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# **Boiler Basics, Operation and Maintenance**

Course No: M08-009  
Credit: 8 PDH

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## **Chapter 9**

### **Boilers**

#### **Topics**

- 1.0.0 Steam Generation Theory
- 2.0.0 Boiler Fittings and Accessories
- 3.0.0 Types of Boilers
- 4.0.0 Boiler Design Requirements
- 5.0.0 Automatic Controls
- 6.0.0 Instruments and Meters
- 7.0.0 Boiler Water Treatment and Cleaning
- 8.0.0 Cleaning Boiler Firesides and Watersides
- 9.0.0 Boiler Maintenance

#### **Overview**

A boiler is an enclosed vessel in which water is heated and circulated, either as hot water or steam, to produce a source for either heat or power. A central heating plant may have one or more boilers that use gas, oil, or coal as fuel. The steam generated is used to heat buildings, provide hot water, and provide steam for cleaning, sterilizing, cooking, and laundering operations. Small package boilers also provide steam and hot water for small buildings.

A careful study of this chapter can help you acquire useful knowledge of steam generation, types of boilers pertinent to Seabee operations, and various fittings commonly found on boilers. The primary objective of this chapter is to lay the foundation for you to develop skill in the operation, maintenance, and repair of boilers.

## **Objectives**

When you have completed this chapter, you will be able to do the following:

1. State the steam generation theory.
2. Describe boiler design requirements.
3. Describe the different types of boilers.
4. Describe the different types of boiler fittings and accessories.
5. Identify the automatic controls associated with boilers.
6. Describe the different types of instruments and meters.
7. Describe the procedures associated with boiler water treatment and cleaning.
8. Describe the procedures for cleaning boiler firesides and watersides.
9. Describe the procedures associated with boiler maintenance.

## **Prerequisites**

None

## 1.0.0 STEAM GENERATION THEORY

To acquaint you with some of the fundamentals underlying the process of steam operation, suppose that you set an open pan of water on the stove and turn on the heat. You find that the heat causes the temperature of the water to increase and, at the same time, to expand in volume. When the temperature reaches the boiling point (212°F or 100°C at sea level), a physical change occurs in the water; the water starts vaporizing. When you hold the temperature at the boiling point long enough, the water continues to vaporize until the pan is dry. A point to remember is that the temperature of water does not increase beyond the boiling point. Even if you add more heat after the water starts to boil, the water cannot get any hotter as long as it remains at the same pressure.

Now suppose you place a tightly fitting lid on the pan of boiling water. The lid prevents the steam from escaping from the pan and this results in a buildup of pressure inside the container. However, when you make an opening in the lid, the steam escapes at the same rate it is generated. As long as water remains in the pan and as long as the pressure remains constant, the temperature of the water and steam remains constant and equal.

The steam boiler operates on the same basic principle as a closed container of boiling water. By way of comparison, it is as true with the boiler as with the closed container that steam formed during boiling tends to push against the water and sides of the vessel. Because of this downward pressure on the surface of the water, a temperature in excess of 212°F is required for boiling. The higher temperature is obtained simply by increasing the supply of heat; therefore, the rules you should remember are as follows:

1. All of the water in a vessel, when held at the boiling point long enough, will change into steam. As long as the pressure is held constant, the temperature of the steam and boiling water remains the same.
2. An increase in pressure results in an increase in the boiling point temperature of water.

A handy formula with a couple of fixed factors will prove this theory. The square root of steam pressure multiplied by 14 plus 198 will give you the steam temperature. When you have 1 psig (pounds per square inch gauge) of steam pressure, the square root is one times 14 plus 198 which equals 212°F which is the temperature that the water will boil at 1 psig.

The equation for figuring out the steam temperature is:

$$\sqrt{\text{Steam Pressure}} \times 14 + 198 = \text{Steam Temperature}$$

Let P = Steam Pressure

Let T = Steam Temperature

Example 1:

$$\sqrt{1} \times 14 + 198 = 212$$

Example 2:

$$\sqrt{100} \times 14 + 198 = 338$$

$$10 \times 14 + 198 = 338$$

$$140 + 198 = 338$$

There are a number of technical terms used in connection with steam generation. Some of these commonly used terms you should know are as follows:

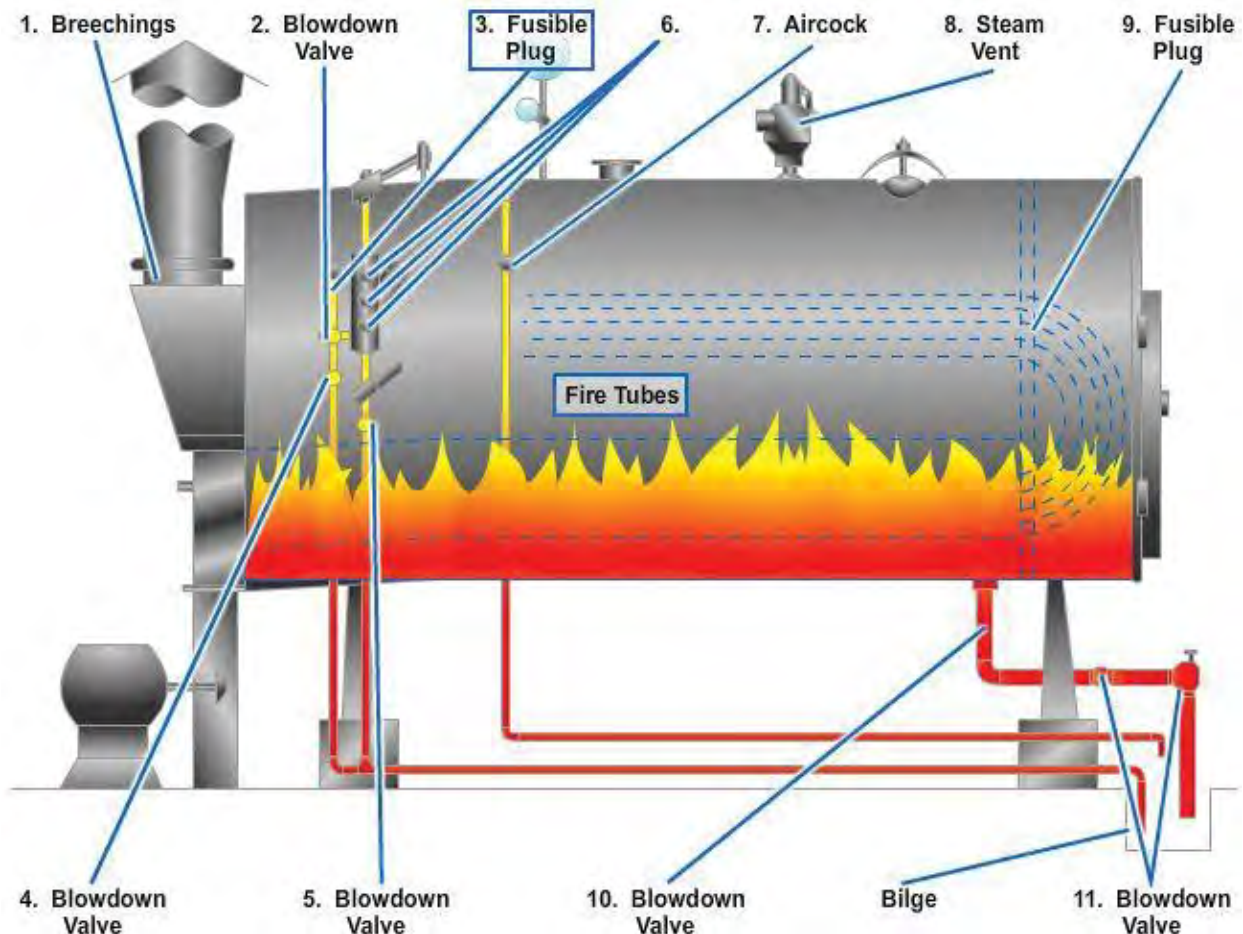
- Degree is defined as a measure of heat intensity.
- Temperature is defined as a measure in degrees of sensible heat. The term sensible heat refers to heat that can be measured with a thermometer.
- Heat is a form of energy measured in **British thermal units (BTU)**. One Btu is the amount of heat required to raise 1 pound of water 1 degree Fahrenheit at sea level.
- Steam means water in a vapor state. Dry **saturated** steam is steam at the saturation temperature corresponding to pressure, and it contains no water in suspension. Wet saturated steam is steam at the saturation temperature corresponding to pressure, and it contains water particles in suspension.
- The quality of steam is expressed in terms of percent. For instance, if a quantity of wet steam consists of 90 percent steam and 10 percent moisture, the quality of the mixture is 90 percent.
- Superheated steam is steam at a temperature higher than the saturation temperature corresponding to pressure. For example, a boiler may operate at 415 psig (pounds per square inch gauge). The corresponding saturation temperature for this pressure is 483°F, and this will be the temperature of the water in the boiler and the steam in the drum. This steam can be passed through a super-heater where the pressure remains about the same, but the temperature will be increased to some higher figure.

**Test your Knowledge (Select the Correct Response)**

1. At what temperature Fahrenheit does water reach the boiling point?
  - A. 200°
  - B. 212°
  - C. 232°
  - D. 275°

## 2.0.0 BOILER FITTINGS and ACCESSORIES

A sufficient number of essential boiler fittings (*Figure 9-1*) and accessories are discussed in this section to provide a background for further study. As a reminder, and in case you should run across some unit or device not covered here, check the manufacturer's manual for information on the details of its construction and method of operation.



**Figure 9-1-Boiler fittings.**

The term "fittings" includes various control devices on the boiler. Fittings are vitally important to the economy of operation and safety of personnel and equipment. You must understand fittings if you are to acquire skill in the installation, operation, and servicing of steam boilers.

All boilers require boiler fittings to operate safely. The American Society of Mechanical Engineers (ASME) requires all boiler fittings to be made of materials that withstand the pressure and temperatures that boilers are subject to. All of the boiler fittings discussed are important and must be operated and maintained properly to operate a boiler safely.

### 2.1.0 Air Cock

An air cock is located in the uppermost steam space of a boiler, as shown in *Figure 9-2*. This design allows for air to enter and escape during filling and draining of the boiler. Before firing a cold boiler with no steam pressure, open the air cock to allow air to

escape during the heating of the water. When steam begins to come out of the air cock piping, close the valve.

### 2.2.0 Chimneys, Draft Fans, and Breechings

Chimneys are necessary for discharging the products of combustion at an elevation high enough to comply with health requirements and to prevent a nuisance because of low-flying smoke, soot, and ash. A boiler needs a draft to mix air correctly with the fuel supply and to conduct the flue gases through the complete setting. The air necessary for combustion of fuel cannot be supplied normally by a natural draft. Therefore, draft fans may be used to ensure that the air requirements are properly attained.



Figure 9-2 - Aircock.

Two types of draft fans used on boilers are forced-draft and induced-draft fans. They are damper controlled and usually are driven by an electric motor.

The forced draft fan forces air through the fuel bed, or fuel oil burner, and into the furnace to supply air for combustion. The induced draft fan draws gases through the setting, thus facilitating their removal through the stack. Breechings (see Item 1 in *Figure 9-1*) are used to connect the boiler to the stack. They are usually made of sheet steel with provision for expansion and contraction. The breeching may be carried over the boilers, in back of the setting, or even under the boiler room floor. Keep breechings as short as possible and free from sharp bends and abrupt changes in area. The cross-sectional area should be approximately 20 percent greater than that of the stack to keep draft loss to a minimum. A breeching with a circular cross section causes less draft loss than one with a rectangular or square cross section.

### 2.3.0 Blowdown Valves

Blowdown valves on boilers are located on the water column and on the lowest point of the water spaces of the boiler (*Figure 9-3*). The blowdown valves on a boiler installed at the bottom of each water drum and header are used to remove scale and other foreign matter that have settled in the lowest part of the water spaces. Boilers are also blown down to control concentration of dissolved and suspended solids in boiler water. The water column blowdown permits removal of scale and sediments from the water column. Additionally, some boilers have what is called a surface blowdown. The surface blowdown is located at the approximate



Figure 9-3 — Blowdown valve.



water level so as to discharge partial steam and water. The surface blowdown removes foaming on the top of the water surface and any impurities that are on the surface of the water.

### 2.4.0 Fusible Plugs

Fusible plugs are used on some boilers to provide added protection against low water. They are constructed of bronze or brass with a tapered hole drilled lengthwise through the plug. They have an even taper from end to end. This tapered hole is filled with a low-melting alloy consisting mostly of tin. There are two types of fusible plugs—fire actuated and steam actuated.

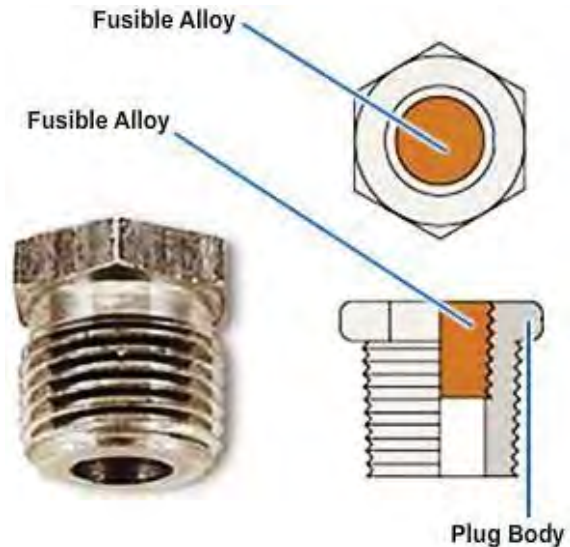
The fire-actuated plug is filled with an alloy of tin, copper, and lead with a melting point of 445°F to 450°F. It is screwed into the shell at the lowest permissible water level. One side of the plug is in contact with the fire or hot gases, and the other side is in contact with the water (*Figure 9-4*). As long as the plug is covered with water, the tin does not melt. When the water level drops below the plug, the tin melts and blows out. Once the core is blown out, a whistling noise will warn the operator. The boiler then must be taken out of service to replace the plug.

The steam-actuated plug is installed on the end of a pipe outside the drum. The other end of the pipe, which is open, is at the lowest permissible water level in the steam drum. A valve is usually installed between the plug and the drum. The metal in the plug melts at a temperature below that of the steam in the boiler. The pipe is small enough to prevent water from circulating in it. The water around the plug is much cooler than the water in the boiler as long as the end of the pipe is below the water level. However, when the water level drops below the open end of the pipe, the cool water runs out of the pipe and steam heats the plug. The hot steam melts and blows the tin out, allowing steam to escape from the boiler warning the operator. This type of plug can be replaced by closing the valve in the piping. It is not necessary to take the boiler out of service to replace the plug.

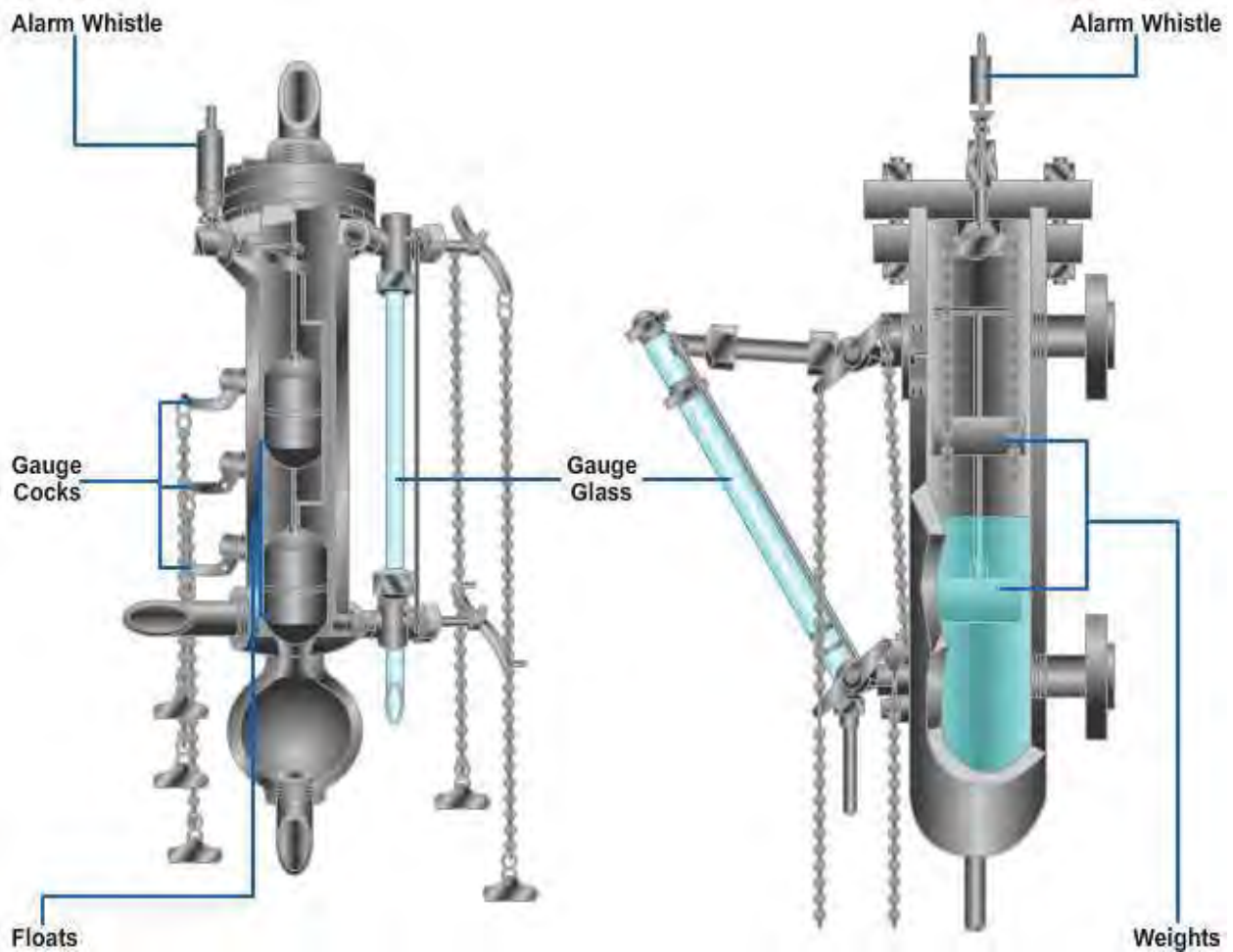
Fusible plugs should be renewed regularly once a year. Do NOT refill old casings with new tin alloy and use again. ALWAYS USE A NEW PLUG.

### 2.5.0 Water Column

A water column is a hollow vessel having two connections to the boiler (*Figure 9-5*). Water columns come in many more designs than the two shown in *Figure 9-5*; however, they all operate to accomplish the same principle. The top connection enters the steam drum of the boiler through the top of the shell or drum. The water connection enters the shell or head at least 6 inches below the lowest permissible water level. The purpose of the water column is to steady the water level in the gauge glass through the reservoir capacity of the column. Also, the column may eliminate the obstruction on small diameter, gauge-glass connections by serving as a sediment chamber.



**Figure 9-4 - Fusible plug.**



**Figure 9-5-Typical water columns.**

The water columns shown are equipped with high- and low-water alarms that sounds a whistle to warn the operator. The whistle is operated by either of the two floats or the solid weights shown in *Figure 9-5*.

### 2.5.1 Water Level Control

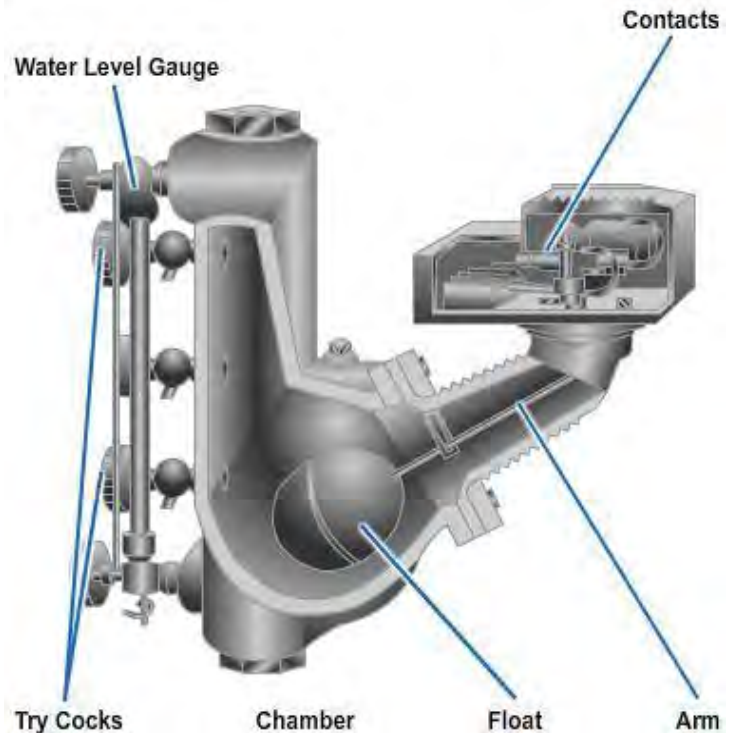
The water level control not only automatically operates the boiler feed pump but also safeguards the boiler against low water by stopping the burner. Various types of water level controls are used on boilers. At Seabee activities, boilers frequently are equipped with a float-operated type, a combination float and mercury switch type, or an electrode probe type of automatic water level control. Each of these types is described below.

The float-operated type of feedwater control, similar in design to the feedwater control shown in *Figure 9-6*, is attached to the water column. This control uses a float, an arm, and a set of electrical contacts. As a low-water cutoff, the float rises or lowers with the water level in an enclosed chamber. The chamber is connected to the boiler by two lines, a setup which allows the water and steam to have the same level in the float chamber as in the boiler. An arm and linkage connects the float to a set of electrical contacts that operate the feedwater pump when the water lowers the float. When the water supply fails or the pump becomes inoperative and allows the water level to continue to drop, another set of contacts operates an alarm bell, buzzer, or whistle, and secures the burners.

The combination float and mercury switch type of water level control shown in *Figure 9-6, Frame 1* reacts to changes made within a maintained water level by breaking or making a complete control circuit to the feedwater pump. It is a simple two-position type control, having no modulation or differential adjustment or setting.

As all water level controllers should be, it is wired independently from the programmer. The control is mounted at steaming water level and consists of a pressurized float, a pivoted rocker arm, and a cradle-attached mercury switch.

The combination float and mercury switch type of water-level control functions as follows: As the water level within the boiler tends to drop, the float lowers.



**Figure 9-6 - Combination float and mercury switch type of feedwater control.**

As the float lowers, the position of the mercury switch changes. Once the float drops to a predetermined point, the mercury within the tube runs to its opposite end. This end contains two wire leads, and when the mercury covers both contacts, a circuit is completed to energize the feedwater pump. The pump, being energized, admits water to the boiler. As the water level within the boiler rises, the float rises. As the float rises, the position of the mercury switch changes. Once the float rises to a predetermined point, the mercury runs to the opposite end of its tube, breaking the circuit between the wire leads and securing the feedwater pump. The feedwater pump remains off until the water level again drops low enough to trip the mercury switch.

Because of the hazards associated with mercury, these switches are being phased out. The electrode probe type of feedwater control and low-water cutoff and the solid state (*Figure 9-6, Frame 2*) type of switches are replacing them. The solid state components are controlled by a ground wire connected to the side of the reservoir and a probe that extends into the water column. When the water is at the acceptable level, current is available and the switch remains closed. When the water level drops, the current is reduced and the switch is activated thus turning on the water pump. If the water level drops too far down the probe, the burner cutout switch is activated and the burner will not come on until the water reaches the appropriate level.

The electrode probe type of feedwater control and low-water cutoff consists of an electrode assembly and a water level relay (Figure 9-7). The electrode assembly contains three electrodes of different lengths corresponding to high, low, and burner cutout in the boiler drum.

To understand the operation of a boiler circuit, refer to Figures 9-7 and 9-8 as you read the information in Table 9-2.

Although this information is not complete, it is presented here to acquaint you with the operation of the electrode type of boiler water-level control.

