to the strut.

Since it is usually impracticable to use oil or grease as a lubricant for underwater bearings, some other material must be employed for that purpose. There are certain materials that become slippery when wet, including natural or synthetic rubber; lignum vitae, a hard tropical wood with excellent wearing qualities; or laminated phenolic material consisting of layers of cotton fabric impregnated and bonded with phenolic resin. Strips of this material, as shown in figure 7-18, are fitted inside the bearing.

A rubber composition is the type most used in modern installations. These bearings, of course, will never be seen while the ship is afloat, and chances are when the ship is in drydock, the naval shipyard personnel will perform the required work. However, the engineer officer should check the bearings visually.

CARE OF BEARINGS

Properly operated bearings may give years of satisfactory service but like all units of engineroom machinery, they require periodic

tests, inspections, and maintenance. When bearings are originally installed, the manufacturer takes oil clearance readings which are usually the differences between the journal O.D. and the bore I.D. These clearance readings are within the tolerance shown in the applicable drawings. At regular intervals the ship's force must take these readings. Any difference between the old and the new readings will be the amount of bearing wear.

Under normal conditions, the main reduction gear bearings and gears will operate for an indefinite period. If abnormal conditions occur, the naval shipyard will normally perform the repairs. Sufficient repair parts are carried aboard to replace some bearings installed in the main reduction gear. Usually each bearing is interchangeable for the starboard or port installation. The manufacturer's technical manual must be checked for interchangeability of gear bearings.

Special tools and equipment needed to lift main reduction gear covers, to handle the quill shaft when removing bearings from it, and to take required readings and measurements, are normally carried aboard. The special tools and equipment should always be aboard in case emergency repairs have to be made by repair ships or bases not required to carry these items.

JOURNAL BEARINGS.—A bearing, used in reduction gears, has a pressure half and a non-pressure half, when referring to the ship's going ahead. The nonpressure half will usually have a radial scribe line at one end of the geometric center. The pressure half of all main