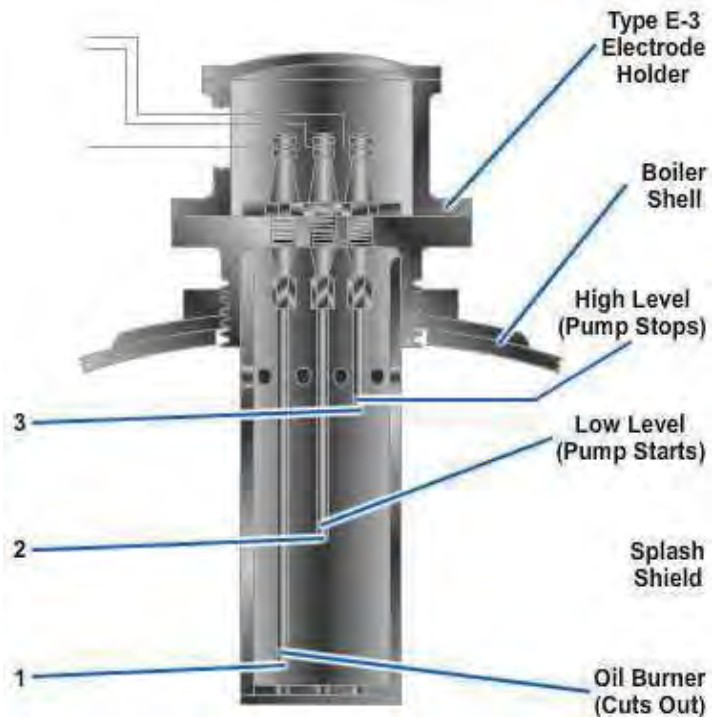


Figure 9-7 - Electrode type of water-level control.

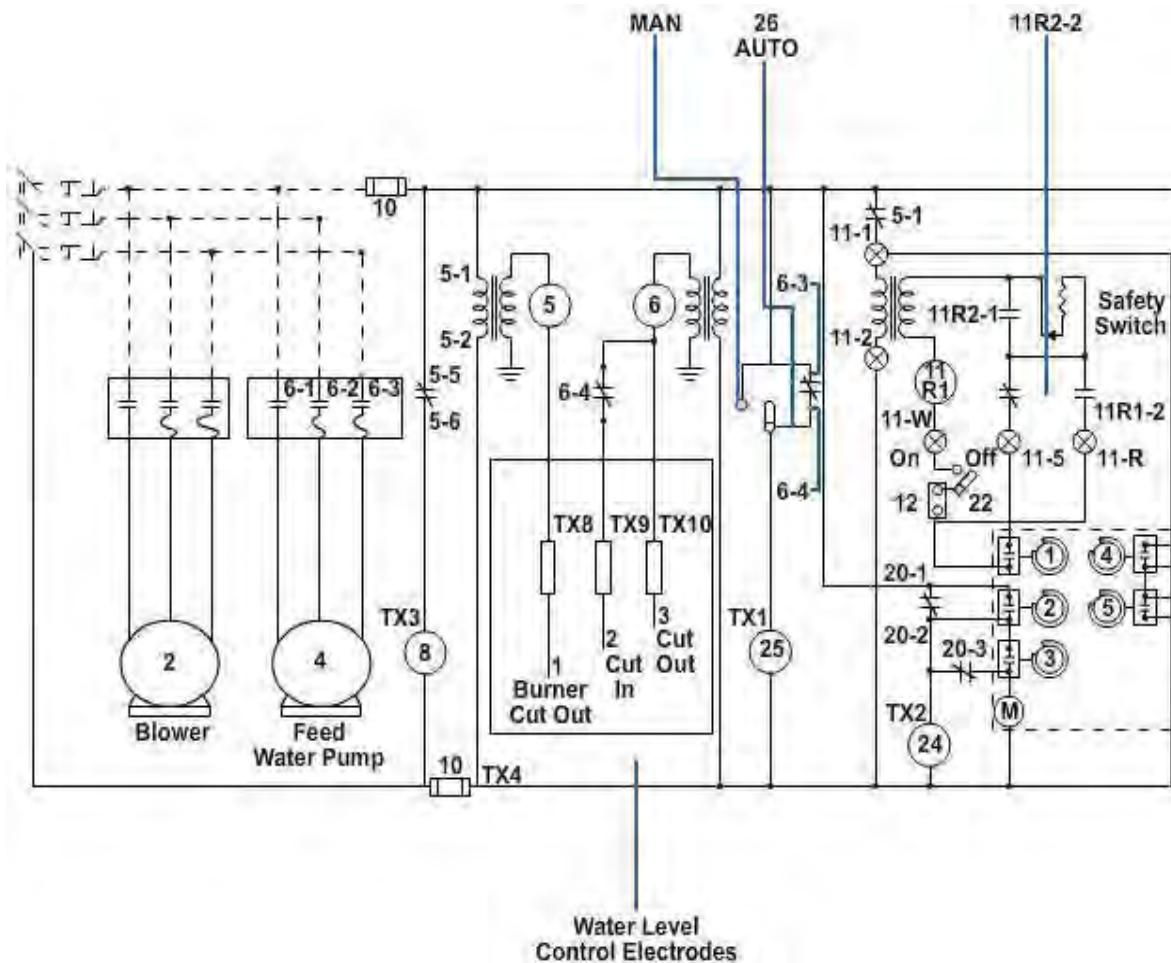


Figure 9-8-Typical boiler circuit.

**Table 9-2 - Operation of a boiler circuit.**

Operation	Action	Results
When the feed pump switch is in the auto position.	The feed pump motor is energized.	The feed pump will operate under control of the water-level relay.
When the water level in the boiler reaches the level of electrode #3.	The circuit through the electrode is grounded and this completes the circuit.	All of the contacts labeled #6 change positions. The three feed pump contacts that are normally closed, open, and contact 6-4 closes which maintains the grounded circuit through electrode #2.
When the water level falls below electrode #2.	The circuit through relay #6 will no longer be grounded because the water is not in contact with the electrode.	This de-energizes relay #6, so all of the contacts labeled #6 return to their normal positions. Contacts 6-1 through 6-3 close and 6-4 opens. The feedwater pump is energized and water is pumped into the boiler.
When the water level rises again to electrode #3.	Relay #6 will energize again.	The cycle continues and the water level in the boiler is maintained.
When the water level falls below electrode #1.	Relay #5 will be de-energized.	Contact 5-1 will open. This action de-energizes the entire control circuit. The boiler is now shut down and the low-water alarm is sounded.

### 2.5.2 Try Cocks

The purpose of the try cocks is to prove the water level in the boiler. You may see water in the gauge glass, but that does not mean that the water level is at that position in the boiler. If the gauge glass is clogged up, the water could stay in the glass, giving a false reading. The try cocks, on the other hand, will blow water, steam, or a mixture of steam and water out of them when they are manually opened. When steam is discharged from the lowest try cock, you have a low-water condition.



When the water level is proved using the try cocks, personnel should stand off to the side of the try cocks away from the discharge. The discharged steam or scalding water can cause severe burns.

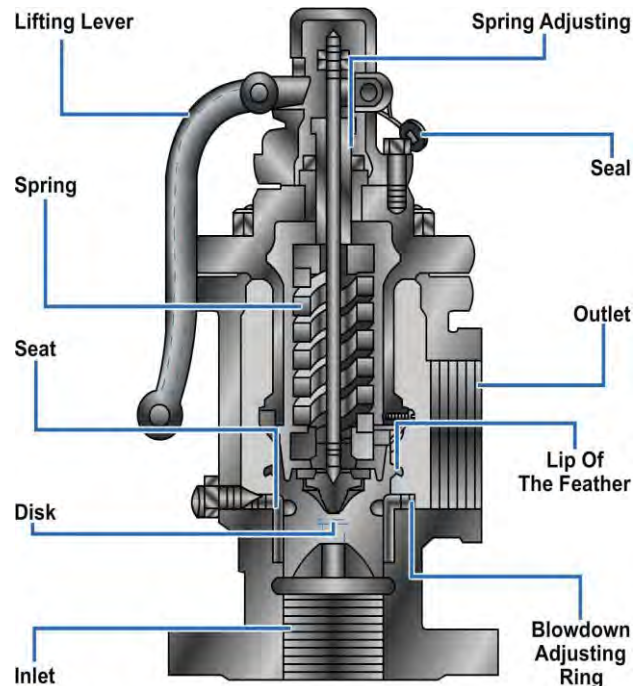
### 2.5.3 Gauge Glass

The gauge glass allows the boiler operator to see the water level in the boiler. Normally there are two valves associated with the gauge glass. One valve is located at the top and one is located at the bottom of the gauge glass. These two valves, named gauge cock valves, secure the boiler water and steam from the gauge glass. Another valve located in line with the gauge glass is used to blow the gauge glass down.

### 2.6.0 Safety Valve

The safety valve shown in *Figure 9-9* is the most important of boiler fittings. It is designed to open automatically to prevent pressure in the boiler from increasing beyond the safe operating limit. The safety valve is installed in a vertical position and attached directly to the steam space of the boiler. Each boiler has at least one safety valve; when the boiler has more than 500 square feet of heating surface, two or more valves are required.

There are several different types of safety valves in use, but all are designed to open completely (POP) at a specific pressure and to remain open until a specified pressure drop (BLOWDOWN) has occurred.



**Figure 9-9 - Spring-loaded safety valve.**

Safety valves must close tightly, without chattering, and must remain tightly closed after seating.

To understand the difference between boiler safety valves and ordinary relief valves is important. The amount of pressure required to lift a relief valve increases as the valve lifts, because the resistance of the spring increases in proportion to the amount of compression. When a relief valve is installed on a steam drum, it opens slightly when the specified pressure is exceeded, a small amount of steam is discharged, and then the valve closes again. Thus a relief valve on a steam drum is constantly opening and closing; this repeated action pounds the seat and disk and causes early failure of the valve. Safety valves are designed to open completely at a specified pressure to overcome this difficulty.

Several different types of safety valves are used on boilers; however, they all lift on the same general principle. In each case, the initial lift of the valve disk, or feather, is caused by static pressure of the steam acting upon the disk, or feather. As soon as the valve begins to open, however, a projecting lip, or ring, of the larger area is exposed for the steam pressure to act upon. The resulting increase in force overcomes the resistance of the spring, and the valve pops, that is, it opens quickly and completely.

Because of the larger area now presented, the valve reseats at a lower pressure than that which caused it to lift originally.

Lifting levers are provided to lift the valve from its seat (when boiler pressure is at least 75 percent of that at which the valve is set to pop) to check the action and to blow away any dirt from the seat. When the lifting lever is used, raise the valve disk sufficiently to ensure that all foreign matter is blown from around the seat to prevent leakage after being closed.

The various types of safety valves differ chiefly as to the method of applying compression to the spring, the method of transmitting spring pressure to the feather, or disk, the shape of the feather, or disk, and the method of blowdown adjustment. Detailed information on the operation and maintenance of safety valves can be found in the instruction books furnished by the manufacturers of this equipment.

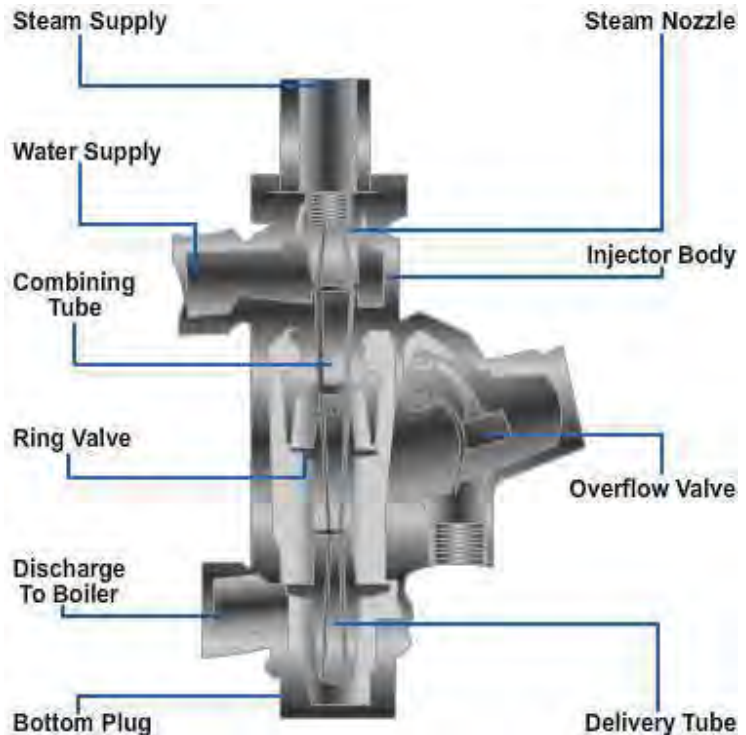
### 2.7.0 Steam Injector Feed System

The steam injector is a boiler feed pump that uses the velocity and condensation of a jet of steam from the boiler to lift and force a jet of water into the boiler (*Figure 9-10*). This injection of water is many times the weight of the original jet of steam.

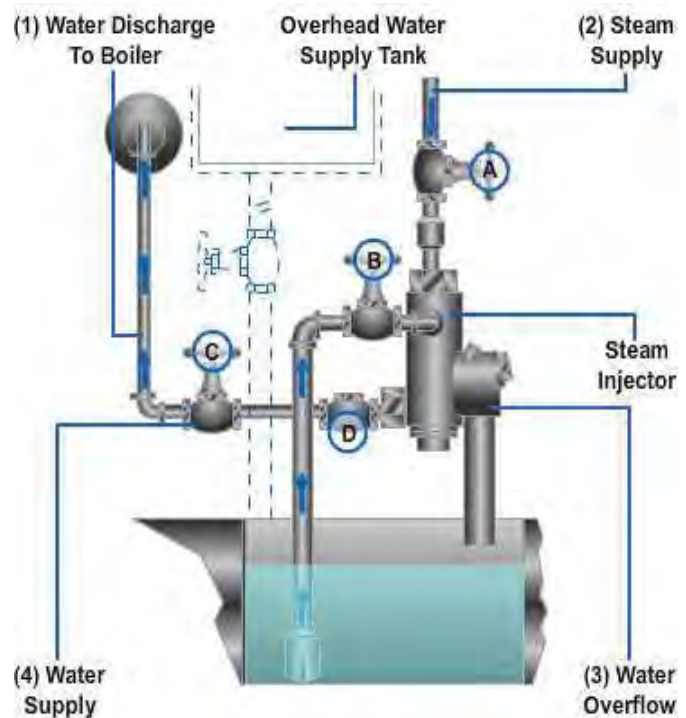
The injector is used to some extent in boiler plants as an emergency or standby feed unit. It does not feed very hot water. Under the best conditions, it can lift a stream of water having a temperature of 120°F about 14 feet.

The installation of an injector is not a difficult operation because the unit is mounted on the side of the boiler. The four connections to the injector are as follows (*Figure 9-11*):

1. The discharge line to the boiler feedwater inlet
2. The steam supply line from the boiler
3. The water overflow line
4. The water supply line from the reservoir.



**Figure 9-10 - Cross-sectional view of a steam injector.**



**Figure 9-11 - Injector piping.**

The controls for the injector include the following (*Figure 9-11*):

- A. Steam supply valve
- B. Water supply valve
- C. Discharge valve to the boiler
- D. Check valve in the discharge line

As you might expect, some degree of skill is needed to start the injector. After the injector begins to operate, however, it continues automatically until shutdown by the operator.

When starting the injector, first open the water supply valve (*Figure 9-11B*) about one full turn. Next quickly turn the steam supply valve (*Figure 9-11A*) all the way open. At this point, steam rushes into the combining tube of the injector. As the steam speeds past the water supply opening, it creates a suction that draws water through the opening into the combining tube. Water and steam are now mixed together inside the injector, and the pressure opens a valve that leads to the boiler. Meanwhile, there is an excess of water in the injector; this excess is discharged through the overflow valve. As the next step of the procedure, slowly turn the water supply valve (*Figure 9-11B*) toward the closed position until the overflow stops. The overflow valve has now closed, and all of the water being picked up from the supply line is going into the boiler. Remember, this feedwater system is used on boilers only as a standby method for feeding water.

For the injector to operate, the water supply should not be hotter than 120°F. When several unsuccessful attempts are made to operate the injector, it will become very hot and cannot be made to prime. When you encounter this problem, pour cold water over the injector until it is cool enough to draw water from the supply when the steam valve is opened.

### **2.8.0 Handholes and Manholes**

Handholes and manholes provide maintenance personnel access into a boiler to inspect and clean it internally as needed. These handholes and manholes will be covered in depth when boiler maintenance is discussed later in this chapter.



## 2.9.0 Boiler Accessories

Figure 9-12 provides a graphic presentation of important boiler accessories. Refer to it as you study Table 9-3, which gives a brief description of each accessory, its location, and function.

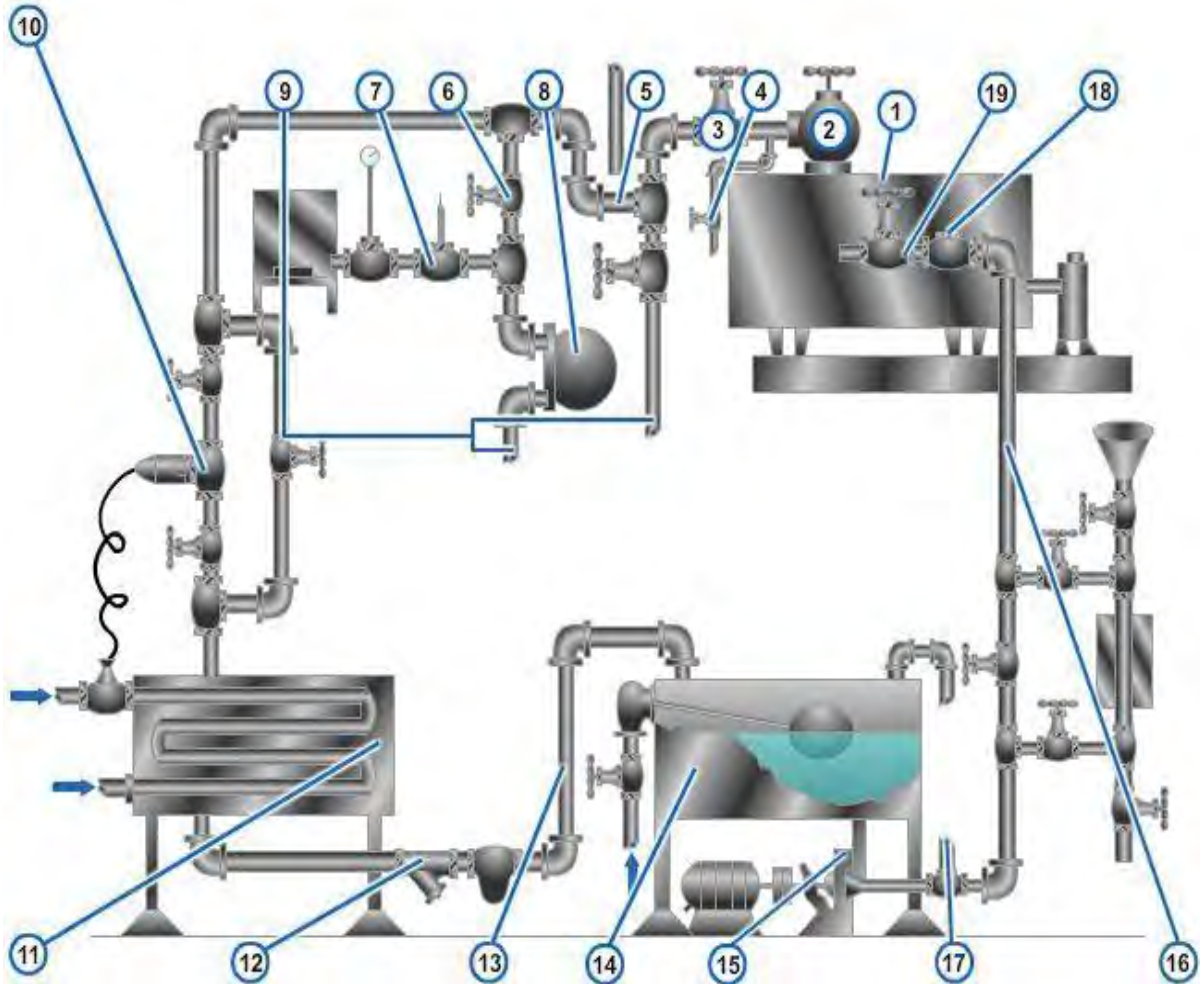


Figure 9-12 - Boiler accessory equipment.

**Table 9-3 - Boiler accessories, location, and function.**

Item	Accessory	Location	Function
1	Boiler	Boiler room	Generate steam or hot water in a closed vessel.
2	Main steam stop	On the steam outlet of a boiler	Place the boiler on line or off line.
3	Guard valve	On the steam outlet of a boiler directly following the main steam stop valve	Guard or backup to main steam stop valve.
4	Daylight (drain) valve	Between the main steam-stop valve and the guard valve	Open only when the main steam and guard valves are closed. Indicates if one of the valves is leaking through.
5	Main steam line	The line that conveys steam from a boiler to all branch or distribution lines. When a system is supplied by a bank of boilers connected into the same header, the line(s) conveying steam for the boiler(s) to the header	Carry steam from the boiler to the branches or distribution lines.
6	Root valve	Installed in branch or distribution lines just off of the main steam line	Isolate a branch or distribution line (serves as an emergency shutoff).
7	Pressure regulating valves (PRV)	Installed as close as practical (after a reducing station) to the equipment or area it serves	Equipment that requires lower pressure than main steam line pressure (coppers, dishwashers, steam chests, or turbines).
8	Steam trap	Installed on the discharge side of all steam heating or cooling equipment, dead ends, low points, or at regular intervals throughout a steam system (automatic drip legs)	Automatically drains condensate and prevents the passage of steam through equipment.
9	Drip legs	Provided throughout a system where condensation is most likely to occur, such as low spots, bottom of risers, and	Remove condensate from a system manually.

		dead ends	
10	Temperature regulating valve (TRV)	Install in the steam supply line close to equipment needing temperature regulation	Control steam flow through a vessel or heating equipment.
11	Heat exchanger	Locate as close as practical to the source for which it is going to supply heated water or oil	An unfired pressure vessel that contains a tube nest or electrical element. Used to heat oil or water.
12	Strainer	Install in steam and water lines just ahead of PRVs, TRVs, steam traps, and pumps	Prevent malfunction or costly repairs to equipment and components by trapping foreign matter such as rust, scale, and dirt.
13	Condensate line	Return line extends from the discharge side of steam traps to the condensate/makeup feedwater tank	Carry condensed steam back through piping for reuse in the boiler or heating vessel.
14	Condensate/makeup tank	Close to the boiler as practical and at a higher level than the boiler feed-pump suction line	Provide storage space for condensate and makeup/feedwater and vent noncondensable gases to the atmosphere.
15	Feed pump	Installed between the condensate/makeup/feedwater tank and the boiler shell or steam drum.	Supplies water to boiler as required.
16	Feedwater pipe	This line extends from the discharge side of the feedwater pump to the boiler shell or drum (installed below the steaming water level)	Provide feedwater to the boiler when required.
17	Relief valve	Between the feed pump and the nearest shutoff valve in the external feed line	Relieve excessive pressure should the external feed line be secured and the feed pump started accidentally. A ruptured line or serious damage to the feed

			pump could occur if there were no relief valve.
18	Feed check valve	Between the feed pump and the stop valve in the feed water pipe	Prevent backflow from the boiler through the feedwater line into the condensate/feedwater tank during the off cycle of the pump.
19	Feed stop valve	In the feedwater line as close to the boiler as possible between the boiler and feed check valve	Permit or prevent the flow of water to the boiler.

**Test your Knowledge (Select the Correct Response)**

2. What is the melting point of a fire-actuated fusible plug filled with an alloy of tin, copper, and lead?
- A. 415°F
  - B. 425°F
  - C. 435°F
  - D. 445°F

**3.0.0 TYPES of BOILERS**

The Utilitiesman (UT) is concerned primarily with the fire-tube type of boiler, since it is the type generally used in Seabee operations. However, the water-tube type of boiler may occasionally be used at some activities. The information in this chapter primarily concerns the different designs and construction features of fire-tube boilers.

The basis for identifying the two types is as follows:

- Water-tube boilers are those in which the products of combustion surround the tubes through which the water flows.
- Fire-tube boilers are those in which the products of combustion pass through the tubes and the water surrounds them.

**3.1.0 Water-Tube Boilers**

Water-tube boilers may be classified in a number of ways. For our purpose, they are classified as either straight tube or bent tube. These classes are discussed separately in succeeding sections. To avoid confusion, make sure you study carefully each illustration referred to throughout the discussion.