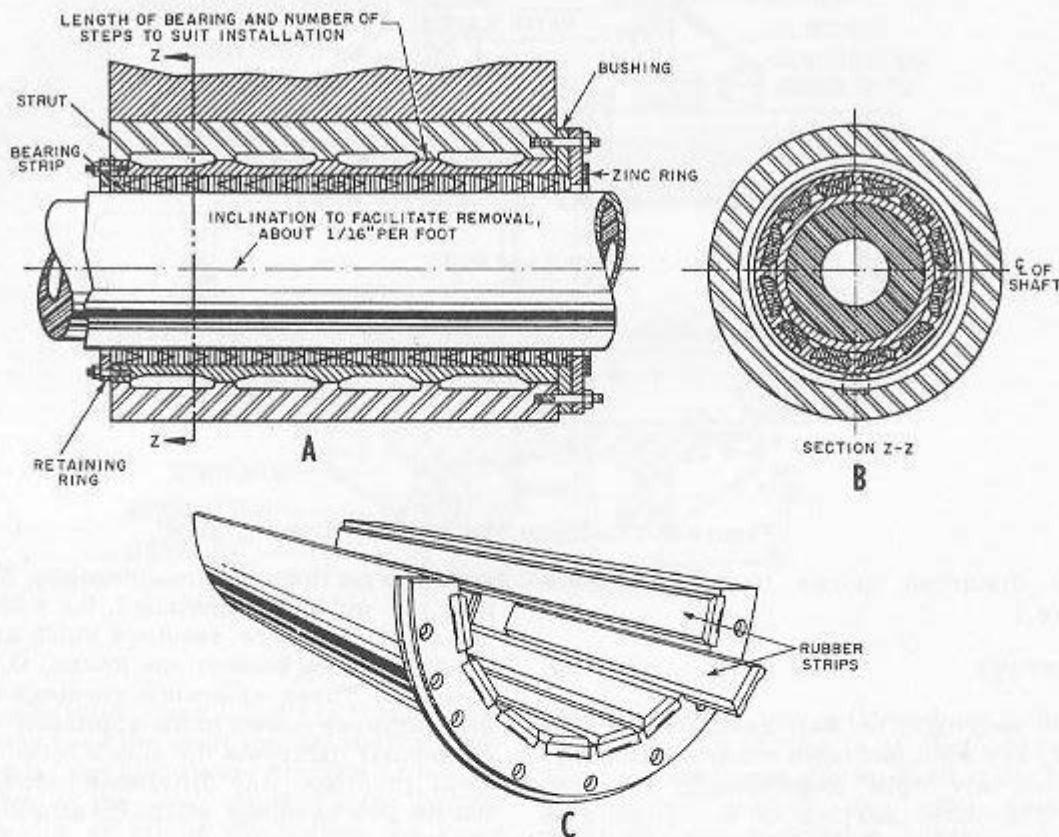


Figure 7-18.—Details of underwater strut bearing. A. Longitudinal view. B. Cross sectional view. C. Rubber stripping in the bearing.

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reduction gear bearing shells usually has three radial scribe lines on each end. These bearings are all marked for crown thickness measurements. The crown thickness is measured approximately $1\frac{1}{4}$ inches from the end of the shell. These measurements are taken and recorded at the initial alignment and are permanently marked adjacent to each scribe line. Directions for reboring are generally marked on those bearings which are designed to be rebabbitted.

The amount of bearing wear allowed should not be great enough to allow incorrect gear tooth contact. The designed bearing clearances and wear data are generally given in the manufacturer's technical manual. These clearances and wear data are also given in the blueprints for the main reduction gears. The maximum allowable clearance can be determined by referring to the Bureau of Ships Technical Manual, chapter 9430 (43).

Replacing bearings in the main reduction gear is a major undertaking. When a casualty (such as the loss of lube oil) occurs, the high speed pinion shaft bearings are more likely to be wiped than the other main gear bearings. These high speed pinion shafts (coupled to the high pressure and low pressure turbines) will have a higher rotary speed than other shafts in the reduction gear. If the bearings are inspected, the high speed pinion bearings should be checked first. The bearings which rotate at lower speeds are normally not wiped. If repairs are to be made by the ship's force, personnel should refer to the manufacturer's technical manual and the blueprints for the reduction gear. A clear understanding of the construction details and repair procedure is most helpful before starting a repair job. Some factors to be considered in determining where repairs are to be made include: location of the ship, available repair facilities, available repair

parts, and the operating schedule of the ship.

In making repairs, the first step is to engage the turning gear and set the brake to ensure that the shaft will not turn while repairs are being made. All oil must be pumped out of the main sump tank. A clean settling or storage tank can be used to store the oil until it is ready for use again. Then a section of the reduction gear cover is lifted by using chain-falls and wire slings. (NOTE: On some installations, journal bearings can be replaced without lifting covers.) When the gear cover is moved out of the way, the bearing cover can be removed. Next the bearing must be turned so that the bearing split is on the horizontal plane and the top half of the bearing can be lifted off. The gear shaft must be supported when the bottom half of the bearing is removed. A dummy, or similar device, bearing is used to support the weight of the shaft and to keep the shaft in position. Special precautions should be taken to prevent the shaft from being turned or lifted, so that the gear teeth do NOT become unmeshed. If the gear teeth become unmeshed and are not match marked, it is necessary to follow a complicated and detailed procedure to reassemble and time the gears. The setting up of the locked train gear system is done at the factory and at naval shipyards.

If the bearing has excessive clearance, is badly wiped, or heavily scored, other representative bearings should be examined to determine the extent of the damage. All bearings on that particular shaft, should be replaced, if necessary, to maintain correct gear alignment.

To replace a bearing, proceed as follows:

1. Review the Material History to determine if special bearings are necessary.

2. Measure the diameter of the journal (with a micrometer) and compare the present readings with the original readings, as recorded in the Material History.

3. Check the crown thicknesses of installed and replacement bearings and compare readings. If scraping is required for the replacement bearing, use a full-sized mandrel and prussian blue to check the work. Shaft parallelism must be maintained.

4. To maintain shaft parallelism, bearings on the ends of gear or pinion shafts shall not differ in crown thickness more than 0.002 inch.

5. When a bearing is installed or a damaged bearing is scraped to maintain correct tooth

contact, the crown thickness shall be stamped on the bearing shell.

6. Dowels are used, between the bearing halves, to locate the bearings in the upper casing. Upper and lower bearing halves must be mated parts. Interchanging of upper and lower bearing halves is prohibited.

7. Examine the condition of the journal whenever bearings are removed. If the surface of the journal is slightly scored, it must be stoned and polished. Only experienced personnel should stone a journal. Always oil a journal before rolling in a new bearing.

NOTE: If journals are badly scored, they may be ground undersize or restored to design diameter by chrome plating. If a journal is ground undersize, it might be necessary to provide undersize bearings. This should be accomplished only by a naval shipyard and in accordance with existing instructions. The new journal diameters and bearing clearances must be recorded in the Material History.

When installing a bearing, make sure that it is well oiled, then roll the lower half into position, removing the dummy bearing. The upper half can be placed in position, and then the complete bearing can be shifted to its proper position. Ensure that the dowels are in place and that the bearing assembly is in its required position, in accordance with the manufacturer's instructions. The bearing cap can be lowered into position and securely bolted down.

Before the gear cover is lowered into position, a careful inspection should be made to see that the inside of the gear installation is free of all dirt, tools, rags, and other foreign matter that would be harmful to the gears. After the gear cover is lowered into position and bolted down, the lube oil can be pumped to the sump. Before the oil is circulated through the system, MUSLIN bags should be placed in oil strainers. The muslin bags will trap any dirt or foreign matter that is too fine to be stopped by the strainer. A lube oil service pump should be started to circulate oil through the system. The muslin bags should be changed at 30-minute intervals until they no longer pick up dirt. The turning gear can then be engaged and started.

THRUST BEARINGS.—This section contains only general information on different methods of taking end play readings on the main thrust bearing. See the manufacturer's technical manual for specific information on any given unit.

Checking the end play for any six-or eight-shoe thrust bearing must always be done with the top half of the bearing bolted down solidly, otherwise the base rings will tilt because of the freedom of movement given the leveling plates, and a false reading will be obtained.

A record of the main thrust readings must be kept in the Material History and referred to when checking the main thrust bearing. Over a period of years, the normal wear of a pivoted-shoe thrust bearing is negligible. However, when the bearing is new, there may be a slight settling of the leveling plates. Any increase in the end play of a main thrust bearing indicates the the surfaces of the thrust shoes should be inspected, and necessary repairs made.

In many main thrust bearings, a port is provided (in the main thrust bearing cap over the thrust shoes) for inspection purposes. This port has a removable cover of sufficient size to permit the withdrawal of thrust shoes that are in line with it.

CHECKING THRUST WHILE UNDERWAY.—The simplest means of checking end play is to use a dial indicator on any accessible flange on the main shaft while the engines are going slowly ahead and then astern. This can usually be done when the ship is maneuvering to approach a pier or an anchorage. The speeds should be slow enough to avoid adding deflections of bearing parts and housing to the actual end play. But, the speed should be sufficient to ensure that the full end play is actually taken up.

Some ships have the main thrust bearing located at the forward end of the main reduction gear, and constructed as a component part of the gear. A spring-loaded pin gage (located in the bearing end cover housing) and a micrometer depth gage are used to measure the end play. The pin gage cover is removed and the anvil of the depth gage is placed on the machined surface of the pin gage housing. The micrometer is carefully turned so that the spindle pushes the installed pin against the main shaft. All slack must be taken up; but excessive force must not be used, as it will lift the micrometer anvil from the machined surface.

Another reading is taken with the main shaft operating in the opposite direction. The difference between the two readings is the end play. It is always good practice to take more than one set of readings to ensure that the total end play was taken up and that the readings are accurate.

JACKING ON A SHAFT FLANGE.—If it is not practical to measure the end play while running, the next choice is to jack the shaft (while it is still warm) fore and aft at some convenient main shaft flange. A dial indicator is mounted on a rigid support, convenient to some main shaft flange and the shaft is jacked forward and then astern. The shaft movement must be free; too great a force should not be used. Excessive force might cause deflections of metal parts to be added to the actual end play. The main difficulty in using the jacking method is finding suitable supports where no structural damage will be done.