**3.1.1 Straight Tube**

The straight-tube class of water-tube boilers includes three types:

1. Sectional-header cross drum
2. Box-header cross drum
3. Box-header longitudinal drum

In the sectional-header cross drum boiler with vertical headers, the headers are steel boxes into which the tubes are rolled. Feedwater enters and passes down through the down-comers (pipes) into the rear sectional headers from which the tubes are supplied. The water is heated and some of it changes into steam as it flows through the tubes to the front headers. The steam-water mixture returns to the steam drum through the circulating tubes and is discharged in front of the steam-drum baffle that helps to separate the water and steam.

Steam is removed from the top of the drum through the dry pipe. This pipe extends along the length of the drum and has holes or slots in the top half for steam to enter.

Headers, the distinguishing feature of this boiler, are usually made of forged steel and are connected to the drums with tubes. Headers may be vertical or at right angles to the tubes. The tubes are rolled and flared into the header. A handhole is located opposite the ends of each tube to facilitate inspection and cleaning. Its purpose is to collect sediment that is removed by blowing down the boiler.

**Baffles** are usually arranged so gases are directed across the tubes three times before being discharged from the boiler below the drum.

Box-header cross drum boilers are shallow boxes made of two plates—a tube-sheet plate that is bent to form the sides of the box, and a plate containing the handholes that is riveted to the tube-sheet plate. Some are designed so that the front plate can be removed for access to tubes. Tubes enter at right angles to the box header and are expanded and flared in the same manner as the sectional-header boiler. The boiler is usually built with the drum in front. It is supported by lugs fastened to the box headers. This boiler has either cross or longitudinal baffling arranged to divide the boiler into three passes. Water enters the bottom of the drum, flows through connecting tubes to the box header, through the tubes to the rear box header, and back to the drum.

Box-header longitudinal drum boilers have either a horizontal or inclined drum. Box headers are fastened directly to the drum when the drum is inclined. When the drum is horizontal, the front box header is connected to it at an angle greater than 90 degrees. The rear box header is connected to the drum by tubes. Longitudinal or cross baffles can be used with either type.

### 3.1.2 Bent Tube

Bent tube boilers usually have three drums. The drums are usually of the same diameter and positioned at different levels. The uppermost or highest positioned drum is referred to as the steam drum, while the middle drum is referred to as the water drum, and the lowest, the mud drum. Tube banks connect the drums. The tubes are bent at the ends to enter the drums radially.

Water enters the top rear drum, passes through the tubes to the bottom drum, and then moves up through the tubes to the top front drum. A mixture of steam and water is discharged into this drum. The steam returns to the top rear drum through the upper row of tubes, while the water travels through the tubes in the lower rear drum by tubes extending across the drum, and enters a small collecting header above the front drum.

Many types of baffle arrangements are used with bent-tube boilers. Usually, they are installed so that the inclined tubes between the lower drum and the top front drum absorb 70 to 80 percent of the heat. The water-tube boilers discussed above offer a number of worthwhile advantages. For one thing, they afford flexibility in starting up. They also have a high productive capacity ranging from 100,000 to 1,000,000 pounds of steam per hour. In case of tube failure, there is little danger of a disastrous explosion of

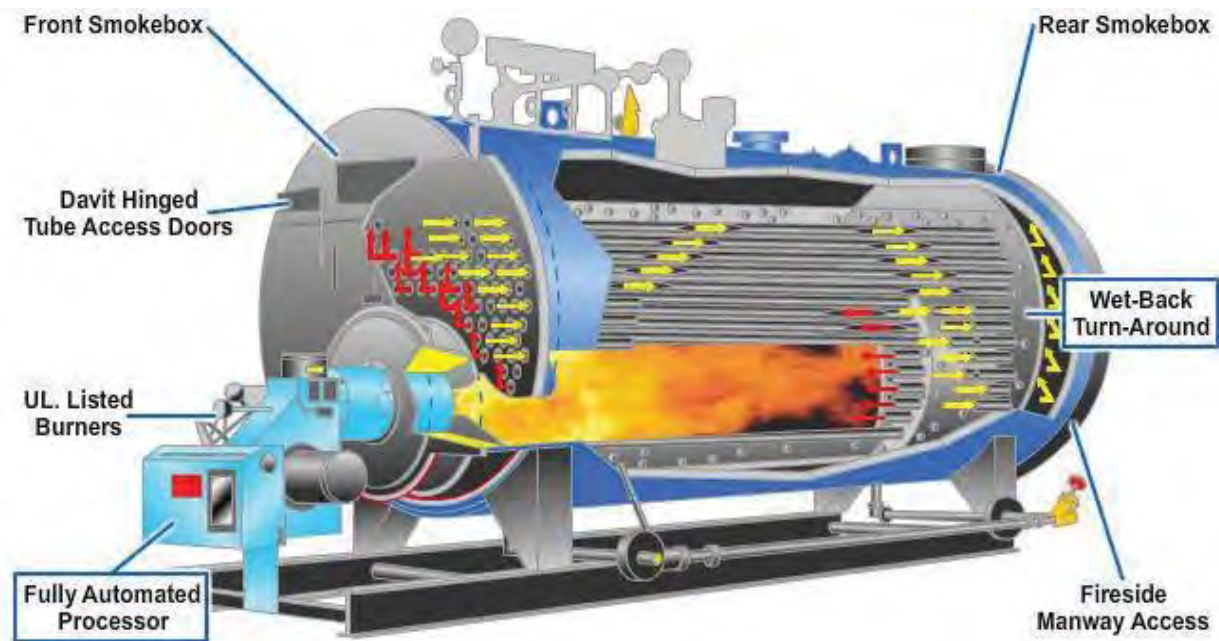
the water-tube boiler. The furnace not only can carry a high overload, it can also be modified for firing by oil or coal. Still another advantage is that it is easy to get into sections inside the furnace to clean and repair them. There are also several disadvantages common to water-tube boilers. One of the main drawbacks is their high construction cost. The large assortment of tubes required for this boiler and the excessive weight per unit weight of steam generated are other unfavorable factors.

### 3.2.0 Fire-Tube Boilers

There are four types of fire-tube boilers-Scotch marine boiler, vertical-tube boiler, horizontal return tubular boiler, and firebox boiler. These four types of boilers are discussed in this section.

#### 3.2.1 Scotch Marine Boiler

The Scotch marine fire-tube boiler is especially suited to Seabee needs. *Figure 9-13* shows a portable Scotch marine fire-tube boiler. The portable unit can be moved easily and requires only a minimal amount of foundation work. A completely self-contained unit, its design includes automatic controls, a steel boiler, and burner equipment. These features are a big advantage because no disassembly is required when you must move the boiler into the field for an emergency.



**Figure 9-13 - Scotch marine type of fire-tube boiler.**

The Scotch marine boiler has a two-pass (or more) arrangement of tubes that run horizontally to allow the heat inside the tubes to travel back and forth. It also has an internally fired furnace with a cylindrical combustion chamber. Oil is the primary fuel

used to fire the boiler; however, it can also be fired with wood, coal, or gas. A major advantage of the Scotch marine boiler is that it requires less space than a water-tube boiler and can be placed in a room that has a low ceiling.

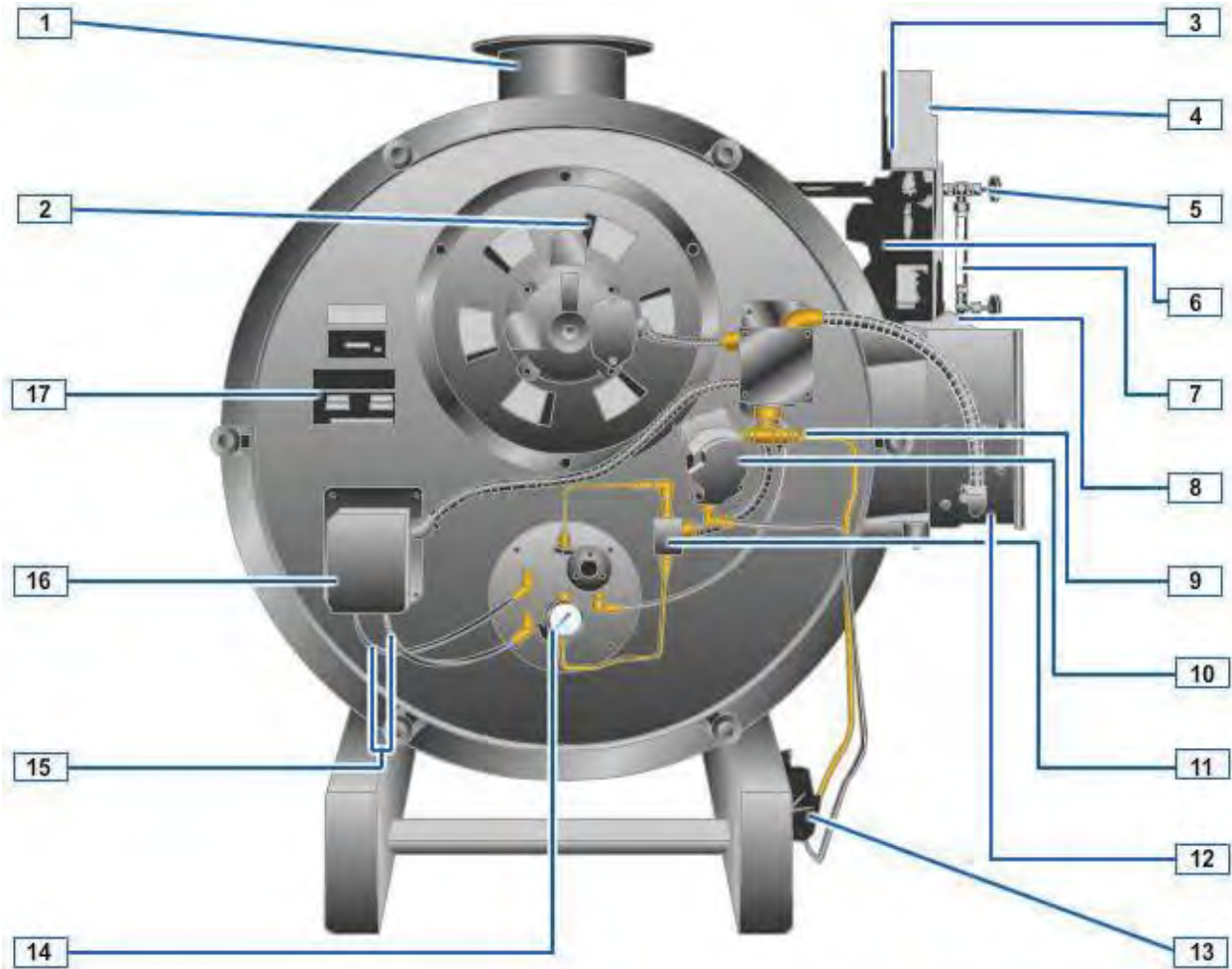
The Scotch marine boiler also has disadvantages. The shell of the boiler runs from 6 to 8 feet in diameter, a detail of construction that makes a large amount of reinforcing necessary. The fixed dimensions of the internal surface cause some difficulty in cleaning the sections below the combustion chamber. Another drawback is the limited capacity and pressure of the Scotch marine boiler.

An important safety device sometimes used is the fusible plug that provides added protection against low-water conditions. In case of a low-water condition, the fusible plug core melts, allowing steam to escape, and a loud noise is emitted which provides a warning to the operator. On the Scotch boiler the plug is located in the crown sheet, but sometimes it is placed in the upper back of the combustion chamber. Fusible plugs are discussed in more detail later in this chapter.

Access for cleaning, inspection, and repair of the boiler watersides is provided through a manhole in the top of the boiler shell and a handhole in the **water leg**. The manhole opening is large enough for a person to enter the boiler shell for inspection, cleaning, and repairs. On such occasions, always ensure that all valves are secured, locked, and tagged, and that the person in charge knows you are going to enter the boiler.

Additionally, always have a person located outside of the boiler standing by to aid you in case of an incident that would require assistance. The handholes are openings large enough to permit hand entry for cleaning, inspection, and repairs to tubes and headers.

*Figure 9-14* shows a horizontal fire-tube boiler used in low-pressure applications. Personnel in the UT rating are assigned to operate and maintain this type of boiler more often than any other type of boiler. Refer to *Table 9-1* for equipment location.



**Figure 9-14-Horizontal fire-tube boiler used in low-pressure applications.**

**Table 9-1 - Horizontal fire-tube boiler parts location.**

1. Vents	7. Water Level Gauge	13. Fuel Oil Supply Connection
2. Air Damper	8. Burner Switch	14. Fuel Oil Pressure Gauge
3. High Limit Pressure Control	9. Priming Tee	15. Ignition Cable
4. Steam Pressure Gauge	10. Oil Unit, Two Stage	16. Ignition Cable Box
5. Gauge Glass Shutoff Cock	11. Solenoid Oil Valve	17. Nameplate
6. Low Water Control	12. Service Connection Box	



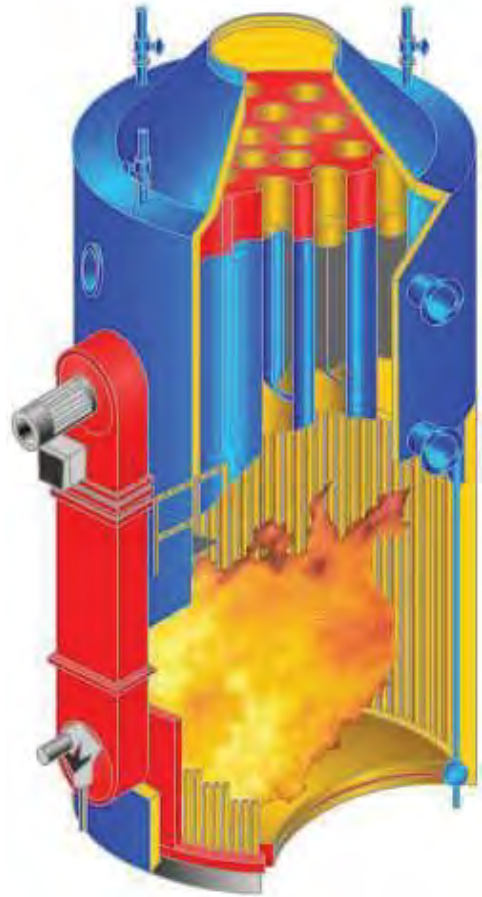
### 3.2.2 Vertical-Tube Boiler

In some fire-tube boilers, the tubes run vertically, as opposed to the horizontal arrangement in the Scotch boiler. The vertical-tube boiler sits in an upright position (*Figure 9-15*). Therefore, the products of combustion (gases) make a single pass, traveling straight up through the tubes and out the stack. The vertical fire-tube boiler is similar to the horizontal fire-tube boiler in that it is a portable, self-contained unit requiring a minimum of floor space.

Handholes are also provided for cleaning and repairing. Though self-supporting in its setting (no brickwork or foundation being necessary), it **MUST** be level. The vertical fire-tube boiler has the same disadvantages as that of the horizontal-tube design—limited capacity and furnace volume.

Before selecting a vertical fire-tube boiler, you must know how much overhead space is in the building where it will be used. Since this boiler sits in an upright position, a room with a high ceiling is necessary for its installation.

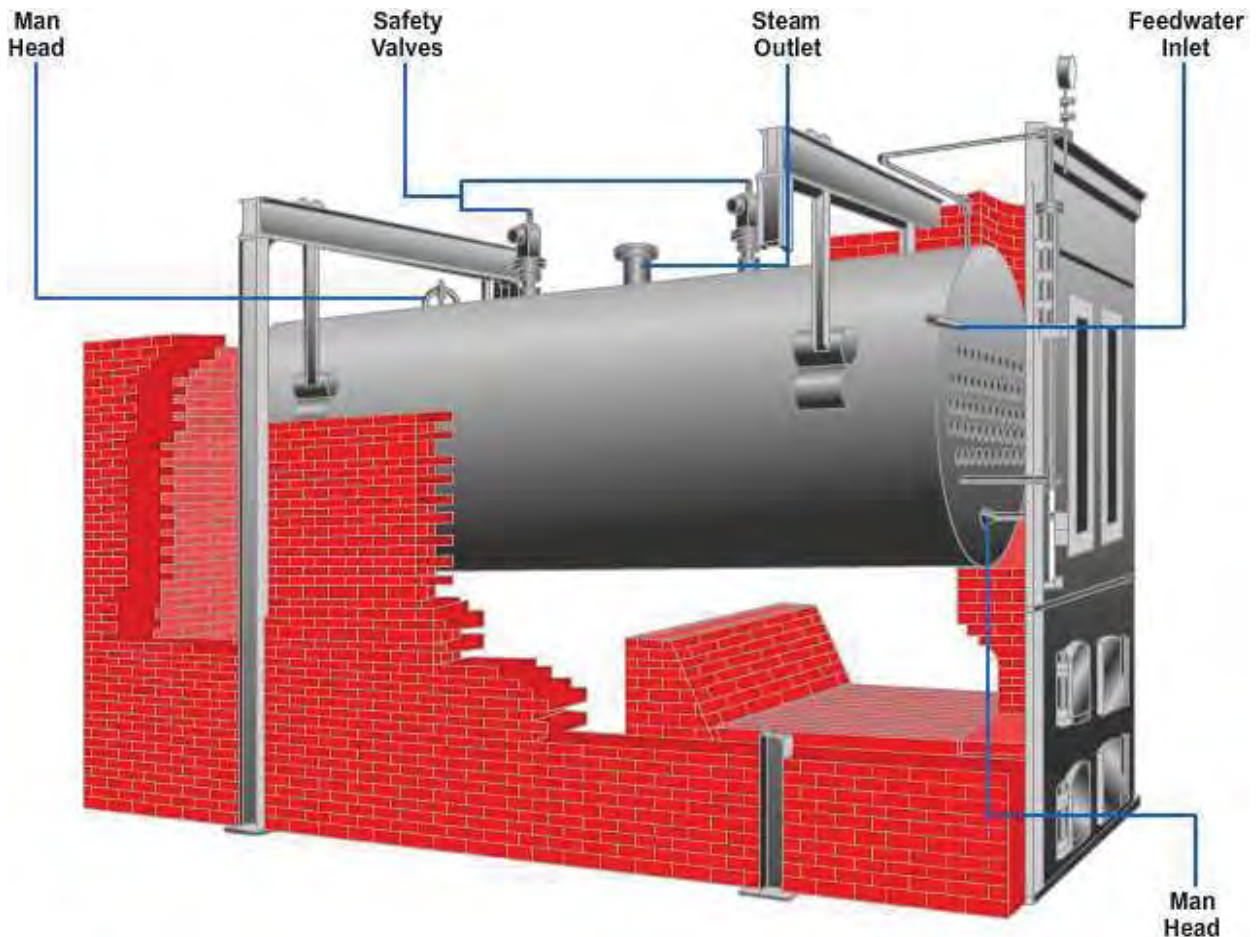
The blowdown pipe of the vertical fire-tube boiler is attached to the lowest part of the water leg, and the feedwater inlet opens through the top of the shell. The boiler fusible plug is installed either (1) in the bottom tube sheet or crown sheet or (2) on the outside row of tubes, one third of the height of the tube from the bottom.



**Figure 9-15-Cutaway view of a vertical fire-tube boiler.**

### 3.2.3 Horizontal Return Tubular Boiler

In addition to operating portable boilers such as the Scotch marine and vertical fire-tube boilers, the UT must also be able to operate stationary boilers, both in the plant and in the field. A stationary boiler can be defined as one having a permanent foundation and not easily moved or relocated. A popular type of stationary fire-tube boiler is the horizontal return tubular (HRT) boiler shown in *Figure 9-16*.



**Figure 9-16-Horizontal return tubular (HRT) fire-tube boiler.**

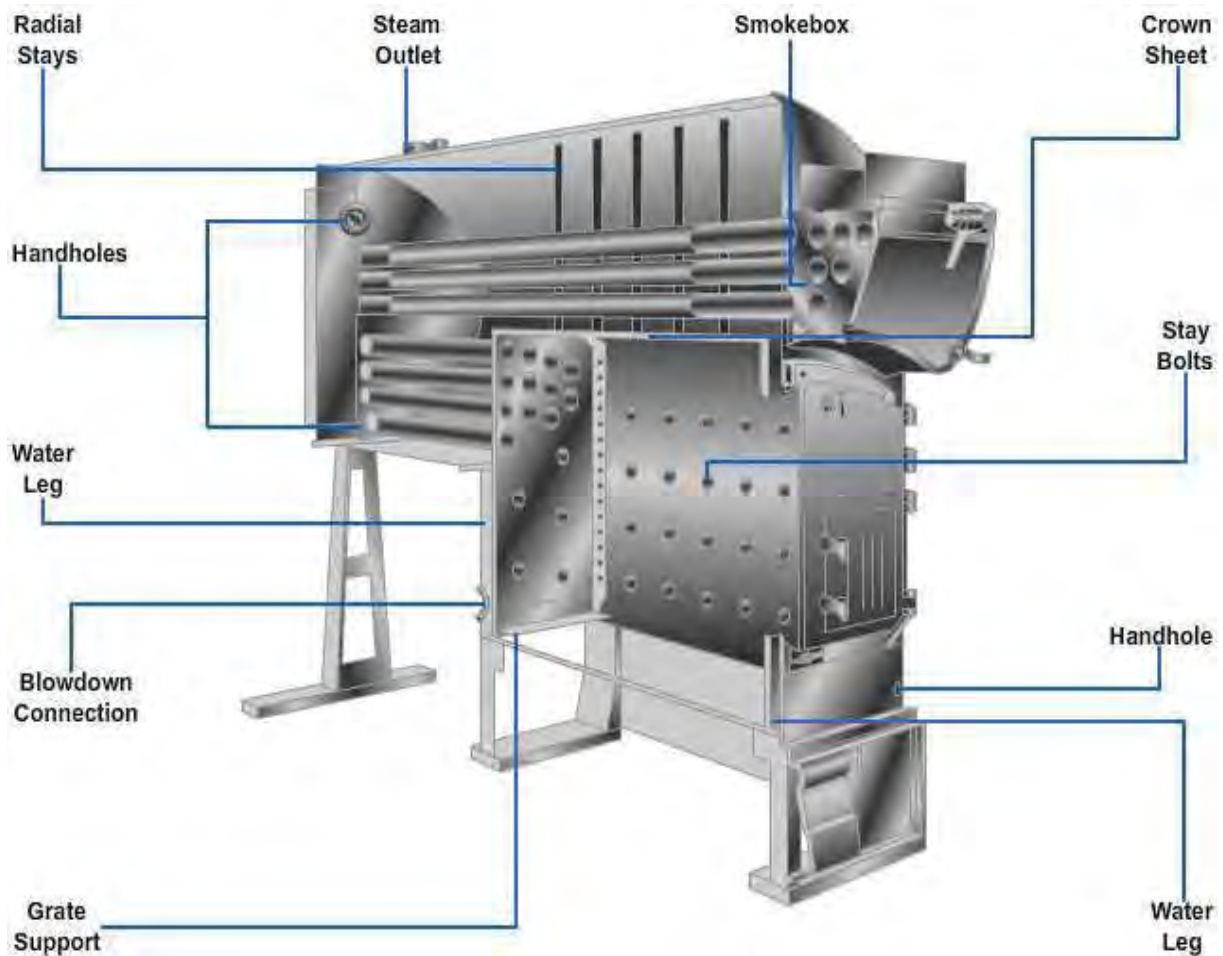
The initial cost of the HRT boiler is relatively low, and installing it is not too difficult. The boiler setting can be readily changed to meet different fuel requirements-coal, oil, wood, or gas. Tube replacement is also a comparatively easy task since all tubes in the HRT boiler are the same in size, length, and diameter.

The gas flows in the HRT boiler from the firebox to the rear of the boiler. It then returns through the tubes to the front where it is discharged to the breaching and out the stack.

The HRT boiler has a pitch of 1 to 2 inches to the rear to allow **sediment** to settle toward the rear near the bottom blowdown connection. The fusible plug is located 2 inches above the top row of tubes. Boilers over 40 inches in diameter require a manhole in the upper part of the shell. Those over 48 inches in diameter must have a manhole in the lower as well as in the upper part of the shell. Do not fail to familiarize yourself with the location of these and other essential parts of the HRT boiler. The knowledge you acquire will definitely help in the performance of your duties with boilers.

### 3.2.4 Firebox Boiler

Another type of fire-tube boiler is the firebox boiler that is usually used for stationary purposes. A split section of a small firebox boiler is shown in *Figure 9-17*.



**Figure 9-17-Split section of a small firebox boiler.**

Gases in the firebox boiler make two passes through the tubes. Firebox boilers require no setting except possibly an ash pit for coal fuel. As a result, they can be quickly installed and placed in service. Gases travel from the firebox through a group of tubes to a reversing chamber. They return through a second set of tubes to the *flue* connection on the front of the boiler and are then discharged up the stack.

## 4.0.0 BOILER DESIGN REQUIREMENTS

A boiler must meet certain requirements before it is considered satisfactory for operation. Three important requirements for a boiler are as follows:

1. The boiler must be safe to operate.
2. The boiler must be able to generate steam at the desired rate and pressure.
3. The boiler must be economical to operate.

### NOTE

Make it a point to familiarize yourself with the boiler code and other requirements applicable to the area in which you are located.

Design rules for boilers are established by the ASME (American Society of Mechanical Engineers) and are general guidelines used by engineers when designing boilers. These rules require that for economy of operation and the ability to generate steam at the desired rate and pressure, a boiler must have the following attributes:

- Adequate water and steam capacity
- Rapid and positive water circulation
- Large steam-generating surface
- Heating surfaces that are easy to clean on both water and gas sides
- Parts accessible for inspection
- Correct amount and proper arrangement of heating surface
- Firebox for efficient combustion of fuel

## 5.0.0 AUTOMATIC CONTROLS

Automatic controls are a big asset since they reduce manual control of the furnace, boilers, and auxiliary equipment. For this reason, UT personnel should be able to recognize and understand the basic operations of different types of boiler operating controls. The types of controls the UT should become familiar with are as follows: float, pressure, combustion, flame failure, and operation controls.

### 5.1.0 Float Control

The float in a boiler control works on the same basic principle as the float in a flush-tank type of water closet. Float, or level, control depends on the level of fluid in a tank or boiler to indicate the balance between the flow out of and the flow into the equipment and to operate a controller to restore the balance.

A float is often used to measure the change in fluid level and to operate the controlled valve to restore the balance. It may be arranged to increase the flow when the fluid level drops. *Figure 9-18* shows one of the methods used to accomplish this. Here, the float is connected to the control valve.

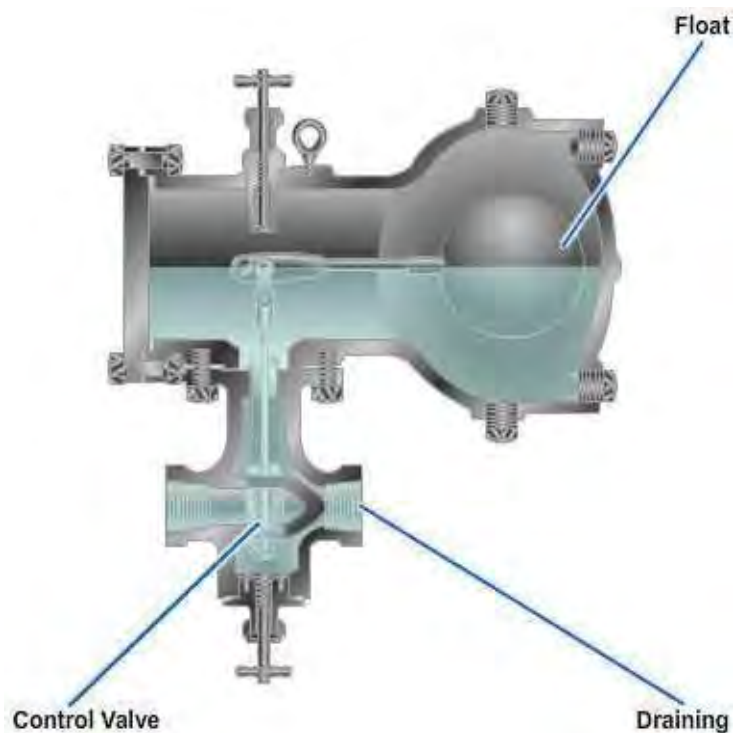


Figure 9-18 - Float controller.

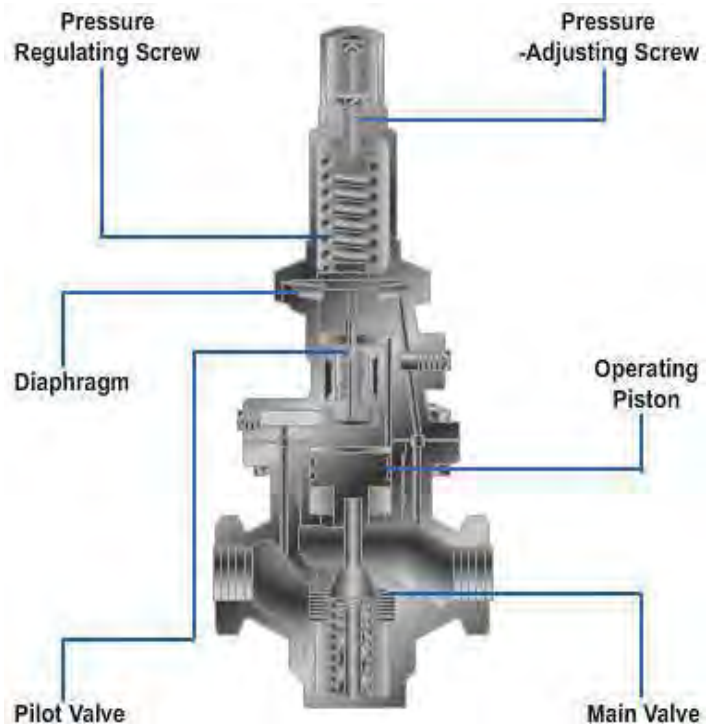
## 5.2.0 Pressure Regulating Control

Pressure regulating is the process of maintaining a difference of pressure between two points in a system. One type of pressure regulating maintains a definite pressure in one part of the system, while the other part fluctuates or changes within certain limits. An example of this type of control is a pressure-regulator valve that maintains a definite pressure on the discharge side of the valve by controlling the flow of steam, air, or gas through the valve (*Figure 9-19*).

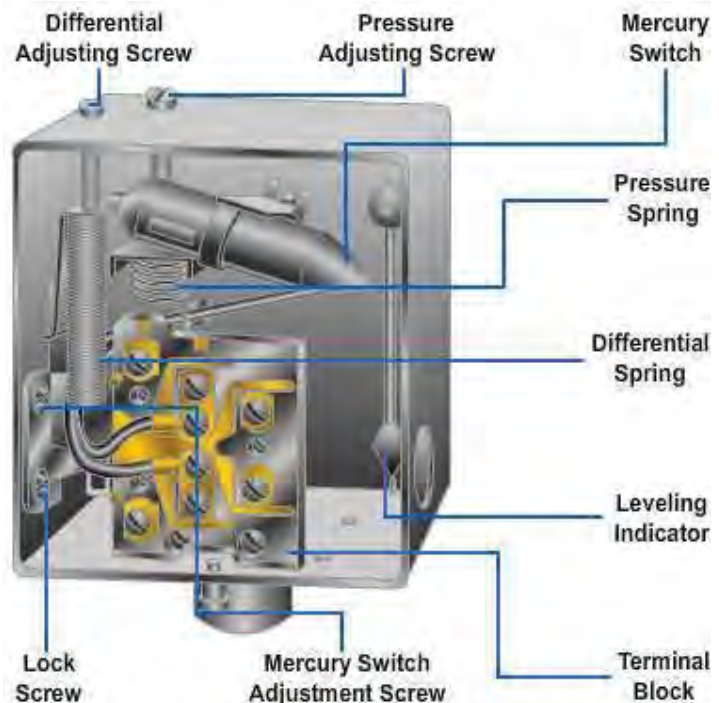
A second type of regulator maintains a definite difference in pressure between two points and also controls the flow. This type of regulator is often applied to a boiler feeding to maintain a fixed difference between the pressure of water supplied at the feed valve and the pressure in the boiler steam drum. The pressure regulator may consist of a self-contained device that operates the regulating valve directly, or it may consist of a pressure-measuring device, such as a Bourdon-tube gauge, that operates a pilot or relay valve. The valve positions the regulating valve or mechanism to maintain the desired conditions.

Pressure controls are designed primarily for steam-heating systems but are also available for controlling air, liquids, or gases that are not chemically injurious to the control (*Figure 9-20*). The function of the pressure control is as follows:

- To control the pressure in the boiler.
- To secure the fuel-burning equipment when the pressure reaches a predetermined cutout.
- To start the fuel-burning equipment when the pressure drops to the cut-in point.



**Figure 9-19 - Pressure regulator.**



**Figure 9-20 - Pressure control.**

There are two settings on the pressure control—the cut-in point and the differential. To find the cut-out point, you add the differential to the cut-in pressure;

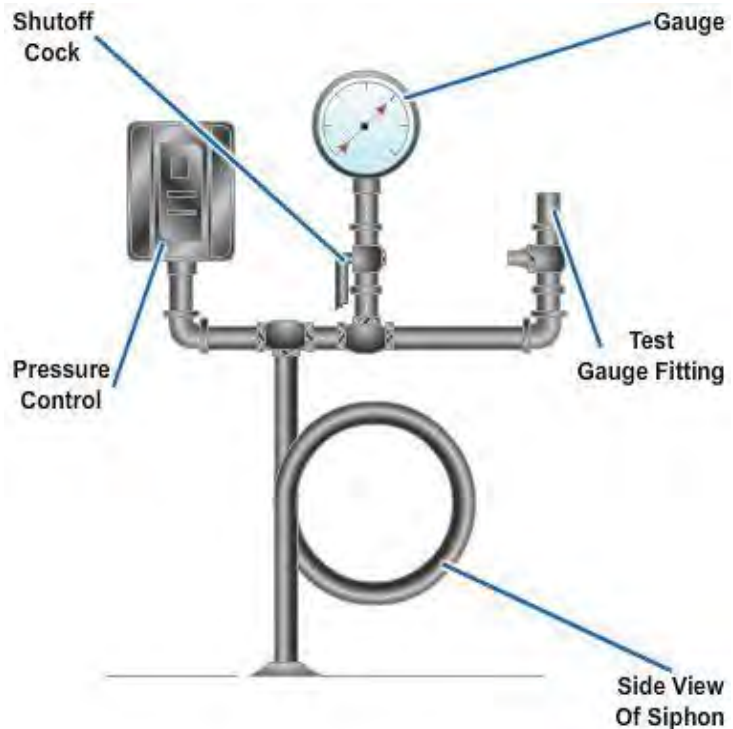
$$\text{Cut-in point} + \text{Differential} = \text{Cut-out point}$$

for example, when you are operating a boiler with a cut-in pressure of 90 pounds and a differential of 13 pounds, the cut-out pressure should be 103 pounds. When you encounter excessive vibrations, mount the pressure control remotely from the boiler on a solid mounting with a suitable piping connection between them. When you use a mercury type of switch control, be sure that it is mounted level and that the siphon (pigtail) has the loop extending in the direction of the back of the control and at a 90 degree angle to the front, as

shown in *Figure 9-18*. This position prevents expansion and contraction of the siphon from affecting the mercury level and accuracy of the control.

Additionally, when you install any pigtail, ensure the tube is filled with water. The water will prevent hot steam from contacting the control.

The pressure control can be mounted either on a tee along with the pressure gauge on the pressure-gauge tapping, as shown in *Figure 9-21*, or it can be mounted on the low-water cutout provided by some manufacturers. In either case, be sure that the pipe dope does NOT enter the control. The procedure you should follow is to apply the dope to the male threads, leaving the first two threads bare.



**Figure 9-21 - Typical steam gauge installation.**

### 5.3.0 Combustion Control

Combustion control is the process of regulating the mixed flow of air and fuel to a furnace as necessary to supply the demand for steam. A modulating pressuretrol controls the movement of the modutrol motor which in turn opens or closes the oil valve and air shutters to adjust the rate of firing to suit the demands of the boiler.

A modulating motor consists of the motor windings, a balancing relay, and a balancing potentiometer (*Figure 9-22*).

The loading is transmitted to the winding through an oil-immersed gear train from

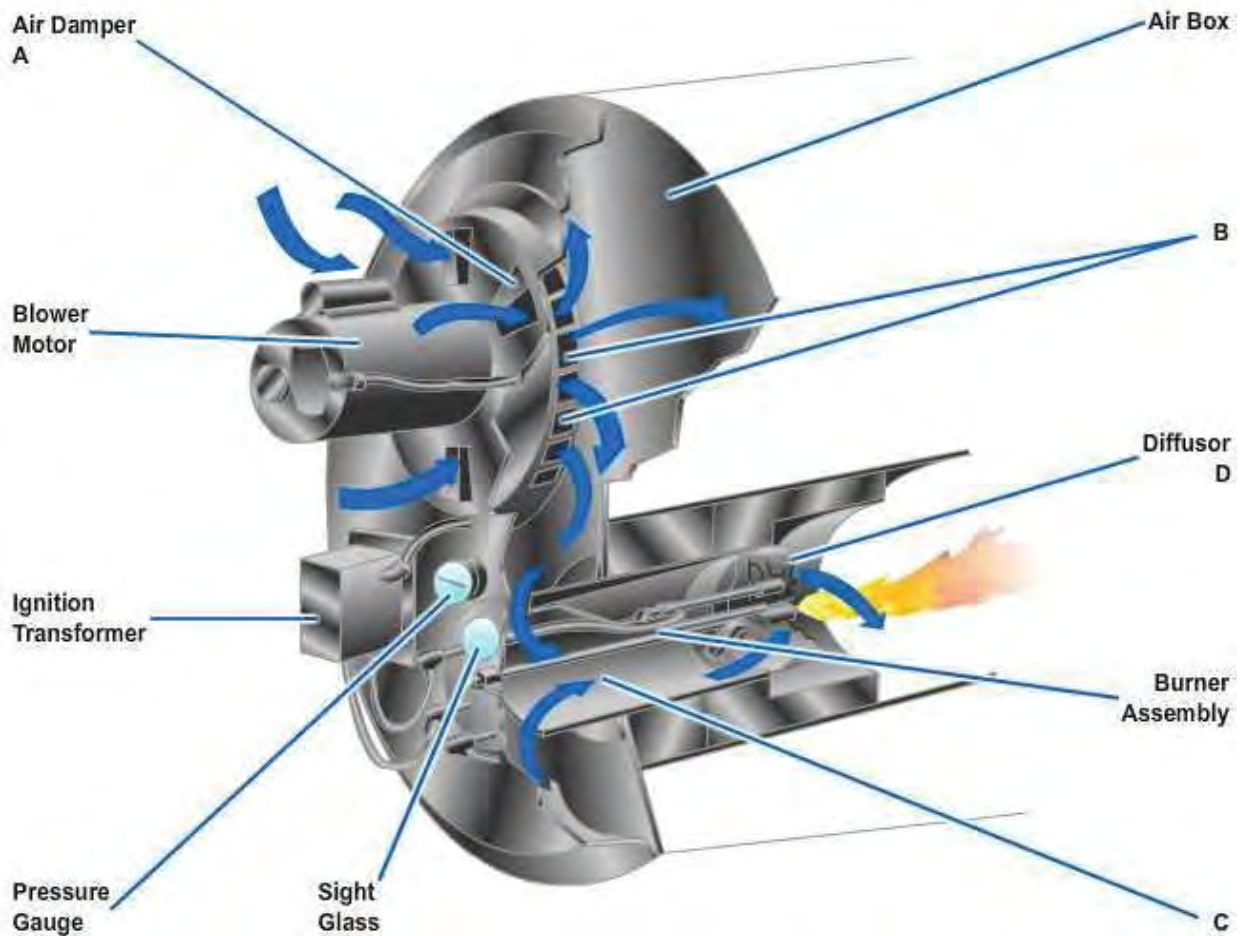


**Figure 9-22 - Modulating motor.**

the crank arm. The crankshaft is the double-ended type, and the crank arm may be mounted on either end of the motor. The motor works with the potentiometer coil in the modulating pressuretrol. An electrical imbalance is created by pressure change signals to the pressuretrol. This causes the motor to rotate in an attempt to rebalance the circuit. The crank arm, through linkage, positions the burner air louvers and the oil regulating valve, maintaining a balanced flow of air and oil throughout the burner firing range.

Another process of controlling combustion air is to use a manually adjusted air damper. A centrifugal blower, mounted on the boiler head and driven by the blower motor, furnishes combustion air. A definite amount of air must be forced into the combustion chamber to mix with the atomized oil to obtain efficient combustion. In operation, a pressure is built up in the entire head and the secondary air is forced through a diffuser to mix thoroughly with the atomized oil as combustion takes place.

The combustion airflow diagram in *Figure 9-23* shows a cutaway view of those components that influence most the path of the air through the burner assembly. Air is drawn into the motor-driven blower through the adjustable air damper at (A) and forced through openings (B) into the air box. Sufficient pressure is built up to force the air through openings (C) and the diffuser (D). In the area immediately beyond the diffuser (D), combustion is completed. The hot gaseous products of combustion are forced on through the remaining three passes, where they give up a large portion of the contained heat to the water which completely envelopes the passes.



**Figure 9-23 - Airflow diagram.**

The rate at which combustion air is delivered can be changed by throttling the intake to the blower by opening or closing the air damper to obtain the exact rate of airflow required for complete combustion. Since the rate at which fuel is delivered is predetermined by the design and is not readily adjustable, setting of the air damper is the only means of obtaining the correct ratio of fuel to air to ensure the most efficient combustion.

A pressure-regulating valve is built into the pump that controls the fuel. The fuel pump contains a two-stage gear-type pump, a suction strainer, a pressure-regulating valve, and a nozzle cutoff valve, all assembled in a single housing (Figure 9-24). There are many other types of fuel pumps, this is just one example.

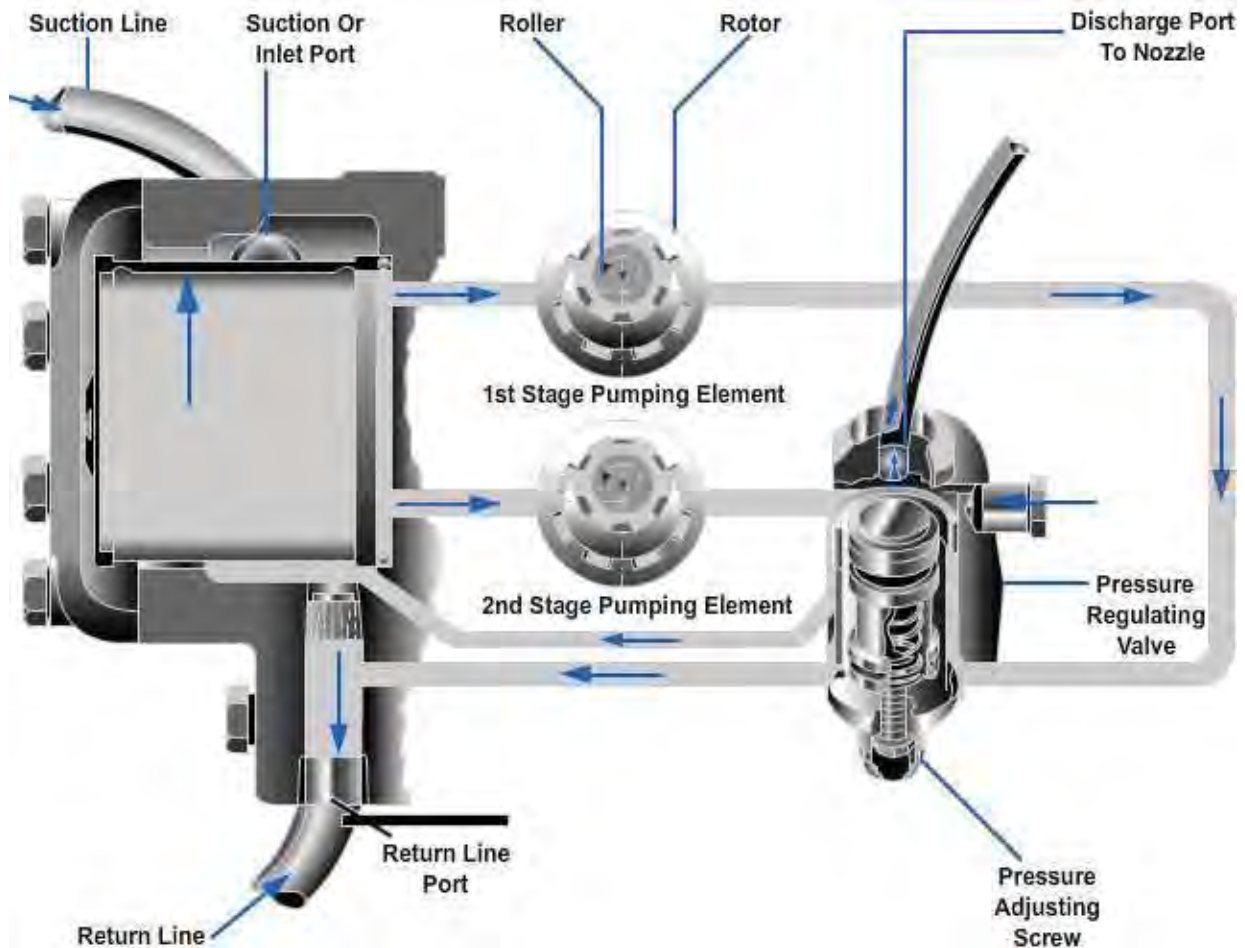
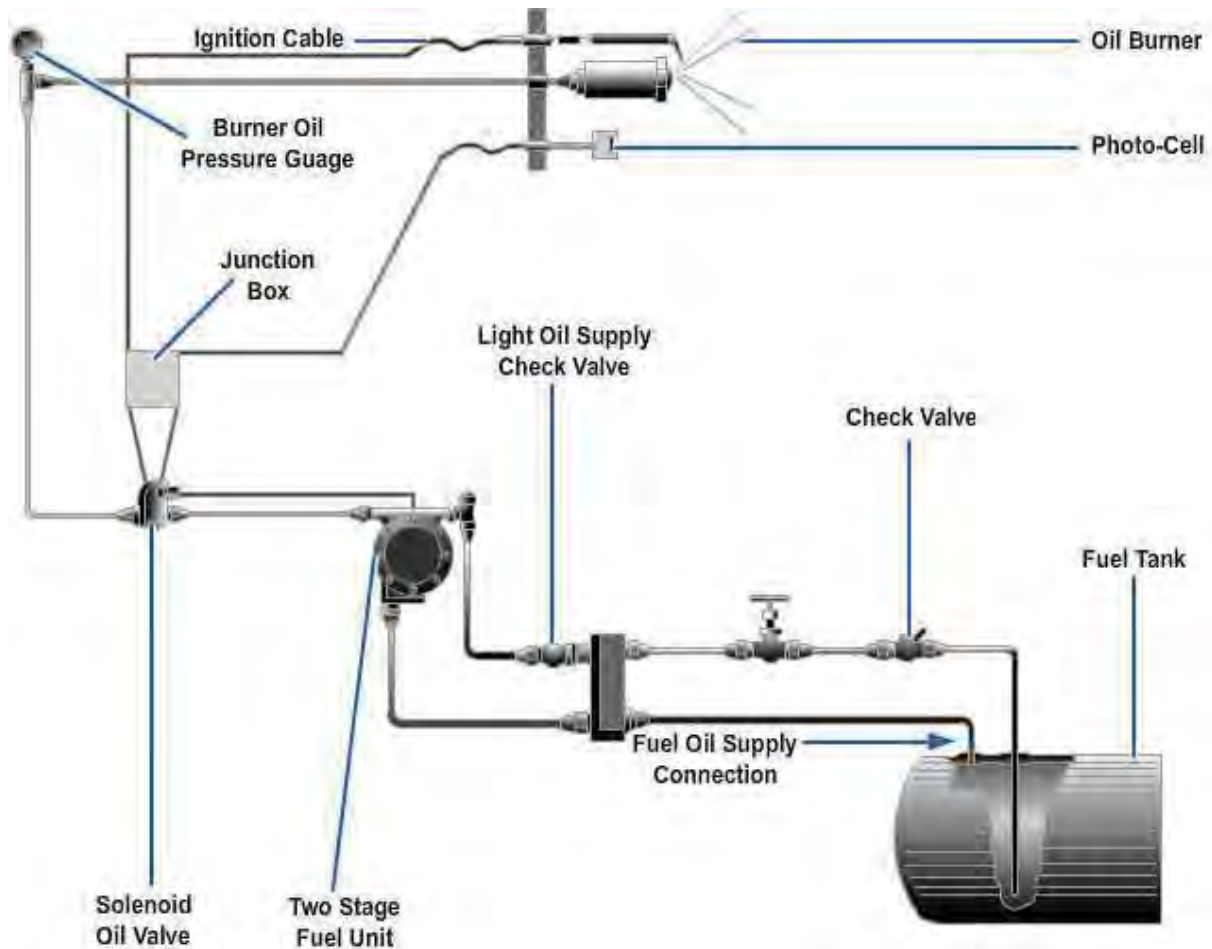


Figure 9-24 - Fuel oil pump.