PROPELLERS AND MAIN PROPULSION SHAFTING

The turbine and reduction gears convert the thermal energy of steam into usable mechanical energy. This mechanical energy is utilized through the propulsion shafting and the propeller. The **MAIN PROPULSION SHAFTING**, which ranges in diameter from 18 to 21 inches for small twin-screw destroyers to approximately 30 inches for large four-screw carriers, is divided into four functional sections—the line shaft, thrust shaft, stern tube shaft, and propeller or tail shaft (fig. 7-19).

MAIN PROPULSION SHAFTING

Segments of the line and thrust shaft sections of the shafting are joined together with integral **FLANGE TYPE COUPLINGS**. The stern tube shaft is joined to the after end of the line shaft with what is known as the **INBOARD STERN TUBE COUPLING**, with a removable after-sleeve flange. The tail shaft is joined to the stern tube shaft with what is known as a **MUFF TYPE OUTBOARD COUPLING**. The shaft bearings have already been discussed in a preceding section.

On single-screw ships, that portion of the outboard shaft which turns in the stern tube bearing is normally covered with a **SHRUNK-ON COMPOSITION SLEEVE**. This is done to protect the shaft from corrosion, and to provide a suitable journal for the water lubricated bearings. On multiple-screw ships, these sleeves normally cover only the bearing areas, and the exposed shafting between the sleeves is covered with synthetic sheet rubber to protect it against sea water corrosion.

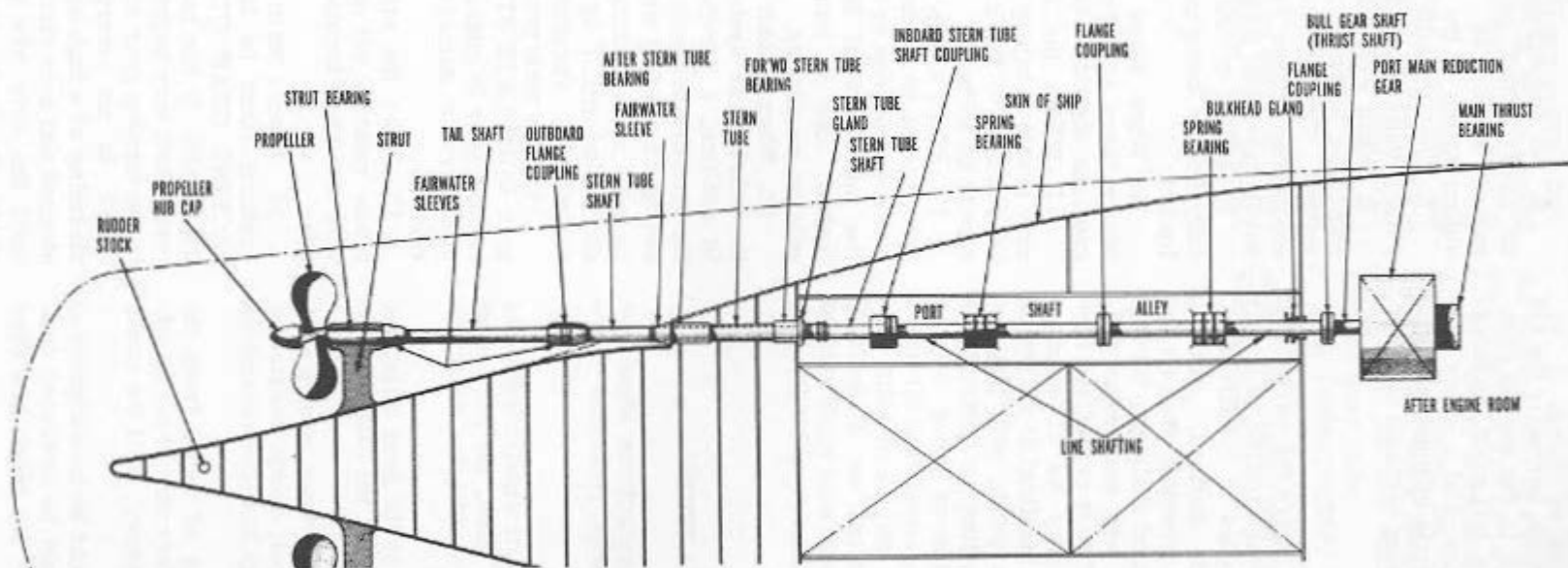


Figure 7-19.—Diagrammatic arrangement of a main propulsion shafting.