You can gain knowledge of the functional relationship of the component parts by studying the internal oil flow diagram shown in *Figure 9-25*.



**Figure 9-25 - Internal oil flow diagram.**

Observe that the two-stage fuel unit consists essentially of two pumps operating in tandem and arranged in a common housing. The first stage develops a pressure below the atmospheric pressure level at its inlet that causes the oil to flow from storage or supply to the strainer chamber reservoir. All air drawn into the unit rises to the top of this chamber. This air and excess oil are drawn into the first-stage-pumping element and pumped back to the fuel oil storage tank. The second stage withdraws air-free oil from the strainer chamber reservoir and raises the oil pressure to that required for proper atomization at the burner nozzles. The second stage, operating against a combination pressure regulating and nozzle cutoff valve, develops atomizing pressure because of the flow restriction imposed by this valve. The pressure-regulating valve also bypasses excess second-stage oil back to the bottom of the strainer chamber reservoir. The atomizing pressure can be varied within a restricted range by adjustment of the spring-loaded pressure-regulating valve. Normal atomizing pressures generally range between 95 and 120 pounds per square inch.

An orifice is included in the fuel line to the main oil burner (*Figure 9-25*). The orifice serves to keep the oil pressure from experiencing a sudden drop when the solenoid oil valve in that line opens. The orifice is commonly built into the solenoid oil valve (*Figure 9-25*, Item 1). Included in the schematic diagram is a photocell (3) which, if it sights no flame, reacts to cause a switching action that results in shutting down the burner.

### 5.4.0 Flame Failure and Operational Controls

Frequently on fully automatic boilers, you will find an electronic type of device provided for the control of flame failure. The device provides automatic start and operation of the main burner equipment. Some controls are designed to close all fuel valves, shut down the burner equipment within 4 seconds after a flame failure, and actuate an alarm.

Some controls also create a safety shutdown within 4 seconds after de-energization of ignition equipment when the main burner flame is not properly established or fails during the normal starting sequence. These controls must create a safety shutdown when the pilot flame is not established and confirmed within 7 seconds after lighting. A safety shutdown requires manual reset before operation can be resumed and prevents recycling of the burner equipment.

## 6.0.0 INSTRUMENTS and METERS

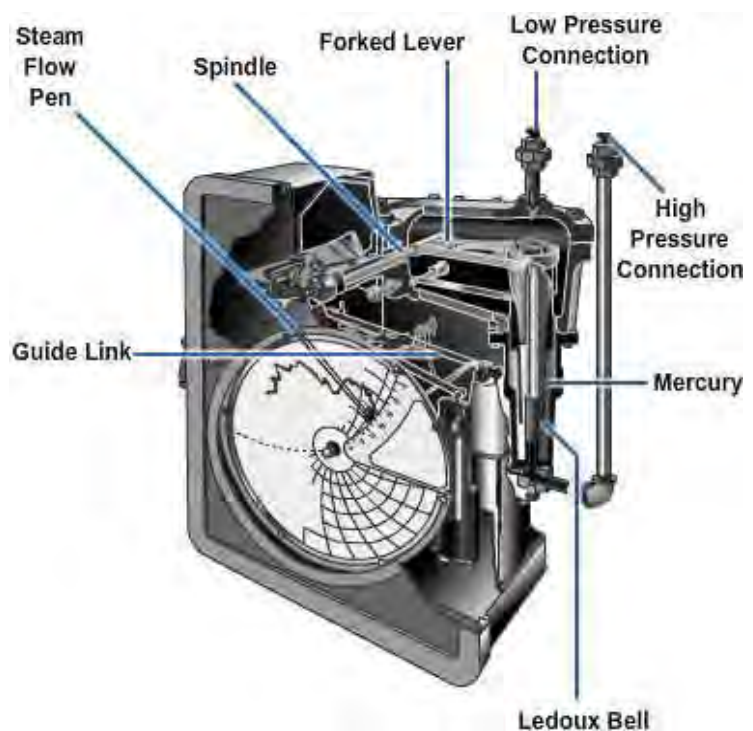
A pressure gauge is essential for safe operation of a boiler plant. However, the use of additional instruments, such as flowmeters and draft gauges, increases safety and promotes efficiency. All of these instruments may be either indicating or recording.

### 6.1.0 Steam Flowmeters

A UT must be able to identify the different types of monitoring instruments and understand their operation and use. Meters used to measure quantities are divided into two general types:

1. Those indicating rate, such as flowmeters
2. Those indicating the total, such as scales

Many devices are designed to measure and indicate the pressure of steam flow. One of these devices is shown in *Figure 9-26*. This meter uses a weighted inverted bell (called a Ledoux bell) sealed with mercury. The bell moves up and down as the rate of flow changes. The movement is transmitted to a pen that records the flow.

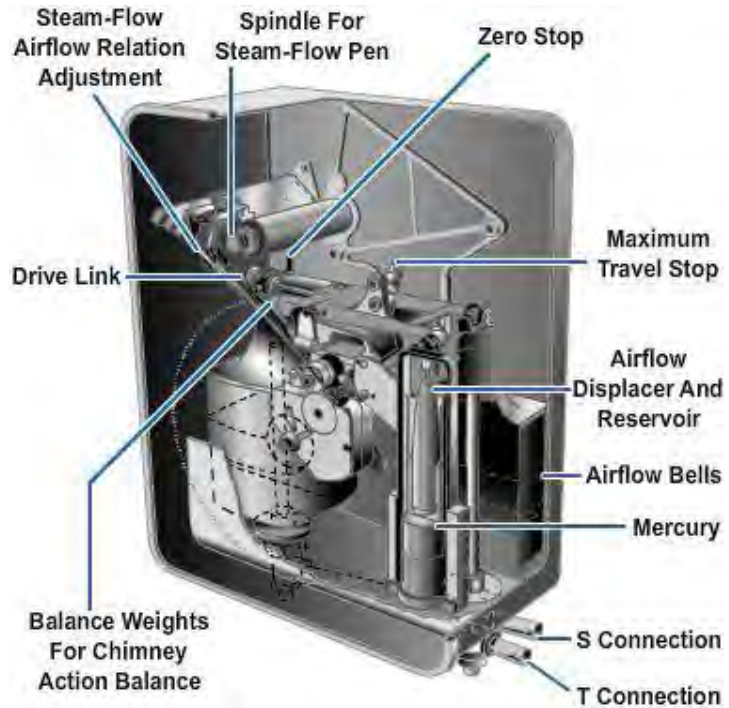


**Figure 9-26 - Flowmeter.**

## 6.2.0 Steam and Air Flowmeters

A combustion air and steam flowmeter is shown in *Figure 9-27*. This meter is used as a guide in controlling the relationship between air required and air actually supplied to burn the fuel. The rate of steam generation is used as a measure of air necessary to burn the required amount of fuel. The flow of gases through the boiler setting is used as a measure of air supplied.

The essential parts of the meter are two airflow bells supported from knife-edges on a beam, which is supported by other knife-edges, and a mercury displacer assembly supported by a knife-edge on the beam. The bottoms of the bells are sealed with oil, and the spaces under the bells are connected to two points of the boiler setting.



**Figure 9-27 - Airflow mechanism of a boiler air flowmeter.**

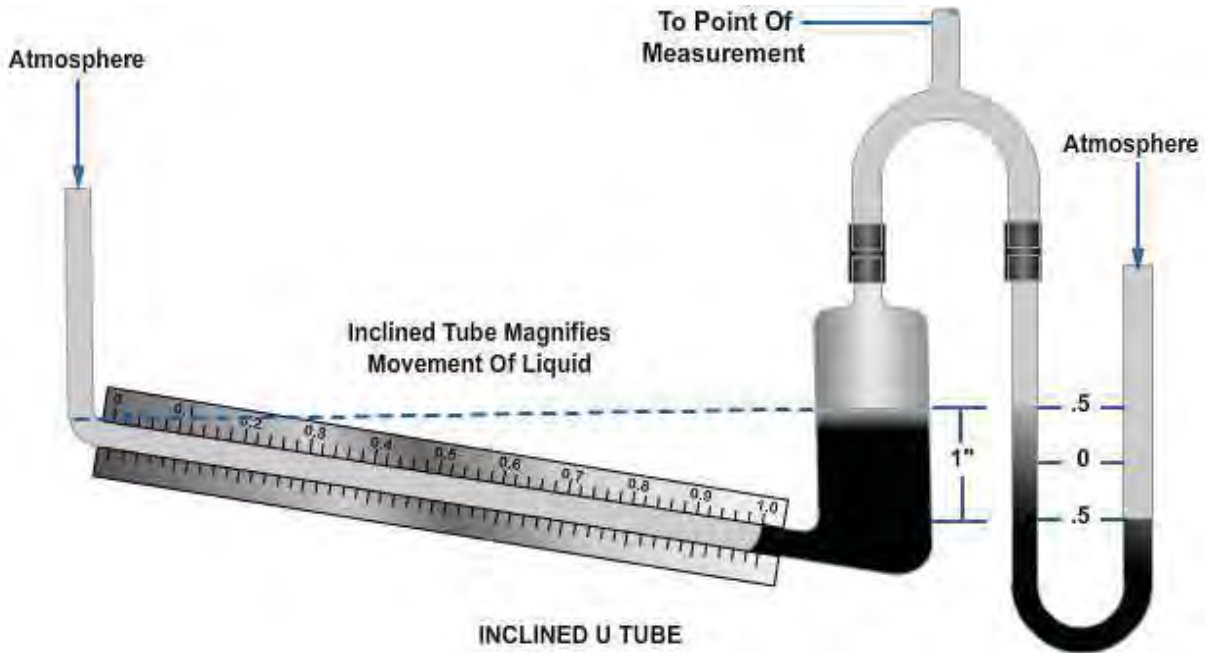
## 6.3.0 Draft Gauges

A draft gauge is a form of pressure gauge. In boiler practice, the term "draft" usually refers to the pressure difference producing the flow. Drafts are pressures below atmospheric pressure. They are measured in inches of water. A draft gauge is essential to boiler operation. Its use increases the safety of operation.

A simple type of draft gauge is the U-tube gauge. The source of draft is connected to one leg of the U and the other end is left open. The difference between the levels of the liquid in the two legs is a measure of the draft. Water is generally used in this type of gauge. Take a close look at *Figure 9-28*, which shows a comparison of an inclined-draft gauge and a U-tube gauge.

When one leg of the U tube is arranged on an incline, the distance moved by the liquid in the inclined portion is increased for a given draft change, which makes more accurate reading possible.

Two or more draft gauges are required for economical boiler operation. The gauges inform the operator of the relative amount of air being supplied to burn the fuel and the condition of the gas passages. Draft gauges are made as indicators, recorders, or both. The measuring element uses a column of liquid, a diaphragm, or a **bellows**. The liquids used are oil, water, or mercury.



**Figure 9-28 - Comparison of inclined-draft gauge and U-tube gauge.**

The gauge shown in *Figure 9-29* is an indicating type that operates on the same principle as the U tube (the difference between the levels of the liquid in the two legs is a measure of the draft).



**Figure 9-29 - Liquid sealed draft gauge.**

The bottom of the inverted bell is sealed with oil or mercury, depending on the magnitude of the draft or pressure to be measured. It is supported by knife-edges on the beam to reduce friction as much as possible. The weights counterbalance the weight of the bell, and the pointer is returned to zero. The source of draft is connected to the tube, which projects into the inverted bell, so an increase in draft causes the pointer to move down.

### 6.4.0 CO<sub>2</sub> Meters (Analyzers)

Figure 9-30 shows one type of carbon dioxide meter. The meters are also known as analyzers and are designed for determining, indicating, and recording the percentage of CO<sub>2</sub> (carbon dioxide) in the products of combustion. The principle of this instrument is based on the fact that the specific weight of flue gas varies in proportion to its CO<sub>2</sub> content (CO<sub>2</sub> being considerably heavier than the remaining parts of the flue gas).

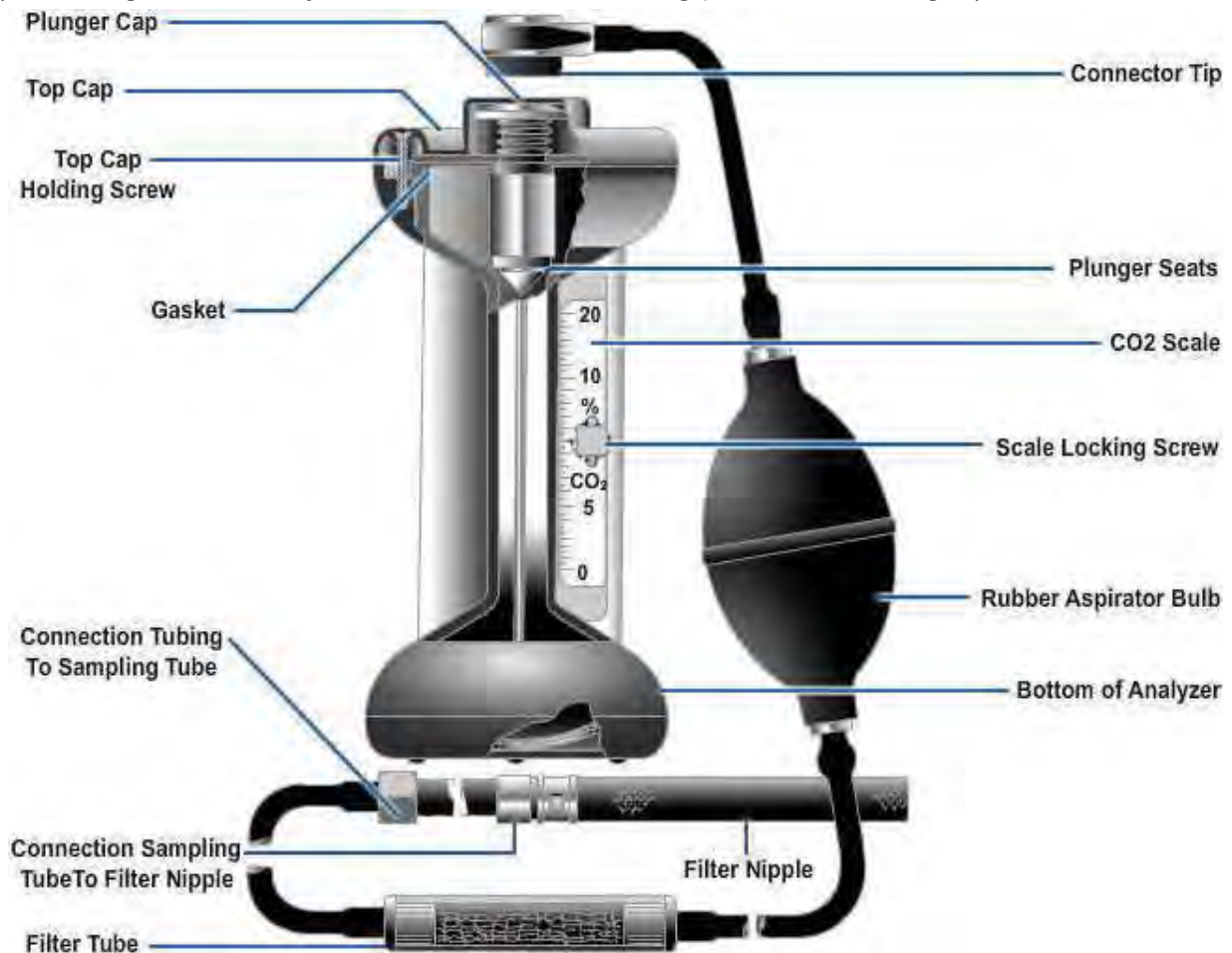


Figure 9-30 - CO<sub>2</sub> meter (analyzer).

### Test your Knowledge (Select the Correct Response)

3. The bottom of the inverted bell of the liquid sealed draft gauge is sealed with which substance?
  - A. Water
  - B. Sand
  - C. Oil
  - D. Steam

## 7.0.0 BOILER WATER TREATMENT and CLEANING

A UT must understand the methods, tests, and safety precautions involved in boiler water treatment and the procedures for cleaning boiler firesides and watersides. To ensure a boiler operates at peak efficiency, you must treat and clean it. Water testing, treatment, and cleaning go hand-in-hand. The reason for this is because the effect of the impurities in the water on interior surfaces determines the method and frequency of boiler cleaning. In this section, we will discuss the relationships between water testing, treatment, and cleaning, and the procedures for each.

### 7.1.0 Water Impurities

All natural waters contain acid materials and scale-forming compounds of calcium and magnesium that attack **ferrous** metals. Some water sources contain more scale-forming compounds than others; therefore, some waters are more corrosive than others. Subsurface or well waters are generally more scale-forming, while surface waters are usually more corrosive. To prevent scale formation on the internal water-contacted surfaces of a boiler and to prevent destruction of the boiler metal by corrosion, chemically treat feedwater and boiler water. This chemical treatment prolongs the useful life of the boiler and results in appreciable savings in fuel, since maximum heat transfer is possible with no **scale** deposits.

### 7.2.0 Scale

Crystal clear water, satisfactory for domestic use, may contain enough scale-forming elements to render it harmful and dangerous in boilers. Two such scale-forming elements are **precipitates** of hardness and silica.

Scale deposited on the metal surfaces of boilers and auxiliary water heat exchange equipment consists largely of precipitates of the hardness ingredients - calcium and magnesium and their compounds. Calcium sulfate scale is, next to silica, the most adherent and difficult to remove. Calcium and magnesium carbonates are the most common. Their removal requires tedious hand scraping and internal cleaning by power-driven wire brushes. When deposits are thick and hard, the more costly and hazardous method of inhibited acid cleaning must be used. Scale deposits are prevented by the following methods: removal of calcium and magnesium in the feedwater to the boiler (external treatment); chemical treatment of boiler water (phosphate, organic extracts, etc.); and changing scale-forming compounds to form soft non-adherent sludge instead of scale that can be easily removed from the boiler by blowdown (internal treatment).

Silica in boiler feedwater precipitates and forms a hard, glossy coating on the internal surfaces. In the feedwater of high-pressure boilers, such as those used in electric generating plants, a certain amount of silica vaporizes under the influence of high pressure and temperature. The vapor is carried over with steam and silica deposits on the intermediate and low-pressure blading of turbines. In boilers operating in the range of 10- to 125-psig pressure, the silica problem is not so troublesome. When the water is low in hardness, contains phosphate that prevents calcium silicate scale from forming, or has enough alkalinity to keep the silica soluble, no great difficulty is encountered. The amount of soluble silica can be limited by continuous or routine boiler blowdown to prevent buildup of excessive concentrations.

### 7.3.0 Corrosion

Corrosion control occurs with the problem of scale control. Boilers, feedwater heaters, and associated piping must be protected against corrosion. Corrosion results from water

that is acidic (contains dissolved oxygen and carbon dioxide). Corrosion is prevented by removing these dissolved gases by **deaeration** of feedwater, by neutralizing traces of dissolved gases in effluent of the deaerating heater by use of suitable chemicals, and by neutralizing acidity in water with an alkali.

#### 7.4.0 Methods of Treatment

The specific method of chemical treatment used varies with the type of boiler and the specific properties of the water from which the boiler feed is derived. In general, however, the chemical treatment of feedwater and boiler water is divided into two broad types or methods--external treatment and internal treatment of makeup water for alkalinity control and for removal of scale-forming materials and dissolved gases (oxygen and carbon dioxide) before the water enters the boiler. Internal treatment means that chemicals are put directly into the boiler feedwater or the boiler water inside the boiler. Frequently, both external and internal chemical treatments are used.

External treatment, frequently followed by some internal treatment, often provides better boiler water conditions than internal treatment alone. However, external treatment requires the use of considerable equipment, such as chemical tanks, softening tanks, filters, or beds of minerals, and the installation costs are high. Such treatment is therefore used only when the makeup water is very hard or very high in dissolved minerals, or when internal treatment by itself does not maintain the desired boiler water conditions. The dividing line between the hardness and the concentration of dissolved matter in water are factors that are taken into consideration when you look at the physical makeup of the plant, the type and design of the boilers used, the percentage of makeup water being used, the amount of sludge the boiler can handle, the space available, and the adaptability of the operators. Many methods of internal treatment are in use. Most of these treatments use carefully controlled boiler water alkalinity, an alkaline phosphate, and organic material. One of the organic materials used is tannin.

Tannin is a boiler water sludge **dispersant**, that is, it makes precipitates more fluid and prevents their jelling into masses that are difficult to remove by blowdown. Because of treatment costs and simplicity of chemical concentration control, the alkaline phosphate-tannin method of internal treatment is perhaps the most widely used. When properly applied and controlled, this treatment prevents formation of scale on internal boiler surfaces and prevents corrosion of the boiler tubes and shell.

#### 7.5.0 Boiler Water Testing

As we have just seen, boiler water must be treated with chemicals to prevent the formation of scale on the internal surface of the boiler and to prevent deterioration of the boiler metal by corrosion. Boiler water must be tested to determine the sufficiency of chemical residuals to maintain clean boiler surfaces. As a UT, you should be able to make various boiler water tests. The procedures for a few types of tests that you may have to make are given here--tests for hardness, phosphate, tannin, caustic alkalinity (with and without tannin), sodium sulfite, and pH. A test kit is provided for the different tests. Each test kit contains the equipment and materials for the specified test. If a kit is not available, you have to use the laboratory equipment provided in the boiler or water treatment plants (*Figures 9-31 and 9-32*).



Figure 9-31 - General laboratory equipment.



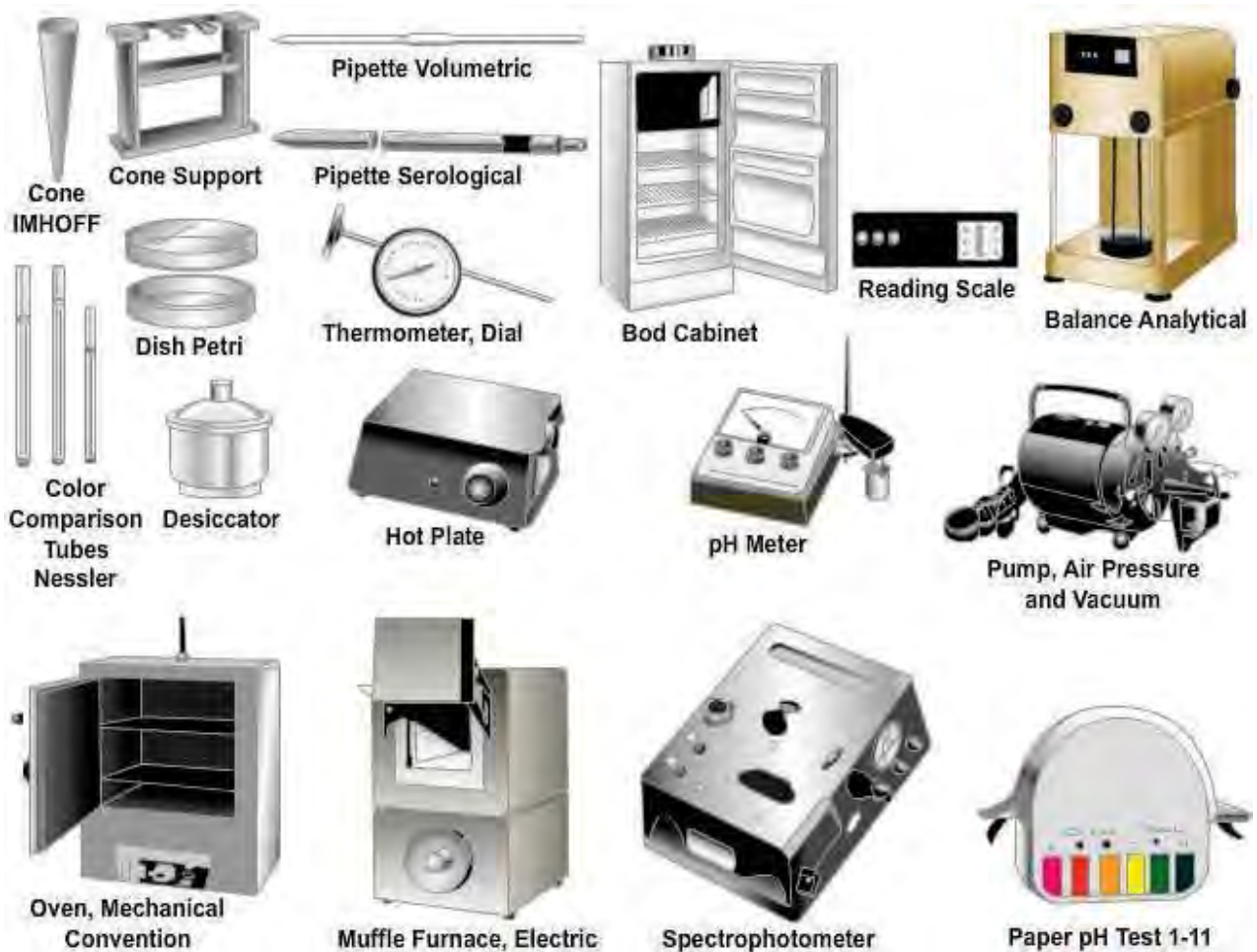


Figure 9-32 - General laboratory equipment.



The following caution applies to each test that is discussed: If the testing procedures of the equipment and/or reagent supplier differs from that prescribed in this text, the supplier's procedure should be used.

### 7.5.1 Test for Hardness

Boilers operating at pressures of 15 psi and less are normally used for space heating and hot-water generation. Practically all the condensate is returned to the plant. Only a small amount of makeup is required, and secondary feedwater treatment usually is sufficient. When appreciable quantities of steam are used in process work and not returned as condensate to the plant, the problem of scaling and corrosion arises, and more complete treatment of feedwater must be considered. The ideal water for boilers does not form scale or deposits, does not pit feedwater systems and boiler surfaces, and does not generate appreciable  $\text{CO}_2$  in steam. However, such raw makeup water is impossible to get in the natural state from wells or surface sources. Does the advantage of treatment make up for the cost of treatment?

Feedwater of 20- to 25-ppm hardness as calcium carbonate ( $\text{CaCO}_3$ ) need not be treated externally to reduce hardness if enough alkalinity is present to precipitate the hardness in the boiler as  $\text{CaCO}_3$ , or if hardness reducers, such as phosphates, are introduced to combine with and precipitate the hardness. Precipitation of this hardness in a low- or medium-pressure boiler generally does not cause wasteful blowdown. When the mixture

of condensate and makeup in a medium-pressure steam plant has a hardness greater than 20 to 25 ppm as  $\text{CaCO}_3$ , the hardness should be reduced to a level of 0 to 2 ppm as  $\text{CaCO}_3$ .

Feedwater of a hardness in excess of 2 ppm as  $\text{CaCO}_3$  should be treated to bring it within the range of 0 to 2 ppm as  $\text{CaCO}_3$ . This small remaining hardness can be precipitated in the boiler by secondary treatment and removed by continuous blow-off equipment.

The test for hardness, as presented here, uses the calorimetric titration method. This test is based on finding the total calcium and magnesium content of a sample by titration with a sequestering agent in the presence of an organic dye sensitive to calcium and magnesium ions. The end point is a color change from red to blue, which occurs when all the calcium and magnesium ions are separated.

The following equipment is used for the hardness test:

- One 25-ml buret, automatic, complete
- One 210-ml casserole, porcelain
- One 50-ml cylinder, graduated
- One stirring rod, glass

The **reagents** for the test are as follows:

- Hardness indicator
- Hardness buffer
- Hardness titrating solution

The steps of the hardness test are as follows:

1. Measure 50 ml of the sample in the graduated cylinder and transfer it to the casserole.
2. With the calibrated dropper, add 0.5 ml of the hardness buffer reagent to the sample, and stir.
3. Add 4 to 6 drops of hardness indicator. If hardness is present, the sample will turn red.
4. Add the hardness titrating solution slowly from the burette, and stir continually. When approaching the end point, note that the sample begins to turn blue, although you can still see a definite reddish tinge. The end point is the final discharge of the reddish tinge. Adding more hardness titrate solution does not produce further color change.

In using this procedure, add the hardness titrating solution slowly because the end point is sharp and rapid. For routine hardness determination, measure 50 ml of the sample, but add only approximately 40 to 45 ml to the casserole at the start of the test. The hardness buffer reagent and the hardness indicator should then be added as directed and the mixture titrated rapidly to the end point. The remaining portion of the sample should then be added. The hardness in the remainder of the sample will turn the contents of the casserole red again. Titrating is continued slowly until the final end point is reached. A record should be kept of the total milliliters of hardness titrating solution used.

To calculate the results in ppm hardness, use the following equation:

$$\text{ppm hardness} = \text{ml titrating solution} \times 1,000 (\text{CaCO}_3) (\text{ml sample})$$

With a 50-ml sample, the hardness in ppm as  $\text{CaCO}_3$  is equal to the ml of titrating solution used, multiplied by 20.

### 7.5.2 Test for Phosphate

The calorimetric test for phosphate uses a decolorizing carbon to remove tannin. Carbon absorbs the tannin, and the carbon and tannin are then filtered out. When tannin is not present, carbon improves the test for residual phosphate by making the tricalcium phosphate sludge more filterable.

The equipment required for the phosphate test is as follows:

- One phosphate color comparator block of two standards-30 ppm and 60 ppm of phosphate as  $\text{PO}_4$ . (The Taylor high-phosphate slide comparator may be used instead.)
- Four combination comparator mixing tubes, each marked 5, 15, and 17.5 ml, with stoppers
- One filter funnel, 65-mm diameter
- One package of filter paper, 11 cm in diameter
- One 20-ml bottle
- One 0.5-ml dropper
- One 1/4-tsp measuring spoon or spatula
- Two plain test tubes, 22 mm by 175 mm (about 50 ml)
- Two rubber stoppers, No. 3 flask
- One 250-ml glass-stoppered bottle or flask, labeled comparator molybdate reagent

The reagents you need are as follows:

- One 32-oz comparator molybdate
- One 2-oz concentrated stannous chloride
- One 32-oz standard phosphate test solution (45 ppm of phosphate,  $\text{PO}_4$ )

One pound decolorizing carbon. (This is a special grade of decolorizing carbon tested to make sure it does not affect the phosphate concentration in the sample.)

For test purposes, the stannous chloride is supplied in concentrated form. The reagent must be diluted and should be prepared from the concentrated stannous chloride on the day it is to be used, because the diluted solution deteriorates too rapidly for supply by a central laboratory. If not fresh, diluted stannous chloride gives low test results.

Concentrated stannous chloride also deteriorates and should not be used if more than 2 months old.

The procedure for making diluted stannous chloride is as follows:

1. Fill the 1/2-ml dropper up to the mark with the concentrated stannous chloride.
2. Transfer it to a clean 20-ml bottle.
3. Add distilled water up to the shoulder of the bottle, then stopper and mix by shaking.



**CAUTION**

Any diluted stannous chloride not used the day it is made should be discarded. The following procedure is used to make the test for phosphate:

1. Without disturbing any settled sludge, transfer enough of the sample to the test tube to fill it about half full.
2. Add 1/4 tsp of decolorizing carbon. Stopper the tube and shake vigorously for about 1 minute. The carbon absorbs the tannin so it can be filtered out.
3. Fold a filter paper and place it in the filter funnel. Do not wet down the filter paper with water. Filter the shaken sample, using a combination mixing tube as a receiver. The carbon absorbs tannin, and the tannin and sludge present are filtered out more rapidly. Avoid jiggling the funnel, as unfiltered boiler water may overflow the edge of the filter paper into the tube. You have to support the funnel.
4. After 5 ml of the sample has filtered through, as indicated by the level in the tube, discard it. Continue filtering to bring the level in the test tube again up to the 5-ml mark. The sample should come through clear and free, or nearly free, of any color from the tannin. If it is not nearly free of tannin color, repeat the test using 1/2 tsp of carbon, adding it in two 1/4-tsp portions, and shaking it for 1 minute after each addition.
5. Add the comparator molybdate reagent to bring the level up to the second mark (15 ml). Stopper and mix by inverting the tube several times.
6. Add fresh diluted stannous chloride up to the third mark (17.5 ml). Stopper and mix by inverting. If phosphate is present, the solution in the mixing tube turns blue.
7. Place the tube in the comparator block. Compare the color of the solution in the tube with the standard colors of the phosphate color block. Colors between the two standard colors may be estimated. Take the reading within 1 minute after adding the stannous chloride, because the color fades quickly.
8. Record the results as LOW, if below 30 ppm; HIGH, if above 60 ppm, or OK, if between 30 and 60 ppm.

### 7.5.3 Test for Tannin

The purpose of the tannin test is to determine the amount of tannin in the boiler water. Tannin holds sludge in suspension. In treating boiler water with tannin, control the dosage by the depth of brown formed in the boiler water by the tannin. To estimate the depth of the color, which is necessary in adjusting tannin dosages, compare a sample of the boiler water with a series of brown color standards of successively increased depths of color. A tannin color comparator, which is used for the comparison, has five glass color standards: No. 1, very light; No. 2, light; No. 3, medium; No. 4, dark; and No. 5, very dark.

The kit for the tannin test contains the following:

- One tannin color comparator
- Two square tubes, 13-mm viewing depth
- One plain test tube, 22 mm by 175 mm
- One filter funnel, 65 mm by 65 mm

- One package of filter paper, 11 cm in diameter

You first fill a plain test tube almost to the top with cool boiler water. Then place a square test tube in the slot of the comparator, and insert the filter funnel in it. Fold a filterpaper and place it in the funnel without wetting it down. Filter water from the plain test tube into the square tube until the tube is neatly full. Remove the square tube from the comparator and hold it up to a good source of natural light. Note the appearance of the filtered boiler water. Is it free of suspended solids and sludge? If not, refilter the sample, using the same funnel and filter paper. Repeat, using a double filter paper if necessary, until the sample does come through free of suspended solids and sludge.

To complete the test, place the square tube of filtered sample in the middle slot of the comparator. Then compare the color of the sample with the five standards, viewing it against a good source of natural light. The color standard most closely matching the color of the filtered sample gives the tannin concentration of the boiler water. For a number of boiler water conditions, the tannin dosage is usually satisfactory if it maintains a medium (No. 3) tannin color. If the tannin color is too high, blow down; if toolow, add tannin.

#### 7.5.4 Test for Caustic Alkalinity (OH) without Tannin

The boiler water sample for this test is collected at a temperature of 70°F or below. The equipment required is as follows:

- Two 8-in. droppers with bulbs
- Two 250-ml glass-stoppered bottles or flasks labeled **causticity** No. 1 and causticity No. 2
- Four marked test tubes, 22 mm by 185 mm
- Three plain test tubes, 22 mm by 175 mm
- Three rubber stoppers, No. 2
- One 14-in. test-tube brush
- One test-tube clamp
- Two 9-in. stirring rods
- One 1-oz indicator dropping bottle for phenolphthalein
- One test-tube rack

The following reagents also are required:

- One 24-oz bottle or flask causticity reagent No. 1
- One 24-oz bottle or flask causticity reagent No. 2
- One 4-oz bottle phenolphthalein indicator

The following are the steps to follow in conducting a test for causticity when tannin is not used:



Avoid exposure of the sample to the air as much as possible to reduce absorption of the CO<sub>2</sub>.

1. Without disturbing the settled sludge, fill a marked test tube exactly to the first mark (25 ml) with some of the original boiler water sample.

2. Shake causticity reagent No. 1 (barium chloride solution saturated with phenolphthalein) thoroughly and add enough to the graduated tube to bring the level exactly to the second, or long, mark (30 ml).
3. Stir the solution with the 9-inch stirring rod, which must be kept clean and reserved for the causticity test only. When the mixture remains colorless or does not turn pink, the causticity in the boiler water is zero and the test is finished. When the mixture turns pink, causticity is present. (If the pink color is not deep, intensify it by adding two drops of phenolphthalein indicator to the mixture in the tube.) Add causticity reagent No. 2 (standard one-thirtieth normal acid), using the 8-inch dropper; thatch must be kept clean and reserved for the causticity test only. Causticity reagent No. 2 is sucked from the reagent bottle into the dropper by its rubber bulb and added, drop by drop, to the test tube. After each addition, stir the mixture with a stirring rod. After sufficient reagent has been added, the pink color disappears; the change point is usually sharp. As soon as the pink color just fades out, stop adding the reagent.
4. The amount of causticity reagent No. 2 required to make the pink color disappear shows the concentration of hydroxide (OH) or causticity in the boiler water. The amount of reagent used is shown by the marks on the test tube above the long mark (30 ml). The distance between any two marks on the test tube equals 5 ml, and readings less than 5 ml can be estimated. For example, when only three fifths of the distance between the long mark and the next mark above were filled, then 3 ml was added. When the distance filled was past one mark plus three fifths of the distance to the next, then  $5 + 3 = 8$  ml was used. To obtain the actual ppm of hydroxide or causticity shown by the test, multiply the number of ml by 23. This constant number, 23, represents the amount of sodium hydroxide in the boiler water by volume. Thus, for 8 ml of causticity reagent No. 2, there are  $8 \times 23 = 184$  ppm hydroxide or causticity in the water.
5. Record the results of the test in a boiler log or chemical log and adjust the range to meet requirements. When causticity is too high, blow down; if too low, add sodium hydroxide (caustic soda).

### 7.5.5 Test for Caustic Alkalinity (OH) with Tannin

For this test, start with a warm sample of about 160°F. It may be reheated by placing the sample-collecting container in a stream of hot boiler water drawn through the boiler water cooler connection. In a test for causticity when tannin is used, make sure you observe the same precautions as carefully as when tannin is not used.



Avoid exposure of the sample to the air as much as possible to reduce absorption of the CO<sub>2</sub>.

The equipment and reagents required for this test are the same as those listed in the preceding section where tannin was not used.

The procedure for conducting a test for causticity with tannin is as follows:

1. Fill two test tubes to the first mark (25 ml) with some of the original boiler water sample, taking care not to disturb the settled sludge in the container. (Transfer as little sludge as possible from the sample-collecting container to the test tubes.)
2. Shake causticity reagent No. 1 thoroughly and add enough to each of the two marked tubes to bring the levels up to the second, or long, mark (30 ml). Stir both

with the stirring rod, which must be kept clean and reserved for the causticity test only.

3. Stopper both tubes and let them stand until any sludge formed has settled to the bottom. The sludge carries down with it much of the tannin or other colored matter in the solution; settling takes a few minutes if the sample is warm.
4. Without disturbing the sludge at the bottom, pour enough solution from the tubes into the third marked tube to fill it to the second, or long, mark. Discard the mixture left in the first two. When the sample in the third tube is still warm, cool it by letting cold water run on the outside of the tube. It is sometimes possible to intensify the pink color by adding two drops of phenolphthalein from the indicator- dropping bottle to the sample in the tube. Stir the solution. When it is not pink, the causticity in the boiler water is zero.
5. When the sample is not pink, the test is finished. But if the mixture turns pink, proceed in the same manner as directed in Steps 3, 4, and 5 when no tannin is used.

Here is a brief explanation of an alternate procedure for making the test for causticity when tannin is used. In this procedure any glass container, such as a large test tube or graduated cylinder, marked for 50 to 60 ml can be used instead of the two standard marked test tubes used in Steps 1 and 2 above. With the large test tube or graduated cylinder, the warm (160°F) sample is added up to the 50-ml mark and causticity reagent No. 1 up to the 60-ml mark. Stir the mixture and stopper the tube, or graduate. After the sludge settles, pour off enough of the solution into one of the standard marked test tubes to fill it to the long mark (30 ml). When the sample is warm, cool it by letting cold water run on the outside of the tube. Adding two drops of phenolphthalein may intensify the pink color. When the solution is not pink, the causticity in the boiler water is zero.

But if it turns pink, proceed in the same manner as in Steps 3, 4, and 5 when no tannin is used.

### 7.5.6 Test for Sodium Sulfite

The sample for this test should be cooled to 70°F, or below, and exposed to the air as little as possible, because oxygen in the air combines with sodium sulfite in the sample and causes low readings. Collect a separate sample, using the boiler water sample cooler, with the line reading to the bottom of the sampling bottle. Allow the boiler water to run until a few bottlefuls overflow to waste.

The equipment necessary to make the sodium sulfite test is as follows:

- One 30-ml acid-dropping bottle, with dropper marked at 0.5 ml for hydrochloric acid 3N
- One 30-ml starch-dropping bottle, with dropper marked at 0.5 ml for starch indicator
- One 150-ml beaker
- One stopper for plain test tube
- One stirring rod
- One 8-in. dropper
- One 1/4-tsp measuring spoon
- One 50-ml beaker

- Two plain test tubes
- Two marked test tubes

The reagents required are as follows:

- One 2-oz bottle of potato or arrowroot starch
- One 8-ml vial of thymol
- One 24-oz bottle of hydrochloric acid 3N
- One 1-pt amber bottle of standard potassium iodate-iodide reagent

The starch indicator for this test must be prepared locally. The procedure to adhere to for good results is as follows:

1. Measure out a level 1/4 tsp of potato or arrowroot starch and transfer it to the 50-ml beaker.
2. Add a few milliliters of distilled water and stir the starch into a thick paste, using the end of the stirring rod.
3. Put 50 ml of distilled water into the 150-ml beaker. (It is convenient in this step to have the 150-ml beaker marked at the point where it holds 50 ml, or one of the marked test tubes can be used by filling it with distilled water to the fourth mark above the long mark.)
4. Bring the water in the 150-ml beaker to a boil by any convenient method.
5. Remove the source of heat and immediately pour the starch paste into the boiling water while stirring the solution.
6. Put a crystal of thymol into the starch solution and stir. After the solution has cooled, pour off any scum on the surface and transfer 30 ml to the indicator-dropping bottle.
7. The starch solution loses its sensitivity as an indicator after a time. Addition of the thymol preserves it for about 2 weeks. The starch should be dated when prepared.

In making the sodium sulfite test, proceed as follows:

1. Transfer 1 ml of hydrochloric acid 3N to a clean, marked test tube by measuring out 0.5-ml portions with the dropper of the acid-dropping bottle.
2. From the starch-dropping bottle, transfer 0.5 ml of starch to the marked test tube.
3. Without disturbing any settled sludge in the sample, pour enough of the sample into the marked test tube to bring the level up to the first mark (25-ml). Stir the mixture in the tube with the plunger end of the stirring rod.
4. To add the standard potassium iodate-iodide reagent to the mixture in the marked test tube, have the marked test tube supported and the stirring rod placed in the tube, so the reagent can be added with one hand while the mixture is stirred with the other. Fill the 8-inch dropper with standard potassium iodate-iodide reagent from the stock bottle by sucking it up with the rubber bulb. (The dropper must be kept clean and reserved for this test only.)
5. Add the reagent to the mixture in the marked test tube, one drop at a time, counting the number of drops and stirring after each is added until a permanent blue color, which is not removed by stirring, is obtained. The standard iodate-iodide reagent reacts with sodium sulfite in the mixture, and the formation of the



permanent blue color from the action of excess reagent with the starch shows that the iodate-iodide reagent has consumed all the sodium sulfite in the mixture.

6. Each drop of iodate-iodide reagent used (except the last one) indicates 5 ppm of sodium sulfite in the boiler water sample. To figure the concentration of sodium sulfite in the boiler water, multiply the total number of drops of the standard iodate-iodide reagent used, less one, by 5. For example, when 5 drops were used, subtract 1 from 5 = 4,  $5 \times 4 = 20$  ppm.
7. Record the results of the test as ppm.

### 7.5.7 Test for pH

The value of pH indicates the degree of acidity or alkalinity of a sample. A pH of 7.0 represents the neutral point; the lesser values denote acidity; the greater values denote alkalinity. The test is made as soon as possible after you take the sample. Avoid exposure to the air as much as possible to reduce absorption of CO<sub>2</sub>.

The following equipment is used in making the pH test of boiler water:

- Two vials of indicator paper, hydrions pH 10 to 20
- Two vials of indicator paper, hydrions C pH 11 to 12
- One 50-ml beaker
- One 2-oz bottle

In conducting the test for pH of boiler water, remove a strip of pH 10 to 12 indicator paper from the vial and dip it into the sample in the beaker. Keep the paper immersed for 30 seconds; then remove it. When the sample does not change the color of the paper or colors it yellow or light orange, the pH of the sample is too low and the test is finished. When the paper turns orange or red, the pH is either satisfactory or too high.

In that case, remove a strip of paper of pH 11 to 12 from the vial and dip it into the sample in the beaker. Keep the paper immersed for 30 seconds; then remove it. When the sample does not change the color of the paper or colors it a light blue, the pH is satisfactory. When the paper turns deep blue, the pH is higher than necessary. Blow down or reduce the dosage of caustic soda (NaOH).

### 7.5.8 Test for pH of Treated Condensate

In making a test for pH of treated condensate, take the sample from a point in the return piping near which condensation takes place, such as after a trap, or preferably where the return-line corrosion is known to occur. The sample must represent water flowing in the return lines. Water taken from the return tank, especially of large installations, generally shows a higher pH. A sample should not be taken from a collecting tank if other water, such as makeup, is received in the tank.

The equipment required for this test is as follows:

- One 4-oz brown bottle of condensate pH indicator
- One 1-oz indicator bottle, with dropper marked at 0.5 ml
- One 100-ml beaker, marked at 50 ml
- One 9-inch stirring rod, glass

In making a test for pH of treated condensate, proceed as follows:

1. Pour a freshly drawn sample into the testing beaker until it is filled to the 50-ml mark. You do not have to cool the sample.
2. Transfer 0.5 ml of indicator solution to the 50-ml testing beaker, using the marked dropper. Stir the solution in the beaker. If the color of the solution changes to light pink, the sample is NEUTRAL, or slightly alkaline; therefore, the condensate pH is satisfactory and the test is over.
3. Record in a log that the pH range is between 7 and 7.5.
4. When the color change is green, the sample is in the acid range and the boiler water must be treated with Amines. Treat the boiler water with Amines gradually (in small amounts at a time), and retest after each treatment. Amines are the only chemicals used to treat boiler water that will vaporize and leave with the steam and thereby protect the return system.



**WARNING**

Permission to treat with Amines must be obtained from your supervisor. Amines are volatile, poisonous, and in the alkaline range.

5. When the color change is red or purple, the sample is in an excessive alkaline(pH) range. In that case, reduce the Amines treatment gradually (in small amounts at a single time), and retest after each treatment. Remember, the condensate pH normal acceptable range is between 7 and 7.5.

### 7.5.9 Test for Total Dissolved Solids

The solu-bridge method is a simple and rapid way to determine the total dissolved solids (TDS) content. Ionizable solids in water make the solution conduct electricity. The higher the concentration of ionizable salts, the greater the conductance of the sample. Pure water, free from ionizable solids, has low conductance and thus high resistance. The solu-bridge instrument measures the total ionic concentration of a water sample, the value of which is then converted to parts per million. The solu-bridge test equipment and reagent are furnished by the supplier in a kit.



**CAUTION**

The model of the solu-bridge given below is not suitable for measuring solids in condensed steam samples or an effluent of the de-mineralizing process. A low conductivity meter is necessary because of the extremely low solids content of condensed steam and de-mineralized water.

The equipment and reagent are as follows:

- One solu-bridge, Model RD-P4 or equivalent, for a 105 to 120-volt, 50- to 60-cycle ac outlet. (This model has a range of 500 to 7,000 micromhos/cm.)
- One polystyrene dip cell, Model CEL-S2.
- One thermometer, 0°F to 200°F.
- One 0.1-g dipper for gallic acid.
- One cylinder, marked at the 50-ml level.
- Gallic acid powder, 1 lb.
- Calibration test solution, 1 qt.