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For carriers and cruisers, normally the wet shafting (shafting outboard in the sea) is composed of three sections, a tail shaft, an intermediate or dropout section, and a stern tube section. Integral flanged ends of these sections are normally used for joining sections together.

PROPELLERS

The screw propellers, where the mechanical energy produced by the main engine is finally utilized, are of various types of construction. They may be left-handed helices, turning counterclockwise in ahead direction when viewed from astern, or right-hand helices, turning clockwise. All starboard and centerline propellers turn clockwise. All port propellers turn counterclockwise. They may be of constant pitch, with pitch of blades identical at all points along the radius; variable pitch, with pitch of blades varying along the radius; or controllable pitch, with blades capable of being rotated within their sockets to change speed and direction of propeller thrust. They may be of solid construction, of single casting, or a built-up construction with individually cast blades bolted to the propeller hub. The number of blades may vary from three to seven.

SAFETY PRECAUTIONS

The following safety precautions should be observed when working with reduction gears and related equipment:

1. If there is churning or emulsification of oil and water in the gear case, the gear must be slowed down or stopped until the defect is remedied.
2. If the supply of oil to the gear fails, the gears should be stopped until the cause can be located and remedied.
3. When bearings have been overheated, gears should not be operated, except in extreme emergencies, until bearings have been examined and defects remedied.
4. If excessive flaking of metal from the gear teeth occurs, the gears should not be adjusted, except in an emergency, until the cause has been determined.
5. Unusual noises should be investigated at once, and the gears should be operated cautiously until the cause for the noise has been discovered and remedied.

6. No inspection plate, connection, fitting, or cover which permits access to the gear casing should be removed without specific authorization by the engineer officer.

7. The immediate vicinity of an inspection plate should be kept free from paint and dirt.

8. When gear cases are open, precautions should be taken to prevent the entry of foreign matter. The openings should never be left unattended unless satisfactory temporary closures have been installed.

9. Lifting devices should be inspected carefully before being used and should not be overloaded.

10. When ships are anchored in localities where there are strong currents or tides, precautions should be taken to lock the main shaft.

11. Where the rotation of the propellers may result in injury to a diver over the side, or in damage to the equipment, propeller shafts should be locked.

12. When a ship is being towed, the propellers should be locked, unless it is permissible and advantageous to allow the shafts to trail with the movement of the ship. When the shaft is locked, lube oil must be supplied to the propulsion machinery.

13. When a shaft is allowed to turn or trail, the lubrication system MUST be in operation. In addition, a careful watch should be kept on the temperature within the low pressure turbine casing to see that windage temperatures cannot be built up to a dangerous degree. This can be controlled either by the speed of the ship or by maintaining vacuum in the main condenser.

14. The main propeller shaft must be brought to a COMPLETE STOP before the clutch of the turning gear is engaged. (If the shaft is turning, considerable damage to the turning gear will result.)

15. When the turning gear is engaged, the brake must be set quickly and securely to prevent the shaft turning and damaging the turning gear.

16. When a main shaft is to be unlocked, precautions must be taken to DISENGAGE THE JACKING GEAR CLUTCH BEFORE releasing the brake. If the brake is released first, the main shaft may begin to rotate and cause injury to the turning gear and to personnel.

17. In an emergency, where the ship is steaming at a high speed, the main shaft can be stopped and held stationary by the astern turbine until the ship has slowed down to a speed at which the main shaft can be safely locked.

18. Where there is a limiting maximum safe speed at which a ship can steam with a locked propeller shaft, this speed should be known and should not be exceeded.

19. Before the turning gear is engaged and started, a check should be made to see that the turning gear is properly lubricated. Some ships have a valve in the oil supply line leading to the turning gear. The operator should see that a lube oil service pump is in operation and that the proper oil pressure is being supplied to the turning gear before the motor is started.

20. It should be definitely determined that the turning gear has been disengaged before the main engines are turned by steam.

21. While working on or inspecting open main reduction gears, the person or persons performing the work should not have any article about their person which may accidentally fall into the gear case.

22. Tools, lights, and mirrors used for working on or inspecting gears and bearings should be lashed and secured to prevent accidental dropping into the gear case.