The test is made as follows:

1. Without shaking, pour 50 ml of the sample into the cylinder. Add 2 dippers of gallic acid powder and mix thoroughly with a stirring rod.
2. Connect the dip-cell leads to the terminals of the solu-bridge and plug the line cord into a 110-volt AC outlet. Turn the switch ON and allow the instrument to warm up for 1 minute.
3. Clean the cell by moving it up and down several times in distilled water. Measure the temperature of the sample to be tested; then set the point of the solu-bridge temperature dial to correspond to the thermometer reading.
4. Place the cell in the cylinder containing the 50-ml sample. Move the cell up and down several times under the surface to remove air bubbles inside the cell shield. Immerse the cell until the air vents on the cell shield are submerged.
5. Turn the pointer of the solu-bridge upper dial until the dark segment of the tube reaches its widest opening.
6. Calculate the result in ppm by multiplying the dial reading either by 0.9 or by a factor recommended by local instructions. For example, when the dial reading is 4,000 micromhos and the factor used is 0.9, then  $4,000 \times 0.9 = 3,600$  ppm.
7. Record the results of the test in ppm.

## 8.0.0 CLEANING BOILER FIRESIDES and WATERSIDES

Boiler heat transfer surfaces must be kept clean to provide for safe and economical boiler operation. In this section we will describe the methods and procedures involved in fireside and waterside cleaning.

### 8.1.0 Cleaning Boiler Firesides

Excessive fireside deposits of soot, scale, and **slag** cause the following conditions: reduced boiler efficiency, corrosion failure of tubes and parts, reduced heat transfer rates and boiler capacity, blocking of gas passages with high draft loss and excessive fan power consumption, and fire hazards.

Methods for cleaning boiler firesides include wire brush and scraper cleaning, hot-water washing, wet-steam lancing, and sweating.

#### 8.1.1 Wire Brush and Scraper Cleaning

When too much soot is deposited and the passages become plugged, hand lancing, scraping, and brushing are generally used. Special tools required for reaching between the lanes of tubes may be made from flat bars, sheet metal strips cut with a saw-toothed edge, rods, and similar equipment. Some boilers have different sizes of tubes, so you need various sizes of brushes and scrapers to clean the boiler tubes. The brushes or scrapers are fastened to a long handle, usually a piece of pipe, inserted and pushed through the tubes. When you are cleaning the passages, be very careful not to score or gouge the tubes because it can lead to weakening and rupturing of tubes under pressure.

#### 8.1.2 Hot-Water Washing

This method of cleaning is often used to clean super heaters, economizers, and other sections of the steam generator that are difficult or impossible to reach by brushing or

scraping. The water may be applied with hand lances and/or boiler soot blowers. Dryout the boiler setting immediately after water washing to reduce damage to the refractory and other parts of the setting.

Safety is always paramount; therefore, always be cautious when washing boiler firesides. Some precautions you should observe are as follows:

- Wet the boiler refractory and insulation as little as possible. Install canvas shields or gutters where possible to reduce wetting of refractories.
- Protect electrical equipment from water damage.
- Provide all necessary instructions and protective equipment for workers.
- Provide a compressed air lance to loosen scale after water washing.
- Provide adequate equipment to heat and pump the hot water. The water should be heated and maintained at a temperature close to about 150°F, because water exceeding this temperature cannot be handled safely and efficiently. However, because cold water does not clean satisfactorily, you have to maintain the water temperature as close as 150 degrees as possible. A water pressure of 200 to 250 psig should be provided at the cleaning lances or soot blowers. The water jets must penetrate the tube banks and strike with enough force to break up the slag accumulations.
- Start the water washing at the top of the unit and work down.
- The unit must be dried out immediately after washing.

### 8.1.3 Wet-Steam Lancing

The wet-steam lancing method is similar to the hot-water method except that wet steam is used instead of hot water. The steam should be wet and at a pressure of 70 to 150 psig. The unit must be dried out immediately after lancing is completed.

### 8.1.4 Sweating

Fireside slag can be removed from the convection super heaters by forming a sweat on the outside of the tubes. Cold water is circulated through the tubes, and moisture from the air condenses on the tubes to produce sweat. The hard slag is changed into mud by the sweat, and the mud can be blown off by an air or a steam lance. A large tank filled with water and ice can be used as the cold-water source. Steam can be blown into the area around the tubes during the cold-water circulating period to provide adequate moisture in the air.

### 8.1.5 Cleaning Procedures

The procedures for cleaning boiler firesides are as follows:



You must wear proper protective equipment when cleaning a boiler. For example, Tyvek® suits, Eye protection, Respirator, and check with your safety department before entering a boiler.

1. Remove the boiler from service and allow it to cool. Make sure the boiler is cool enough for a person to enter. Someone must be standing by whenever a person is in the boiler. DO NOT force-cool the boiler.

2. Disconnect the fuel line openings. Secure all valves, and chain, lock, and tag all fuel lines to the burner and install pipe caps.
3. Disconnect the electrical wiring. Secure and tag the electrical power to the boiler. Disconnect the burner conduit and wiring. Mark and tag all electrical wiring to ensure proper reinstallation.
4. Open the boiler access doors by loosening all nuts and dogs and swing the door open. Be careful not to damage the refractory door lining.
5. Remove the burner from the boiler openings. Follow the manufacturer's instructions for specified burners. Wrap this equipment with plastic, rags, or other suitable protective coverings. Remember, soot and loose carbon particles must be kept out of the moving parts of the burner because they can cause the burner to malfunction.
6. Provide all spaces with free-air circulation by opening doors and windows, or provide fresh air by mechanical means. An assistant should be stationed outside the opening and be ready at all times to lend a hand or to be of service in case of a mishap.
7. Cover the floor area around the tube ends with drop cloths to catch soot. Position a vacuum cleaner hose at the end of the tube being cleaned. Keep soot from contacting wet areas because soot and water form carbonic acid.
8. Remove tube baffles where possible and pass a hand lance or rotating power cleaner brush through each tube slowly and carefully so no damage occurs to personnel or equipment.
9. Inspect tube surfaces for satisfactory condition before continuing on to the next tube. Use a drop cord or flashlight for viewing through the entire length of a tube. Wire brush all tube baffles either by hand or use of power tools.
10. Apply a light coat of mineral oil to all cleaned surfaces. To do this, fix an oil-soaked rag to the end of a brush or rod long enough to extend through the tubes, and thoroughly swab each surface, including baffles. Mineral oil is the only lubricant that prevents rusting and also burns off freely without leaving a carbon deposit.
11. Clean all flat surfaces by brushing with the hand or power tools. Make sure that powered equipment is grounded.
12. Use an industrial vacuum cleaner to remove loose soot.

### **8.2.0 Cleaning Boiler Watersides**

Any waterside deposit interferes with heat transfer and can cause overheating of the boiler metal. Where waterside deposit exists, the metal tube cannot transfer the heat as rapidly as it receives it. This causes metal to become overheated so that it becomes plastic in nature which commonly results in bubbles, blisters or ruptures to tube walls.

Waterside deposits include sludge, oil, scale, corrosion deposits, and high-temperature oxide. Except for oil, these deposits are not usually soluble enough to be removed by washing or boiling out the boiler.

The term "waterside corrosion" is used to include both localized pitting and general corrosion. Most, if not all, is probably electrochemical. There are always some slight variations (both chemical and physical) in the surface of boiler metal. These variations

in the metal surface cause slight differences in the electric potential between one area of a tube and another area. Some areas are anodes (positive terminals).

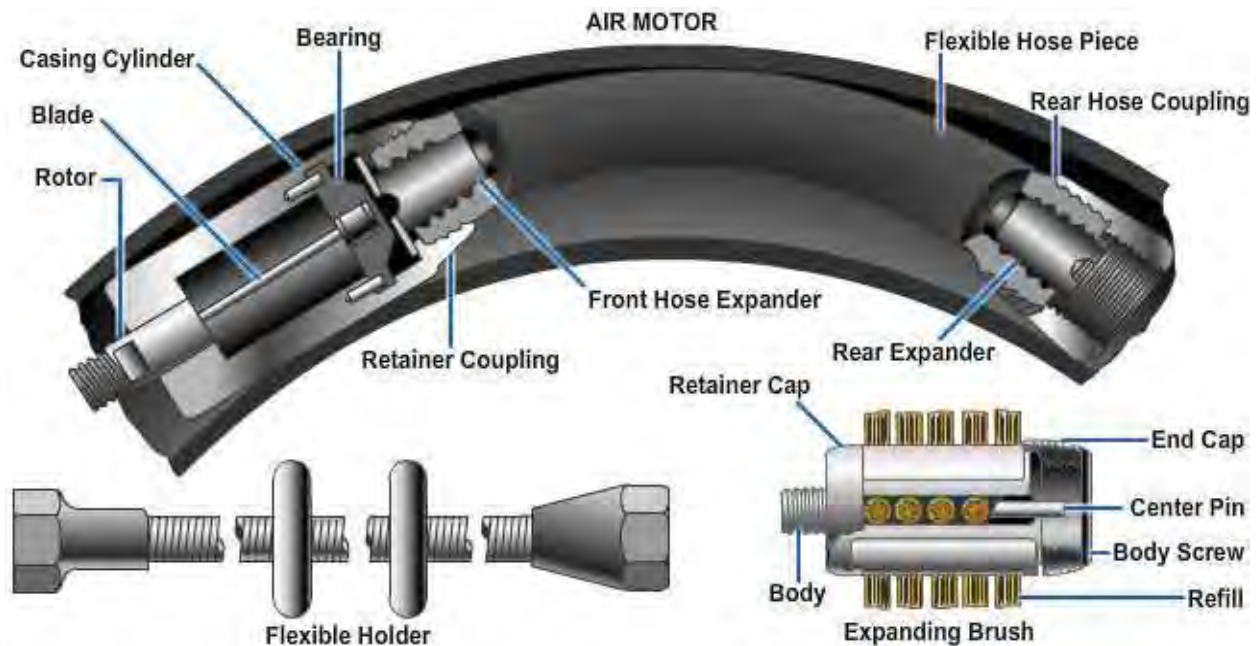
Iron from the boiler tube tends to go into solution more rapidly in the anode areas than at other points on the boiler tube. This electrolytic action cannot be completely prevented in any boiler. However, it can be reduced by maintaining the boiler water at the proper alkalinity and by keeping the dissolved oxygen content of the boiler water as low as possible.

The watersides of naval boilers may be cleaned in two ways-mechanically, by thorough wire brushing of all drums, headers, and tubes, and chemically by circulating chemical cleaning solutions through the boiler.

### 8.2.1 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 apronplates) must be marked or otherwise identified as to position in the steam drum to ensure their correct reinstallation. All internal fittings must be wire brushed and cleaned before they are reinstalled.

Cleaning the watersides of the generating tubes requires a special tube cleaner. There are several types available, but perhaps one of the most common is the pneumatic turbine-driven tube cleaner shown in *Figure 9-33*.



**Figure 9-33 - Boiler tube cleaner (pneumatic turbine-driven type).**

This type of cleaner consists of a flexible hose, an air-driven motor, a flexible brush holder, and an expanding wire bristle brush. The turbine-driven motor consists of a set of turbine blades made to revolve when compressed air is admitted through the hose. The turbine-driven motor, in turn, drives the wire brush. There are several sizes of brushes available, *Figure 9-34* shows two views of a brush and a refill.

Before you start cleaning tubes, be sure that adequate ventilation and lighting have been arranged. Someone should also be stationed outside the drum to act as tender and to assist whoever is working in the drum. Keep a written checkoff list of all tools and

equipment taken into the watersides and be sure that the same tools and equipment are removed.

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 show 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. Remember that the tubes in each row are the same length; however, the tube lengths vary from row to row. Therefore, separate markings have to be made on the hose for each row of tubes.



**Figure 9-34 - Various wire brush sizes.**

After the hose has been marked, insert the brush in the tube and turn on the air to start the 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. You do not have to shut off the air to the tube cleaner each time the cleaner is withdrawn from the 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 tubes.

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. Be careful, also, to see that the brush and the flexible shaft do not protrude from the other end of the tube, as this may result in a broken shaft.

The tube is most easily cleaned 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.

You may also find tubes bent so that brushes cannot be forced around the bend without breaking the tube cleaner. These tubes must be cleaned from both ends. 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 flexible shafts should be inspected frequently and renewed when they show signs of wear or damage. When the brushes become too worn to work efficiently, a new set of brush refills should be inserted into the brush body. Store tube cleaners in a clean, dry container.

After all tubes, drums, and headers have been cleaned and after all tools and equipment have been removed from the watersides, blow through the tubes with air; then wash out the drums, tubes, and headers with fresh water. Ensure all dirt is removed from the 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 under the manufacturer's instructions during each waterside cleaning.

After washing, thoroughly dry out the boiler watersides. Inspect the watersides to determine the condition of the metal to see if the cleaning was satisfactory. Also, inspect the boiler to be sure that all the parts are tight. Be sure that all openings between drums and gauge glasses, blow valves, and safety valves are clean and free of foreign matter. These openings are sometimes overlooked.

### **8.2.2 Chemical Cleaning**

In most cases mechanical cleaning is the preferred method for cleaning watersides. Chemical (acid) cleaning requires special authorization since it requires elaborate and costly equipment and rather extensive safety precautions. However, you may have to use the chemical method, so a limited discussion on it is given here.

Inhibited acid cleaning is used to remove mill scale from the watersides of new or recently serviced boilers. When compared with mechanical cleaning, acid cleaning of boilers has the following advantages:

- Less outage time is required
- Less dismantling of the unit
- Lower cost and labor
- More thorough job accomplished because the acid reaches areas inaccessible to mechanical cleaners
- Increased ability to examine the unit thoroughly for defects, such as cracks and corrosion pitting, because the cleaning is more complete

#### **8.2.2.1 Acids for Cleaning**

The following acids are used to clean boilers: hydrochloric acid, phosphoric acid, sulfamic acid, citric acid, and sulfuric acid.

##### **8.2.2.1.1 Hydrochloric Acid**

Hydrochloric acid is most frequently used for boiler cleaning because it has a relatively low cost, and satisfactory inhibitors are available. Also, the chemical reactions of the hydrochloric acid with the boiler deposits usually result in soluble chlorides.

##### **8.2.2.1.2 Phosphoric Acid**

Phosphoric acid can remove mill scale from new boilers. With this acid, the boiler can be fired directly without producing noxious or corrosive fumes. Direct firing produces good circulation and distribution of the cleaning solution. Another advantage of phosphoric acid cleaning is that the metal surfaces resist corrosion after cleaning. When cleaned with phosphoric acid, you must protect metal surfaces from surface corrosion during draining and before neutralization.

##### **8.2.2.1.3 Sulfamic Acid**

Sulfamic acid is available in a powder that must be placed in solution. The powdered acid is easier and safer to handle than liquid acids in carbons. It does not produce noxious fumes as it dissolves and it is less corrosive than hydrochloric acid, especially at higher concentrations and temperatures.



#### 8.2.2.1.4 Citric Acid and Sulfuric Acid

Citric acid and sulfuric acid are used for removing boiler waterside deposits. Sulfuric acid is economical and easily inhibited. However, a danger is that the sulfuric acid can form insoluble salts such as calcium sulfate.

#### 8.2.2.2 Inhibitors

Without inhibitors, acid solutions attack the boiler metal as readily as they attack the deposits. With the addition of suitable inhibitors, the reaction with the boiler metal is greatly reduced. Inhibitors used include arsenic compounds, barium salts, starch, quinolin, and pyridin. Commercial inhibitors are sold under trade names by various chemical concerns. Other inhibitors are manufactured by companies that furnish complete acid cleaning services.

#### 8.2.2.3 Safety Precautions

When acid cleaning a boiler installation, you must observe safety precautions as follows:

- Before acid cleaning, replace all brass or bronze parts temporarily with steel or steel alloy parts.
- Provide adequate venting for safe release of acid vapors.
- Close all valves connecting the boiler with other piping or equipment.
- Provide competent chemical supervision for the cleaning process.
- Do not exceed the specified acid and inhibitor allowable temperature. The inhibiting effect decreases with the temperature rise and the probability of acid attack of the boiler metal increases.
- After acid cleaning, be sure to thoroughly flush out all of the tubes that are horizontal or slightly sloping. Obstructions in these tubes can cause poor circulation, overheating, and failure of tubes when the unit is placed in service.
- Use goggles, rubber gloves, and rubber aprons when handling acids.
- Slowly pour the acid into the water when mixing the solutions.



Never pour water into acid.

- Do not chemically clean boilers with riveted joints.
- During acid cleaning, hydrogen gas can develop through the reaction of the acid on the boiler metal. Some of the generated gas becomes part of the atmosphere inside the boiler, and the remainder is absorbed by the boiler metal, then liberated gradually. Because hydrogen air mixtures are potentially explosive, be careful when opening a unit for inspection after acid cleaning. Until the atmosphere within the boiler pressure parts has been definitely cleared of explosive gases, do NOT use open flames, flashlights, lighting equipment, or anything that might produce a spark near the openings to the pressure parts. Do NOT enter the boiler. The unit can be cleared of explosive gases by thoroughly flushing the unit with warm water with a positive overflow from the highest vent openings. The water temperature should be as near to 212°F as possible to accelerate the liberation of hydrogen absorbed in the metal. After opening the unit, place air blowers at the open drum manholes to circulate air through the unit.

Use a reliable combustible gas indicator to test the boiler atmosphere for explosive mixtures.

#### 8.2.2.4 Acid Cleaning Procedures

Boiler units can be acid cleaned by either the "circulation" or "fill and soak" method. The circulation method can be used to clean units with positive liquid flow paths, such as forced circulation boilers (*Figure 9-35*). The inhibited acid solution is circulated through the unit at the correct temperature until test analyses of samples from the return line indicate that the acid strength has reached a balance and no further reaction with the deposits is taking place. Because the strength of the acid solution can be determined frequently during the cleaning process, this method can be more accurately controlled and can use lower strength solutions than the fill-and-soak method.

The fill-and-soak method is used for cleaning units with natural circulation (*Figure 9-36*). The boiler unit is filled with the inhibited acid solution at the correct temperature and allowed to soak for the estimated time. It is not possible to obtain accurate representative samples of the cleaning solution during the soaking period.

#### 8.2.2.5 Flushing and Neutralizing

After acid cleaning, drain and then flush the unit with clean, warm water until the flushing water effluent is free of acid and soluble iron salts.

Next, circulate a neutralizing solution through the unit until the effluent shows a definite alkaline reaction.

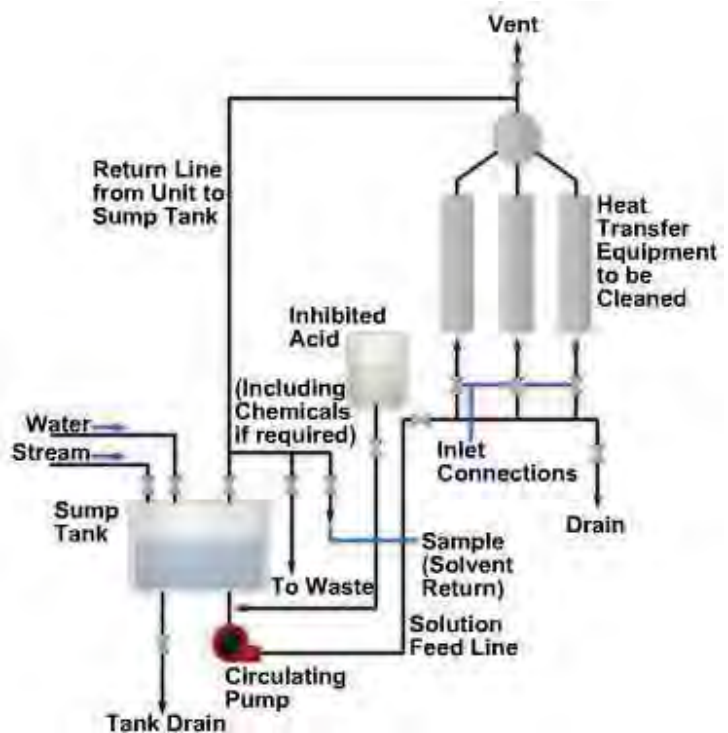


Figure 9-35 - Acid cleaning by circulation method.

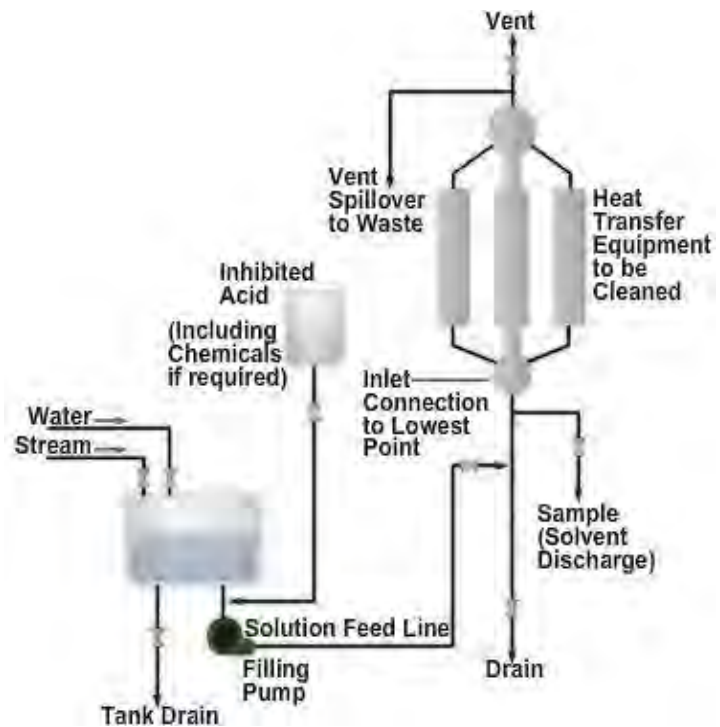


Figure 9-36 - Acid cleaning by fill-and-soak method.

The types of neutralizing solutions used are as follows: soda ash, trisodium phosphate, sodium tripolyphosphate, or other nontoxic chemicals. After circulation of the neutralizing solution, you can drop the water level to the normal level and fire the boiler at 50 psig with open vents to permit the escape of liberated gases. Finally, drain the boiler again and flush it with clean, warm water.

### 8.2.3 Boiling Out

New boilers, or boilers that have been fouled with grease or scale, should be boiled out with a solution of boiler compound. New boilers must be washed out thoroughly. The steps required for one method of boiling out are as follows:

1. Dissolve 5 pounds of caustic soda and 1 1/2 pounds of sodium nitrate or 10 pounds of trisodium phosphate for each 1,000 gallons of water the boiler holds at steaming level. Put the mixture into the boiler as a solution. In multiple-drum boilers, divide the charge and put equal amounts in each of the lower drums.
2. Fill the boiler with hot feedwater to the level of the bottom of the steam drum. Turn the steam into the boiler through the usual boiling out connections, or bottom blow, and allow the boiler to fill gradually to the top of the gauge glass.
3. Steam pressure in the boiler should be kept between 5 and 10 pounds. The boiling out should continue for 48 hours. Immediately after boiling out, give a series of bottom blows to remove the bulk of the sludge. The boiler should be cooled, washed out immediately, and given the usual mechanical cleaning.

You may not always want to use the above method for boiling out. The steps for a second satisfactory method for boiling out are as follows:

1. Clean out all loose scale and any scale adhering to the boiler that can be removed manually.
2. Place about 15 pounds of caustic soda or soda ash and 10 pounds of metaphosphate for each 100-boiler horsepower (hp) of the boiler.
3. Seal the boiler openings but open all vents. Fill the boiler about three-quarters full with water.
4. Start the burner and raise the temperature of the water in the boiler to about 200°F. Maintain this temperature for about 24 to 48 hours. Add makeup water as required during this period to fill the boiler to the base of the safety valve.
5. Analyze the boiler water during the boiling out period and add enough caustic soda and metaphosphate to maintain the following concentrations:

Causticity as ppm OH 300 to 500 Phosphate  
as ppm PO<sub>3</sub> 100 to 150

6. Open the boiler at the end of the boiling-out period and clean out the sludge and loose scale. Pay particular attention to removing scale and sludge from water legs in fire-tube boilers.
7. Flush the boiler thoroughly.
8. If a lot of corrosion is exposed when the scale is removed, notify your superior so a boiler inspection can be made.

When the boiler is operated, any residual scale may cause faulty operation. The boiler should be taken out of service at frequent intervals to remove sludge formed from disintegrated scale. As soon as personnel can work in the boilers, wire brush the drums and ends of all tubes.

Then clean the interior of all tubes, using the approved style of boiler tube cleaning brushes.

You should operate all cleaners in the same way. After cleaning all the tubes, follow up by blowing them out thoroughly with a strong air jet. Then inspect to see if replacement of any of the tubes is necessary.

### **Test your Knowledge (Select the Correct Response)**

4. Which method is used to clean out a boiler fouled with grease?
- A. Fill-and-soak
  - B. Circulation
  - C. Percolation
  - D. Boiling out

## **9.0.0 BOILER MAINTENANCE**

As a UT, it is your responsibility to operate, maintain, and repair boilers. You can perform operator maintenance on shore-based boilers; perform preventive maintenance and minor repairs on boilers and associated equipment; complete chemical tests on boiler water and feedwater; replace defective boiler tubes; and test, adjust, and recalibrate boiler gauges and other accessories.

This section provides information on some of the methods, procedures, and techniques used to operate, maintain, and repair boilers and associated equipment safely under typical conditions. Because of the broad scope of tasks involved in operating and servicing boilers, this section does not tell you all you need to know about the subject. Learning how to accomplish the procedures given in the following sections can help you acquire a basis on which to develop more advanced skills. While the procedures given in this section are typical, you should always follow the manufacturer's instructions for the equipment.

### **9.1.0 Maintenance of Auxiliary Equipment**

A well-planned maintenance program is the key to avoiding unnecessary downtime or costly repairs, promoting safety, and aiding local inspection. An inspection schedule listing the procedures should be established. It is recommended that a boiler room log or record be maintained for recording the daily, weekly, monthly, and yearly maintenance activities. This provides a valuable guide and aids in the operational efficiency, length of service, and safe operation of a boiler. It is also important to remember that improperly performed maintenance is just as damaging to a boiler as no maintenance at all.

#### **9.1.1 Maintenance Requirements for Control of Water Level**

The need to check water level controls and the waterside of the pressure vessel periodically cannot be overemphasized. Most instances of major boiler damage are the result of operating with low water or using untreated (or incorrectly) treated water. Always be sure of the boiler water level and blow down the water column routinely. Check samples of boiler water and condensate according to procedures recommended by your water consultant.

Since the manufacturer generally sets low water cutoff devices, do not attempt to alter or adjust these controls. If a low water device should become erratic in operation or if

the setting changes from previously established levels, check for reasons and correct it by repair or replacement.

*Figure 9-34* is a replica of the low water cutoff plate attached to a steam boiler. These instructions should be followed on a definite schedule. These controls normally function for long periods of time and may lead to laxity in testing on the assumption that normal operation will continue indefinitely.

On a steam boiler, the head mechanism of the low water cutoff devices should be removed from the bowl at least once a month to check and clean the float ball, the internal moving parts, and the bowl or water column. Remove the pipe plugs from the tees or crosses, and make certain the cross-connecting piping is clean and free of obstructions. Controls must be mounted in a plumb position for proper performance.

A scheduled blowdown of the water controls on a steam boiler should be maintained. It is impractical to blow down the low water cutoff devices on a hot-water boiler since the entire water content of the system would be involved. Many hot-water systems are fully closed and any loss of water would require makeup and additional feedwater treatment that might not otherwise be necessary. Since the boiler and system arrangements usually make it impractical to perform daily and monthly maintenance of the low water cutoff devices, it is essential to remove the operating mechanism from the bowl annually or more frequently if possible, to check and clean the float ball, the internal moving parts, and the bowl housing. Also, check the cross-connecting piping to make certain that it is clean and free of obstructions.

### **9.1.2 Gauge Glass Replacement**

A broken or discolored gauge glass should be replaced at once. Always use new gaskets when replacing a gauge glass. Use the proper size rubber packing. Do not use "loose packing" that could be forced below the glass and possibly plug the valve opening.

Close the valves when replacing the glass. Slip a packing nut, a packing washer, and a packing ring onto each end of the glass. Insert one end of the glass into the upper gauge valve body far enough to allow the lower end to be dropped into the lower body. Slide the packing nuts onto each valve and tighten.

If the glass is replaced while the boiler is in service, open the blowdown valve and slowly bring the glass to operating temperature by cracking the gauge valves slightly. After the glass is warmed up, close the blowdown valve and open the gauge valves completely. Check the try cocks and gauge cocks for freedom of operation and clean them as required. It is imperative for the gauge cocks to be mounted in exact alignment. If they are not, the glass will be strained and may fail prematurely.

### **9.1.3 Feedwater Regulator Maintenance**

Proper control of the water level requires that the feedwater regulator be maintained. Here are a few pointers for regulators.

If the water level changes from its normal position, make sure you adjust the bypass to manual operation and check promptly for the source failure. If leaks develop around the packed stems, see that they are stopped immediately. If the boiler is off line, close the hand valve in the feed line. Bear in mind that the regulator is not designed for use as a stop valve. About once every 3 months, you will probably be called on to assist in blowing down the steam and water connections separately.

### 9.1.4 Valve Maintenance

Valves require special care and attention if they are to work as intended. There may be variations among activities in the type and frequency of valve inspection and servicing requirements. Therefore, follow instructions issued by your activity when they differ from those outlined here.

Types of valves that you may be responsible for helping service and maintain at regular intervals include (1) stop valves of the globe or gate type and (2) stop-and-check valves, which combine in one tray and angle or stop valve of the globe type and a check valve. At least once every 3 months, valves that have not been operated for some time should be operated to prevent sticking. Make sure that you also check for leaks, bent stems, or a missing or broken handle, and lubricate the exposed threads and gearing of the valve stem.

Loosen and lift the packing follower about once every 3 months or more often if possible. Lubricate the packing with graphite bearing oil or graphite bearing grease. Replace the packing followers and tighten sufficiently to ensure against leaks.

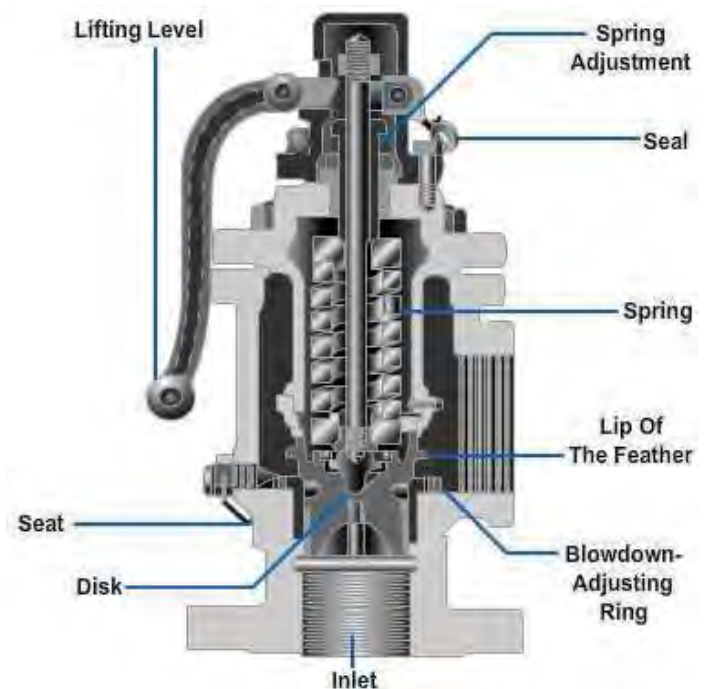
Blowoff or blowdown valves should be opened at least once a day. There are four reasons for using these valves:

1. Controlling high water
2. Removing sludge and sediment
3. Controlling chemical concentrations in the water
4. Dumping a boiler for cleaning or inspection

The amount and frequency of blowing down depends on a chemical analysis of the water in the boiler and operating conditions.

On a quarterly basis, inspect the blowoff valves when the boiler is washed out and an internal inspection is made. Check the valves for leaks, and inspect the pipe and fittings between the blowoff valves and the boilers. If repairs are needed, see that they are made promptly. In making a quarterly check on the blowoff valves, do not overlook the insulation, bearing in mind that it should be kept dry. Another item is the discharge piping leaking from the valves. Make sure the discharge piping is not mounted so rigidly that proper expansion and contraction are affected.

Keep safety valves in top working order (*Figure 9-37*). At regular intervals, depending upon operating conditions, the safety valves must be lifted manually. At least once each year the valves should be tested by raising steam pressure to popping pressure of the respective



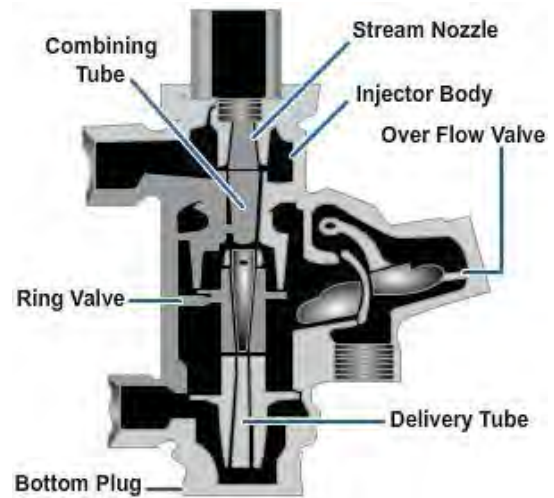
**Figure 9-37 - Typical spring loaded safety valve.**

valve. If safety valves function improperly, promptly report the matter to your immediate supervisor. For detailed information on the maintenance of safety valves, refer to manufacturer's manual.

### 9.1.5 Steam Injector Maintenance

With injectors, little maintenance is required. At times you will have to reset the overflow and ring valve. Lime deposits also can reduce the operation by closing down the size of the combining and delivery tubes. A good way to remove lime deposits is to place the injector in a tube of muriatic acid for several hours.

To clean the injector, remove the bottom plug (*Figure 9-38*). The delivery tube and ring valve drop out. Examine and clean all passages and holes. After cleaning, replace them in the plug (which acts as a guide) and screw tightly in place.



**Figure 9-38 - Cross-sectional view of an injector.**

### 9.1.6 Steam Trap Maintenance

Once each month, see that steam traps are tested for correct operation.

Once a year, or more often if required, dismantle and clean all traps. Inspect for the following:

1. Accumulation of foreign matter
2. Plugging of orifices, valves, and vents
3. Cracked, corroded, broken, loose, worn, or defective parts
4. Excessive wear, grooving, and wire drawing of valves and seats
5. Defective bellows, buckets, or floats
6. Leaky vessels and pipes
7. Defective bypass valves

Repair or replace defective parts as required following yearly inspection. Replace or repair all defective gaskets, bellows, valves, valve seats, floats, buckets, linkages, and orifices. Use only matched sets of replacement valves and seats. Make certain all replacement parts are of the correct size. Do not change the weight of floats or buckets when repairing traps, or operation may be affected. Often, it is more economical to purchase and install new parts than to recondition defective elements. Repair or replace leaking bypass valves. Repack valve stems.

### 9.1.7 Fan Maintenance

The forced-draft fan should be checked daily to prevent an accumulation of dust in or around the fan. Keep the fan clean! Also, check daily on the sound of the fan. If it is not normal, report the matter promptly to your supervisor.

A daily check should also be made to ensure adequate lubrication of the fan. The temperature is another item that should not be overlooked. This you can test by feel. In case of excessive temperature, notify your supervisor immediately.

Because induced-draft fans are exposed to hot, dirty gases, they must be observed closely to prevent operating difficulty. Taking proper care of the fan requires daily attention to ensure that the following conditions are met:

1. Bearings are kept cool and well lubricated.
2. Fan is kept clean. Also, see that any change from the normal in sound is reported promptly to your supervisor.

### 9.1.8 Handhole and Manhole Gasket Maintenance

At each regular boiler overhaul, all handhole and manhole fittings and gasket seating surfaces on the drums and headers must be cleaned, inspected, repaired, or renewed if necessary. If the plates are warped, distorted, or otherwise damaged, they must be repaired or renewed.

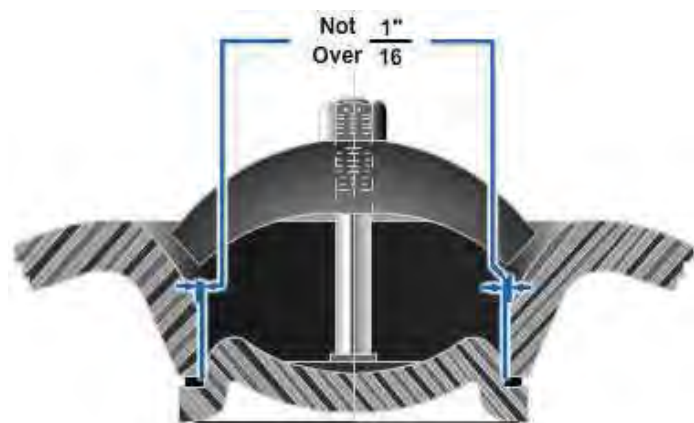
Whenever handholes and manholes are opened, new gaskets must be fitted. After a gasket has once been compressed, it must be discarded, as it will not provide a seal. Be sure to use the correct size and type of gasket. Never use any makeup compound on the seating surfaces when installing the gaskets. Graphite may be used on the threads of the stud to prevent seizure of the nut.

Before installing a new gasket, thoroughly clean the two gasket seating surfaces (one on the drum or header and one on the plate). Be sure you remove all the corrosion or other surface deposits and all adhering pieces of the old gasket. 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. Be sure to water-soak the new gasket for 24 hours before installation.

Power-driven wire brushes are best for cleaning the seating surfaces. Scrapers should be used only when wire brushes are not enough to clean the surface. Scrapers 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 a lot of pitting, you may have to get these surfaces machined or reground. If the seating surface on a handhole or manhole plate is badly pitted or damaged, discard the plate and replace it with a new one or one that has 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 9-39* shows where the clearance is



**Figure 9-39 - Manhole plate clearance.**



measured. If the clearance is greater than 1/16 inch, the plate should be built up by electric welding at the inner edge of the shoulder. Steelworkers should do the welding, so the manhole plate may be stress-relieved after it is welded and the welded surface may be re-machined.

To position a manhole gasket properly, fit 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 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; 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 decreases as the pressure is increased. When the pressure is within 50 psi of the test pressure, most of the leakage stops although the nuts are still loose.

If some plates are leaking 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 counter-bore for the seat. A light blow with a hammer on the outside of the plate usually relieves the tension on the gasket and allows it to seat properly.

After leaky gaskets have been adjusted and while full test pressure is on the boiler, tighten up all plates firmly. Use only the wrenches specified for this purpose.

Some economizer headers and a few super heater headers are fitted with handhole plugs instead of handhole plates. Also, some economizers have bayonet types of cleanout plugs on the front ends of the tube loops to allow access to the tubes at the return bend end. Detailed instructions for installing and removing the plug type of manhole fittings and the return bend cleanout fittings are given in appropriate manufacturer's technical manuals.

### 9.1.9 Hydrostatic Tests

The boiler should be given a hydrostatic test annually or whenever the operator doubts the boiler strength. The purpose of the test is to prove the tightness of all the parts of the boiler or the strength of the boiler and its parts.

In preparing the boiler for a test, rinse it out with fresh water. Then check carefully to see that no loose scale or tools are left in any part of the boiler.



Do NOT exceed the test pressure. NEVER apply more than 10 pounds of pressure above the maximum working pressure on a low-pressure boiler. Consult the ASME code for testing procedures for other than welded steel boilers. In case of unusual conditions, discontinue the test immediately and notify your supervisor.

The procedures for making boiler hydrostatic tests are as follows:

1. Close all openings and "gag" (clamp down) all safety valves. Gags should be only hand tight and straight. Do NOT use a wrench; it will bend the valve stem and possibly damage the seat. Remember that valves are easily damaged if lifted by water pressure. Close all connections on the boiler except air cocks, test pressure gauge, and valves of the line through which pressure is to be applied.
2. Reduce the water level in the boiler by opening an air cock, and blow down the boiler until the water level is below the feedwater inlet connection. Clear the blowdown area before blowdown.
3. Connect a hydrostatic pump between the boiler and water service connection. Install all pipe and fittings between the pump and the boiler. Remember, the pipe and fittings must be able to withstand test pressures. Install a hose between the pump and the chosen water service. Ensure the chosen water service supplies ample water pressure to conduct the test.
4. Remove the plug from the feedwater inlet cross by turning it in a counterclockwise direction.
5. Open the boiler casing access doors or plates so tube ends can be inspected during the test.
6. Install a wedge between the control switch and the pressure-actuating platform. Also, install a stop valve before the control switch to protect the control so hydrostatic pressure will not actuate or damage the control. The range of the pressure control is usually less than the hydrostatic pressure being applied. Do NOT bend or damage the actuating parts.
7. Fill the boiler with water until water discharges out of the air cock; then close the air cock. Ensure all the air is expelled from the boiler before closing the air cock. Turn on the water service valve. The water temperature should be the same as the surrounding atmosphere. The minimum water temperature must be 70°F.
8. Check the boiler steam pressure gauge in-line cock to ensure that it is open. Ensure the butterfly handle is in line (parallel) with the tubing.
9. Apply water pressure of 1 1/2 times the maximum allowable working pressure. To avoid rapid shock and strain, bring this pressure up in 10 equal increments, inspecting for leaks and deformities at each increase.
10. Inspect tube ends, boiler seams, pressure fittings, and connections. Make the corrections and repairs wherever possible.
11. Secure pressurizing connections at the required test pressure. Continually inspect the boiler tubes, seams, fittings, and connections. If the boiler and fittings are tight, the pressure should NOT drop more than 1.5 percent in 4 hours. If loss of pressure is over 1.5 percent, find the leak(s) and make the repairs.

Following all hydrostatic testing, steam pressure is raised to lift safety valves and to determine the fitness of the boiler for use.

### **9.2.0 Boiler Tubes**

For any boiler re-tubing job, it is absolutely essential to use tubes that conform in everyway to the tube requirements of the particular boiler. Boiler tubes are NOT identical. They differ in such important characteristics as composition of the metal, outside diameter, wall thickness, length, and curvature.

Much of the required information on sizes, thickness, and number of tubes per boiler is given in the manufacturer's technical manual. Some of the information is under the heading of "Tube Data." More detailed information is usually given on the drawings included in the manual.

### **9.2.1 Composition of Boiler Tubes**

Generating tubes are usually made of low carbon steel. They may be either seamless or resistance-welded. Seamless tubes were once definitely preferred for naval use. However, improved methods of manufacturing the welded tubes have led to an increased use of welded tubes in naval boilers. Repair ships, tenders, and other naval activities that use, handle, or issue plain carbon steel tubes have been instructed to make no distinction between the seamless and the welded tubes, but to stock, issue, and install them interchangeably without regard to the method of manufacture.

Super heater tubes usually are not made of plain low carbon steel. On boilers where the superheated steam temperature reaches 850°F or higher, the super heater tubes may be made of carbon-molybdenum steel, chromium-molybdenum steel, or an 18-8 chromium-nickel (stainless) steel.

To find detailed information on the composition of the metals used for generating tubes and super heater tubes in any particular boiler, check the manufacturer's technical manual. The information may be given on the drawings, or it may be included in the text.

Although we all have a general idea of what we mean by the word metal it is not easy to give a simple, accurate definition. Chemical elements are metals if they are lustrous, hard, good conductors of heat and electricity, malleable, ductile, and heavy. In general, these properties of hardness, conductivity, malleability, and so forth are known as metallic properties, and chemical elements that possess these properties are generally called metals. Chemical elements that do not possess these properties are called nonmetals. Oxygen, hydrogen, chlorine, and iodine are a few examples of nonmetallic chemical elements. A few chemical elements behave sometimes like metals and sometimes like nonmetals. These elements are often called metalloids. Carbon, phosphorus, sulfur, and silicon are examples of metalloids.

Most types of steel look quite a lot alike, so you cannot go by appearances. On Navy blueprints and on drawings furnished in the manufacturer's technical manuals, materials are usually specified by federal or military specification numbers. In addition, the blueprints and drawings may refer to a commercial classification system, such as the Society of Automotive Engineers (SAE) system or the American Iron and Steel Institute (AISI) system.

Federal or military specifications usually require the tubes to be identified by some marking system. For example, one specification for boiler tubes requires that boiler tubes 1 1/4 inches or greater in diameter and 3 feet in length be legibly marked by paint stenciling, while smaller or shorter tubes may be bundled and tagged. Another boiler tube specification requires the tubes to be marked by ink stenciling approximately 3 inches from each end and again in the middle of the tube. As a general rule, boiler tube identification markings must include (1) the name or trademark of the manufacturer, (2) the heat number, (3) the class letter, (4) the specification number, and (5) the outside diameter, the wall thickness, and the length.

### **9.2.2 Renewing Tubes**

Boiler tubes should be replaced when they cannot be made tight, or when they are warped, or otherwise seriously damaged. As a general rule, boiler tubes should not be straightened in place; leaks may develop that could cause permanent damage to other parts of the boiler. Occasionally, however, you may find a screen tube or a wall tube that has bowed out of position for no apparent reason; you can straighten the tube in place and re-roll it if a replacement tube is not available. Tubes that have bowed out of position because of low water should not be straightened.

To renew tubes in the A row, the corresponding tubes in the B row must also be renewed, regardless of their condition. Similarly, whenever superheated tubes are renewed, remove the super heater support tubes when they are not accessible without removal of the super heater tubes.

General renewal of tubes in a boiler should not be undertaken without approval of the Chain of Command. The commander's decision as to whether to approve a general renewal of the tubes will be based on the results of inspection and examination of tube samples.

Before beginning to renew tubes, be sure all preparations have been made. Be sure the right types of replacement tubes are available and that all tools and equipment required for the job are on hand and in good working order. Check the cutters, the air hoses, and the fittings for the pneumatic tools, the tube benders, the electric equipment, and the staging.

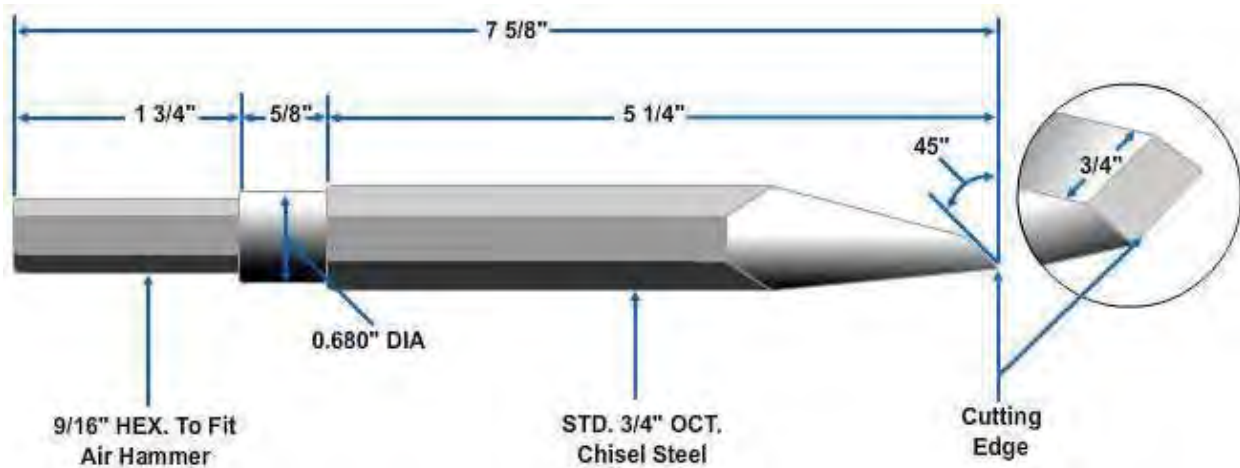
The steam drum must be opened and some fittings removed to allow access to the ends of the tubes. Also, the water drums and headers must be opened. Any fittings removed from the drums should be carefully set aside and marked, if necessary, to ensure correct replacement.

Before allowing a person to enter the boiler, be sure all safety precautions are observed. Make it your personal responsibility to see that all cross-connecting valves between the boiler being re-tubed and any steaming boiler are closed and locked or wired shut and are tagged DANGER. DO NOT OPEN. Be sure, also, that the control valves of the steam-smothering system are locked in the CLOSED position. See that enough ventilation is provided; keep portable blowers running at all times while people are working in the boiler. Do not allow unauthorized types of lights in the boiler.

Flashlights are preferred for boiler work. If portable lights are used, the electric leads must be thoroughly insulated and the portable fixture itself must be the grounded, watertight type. Before use, portable lights should be checked by an electrician to ensure they are safe.

### 9.2.3 Removing Tubes

Using an air-powered side-cutting chisel to cut the old tube flush with the drum or header (*Figure 9-40*) is one method of removing tubes. Carefully work the cutter so as not to damage the surface of the drum or header. When you are removing super heater tubes, it will be impossible to cut the tube flush with the header with a side-cutting chisel. An expandable fly cutter must then be used to cut out the tubes.



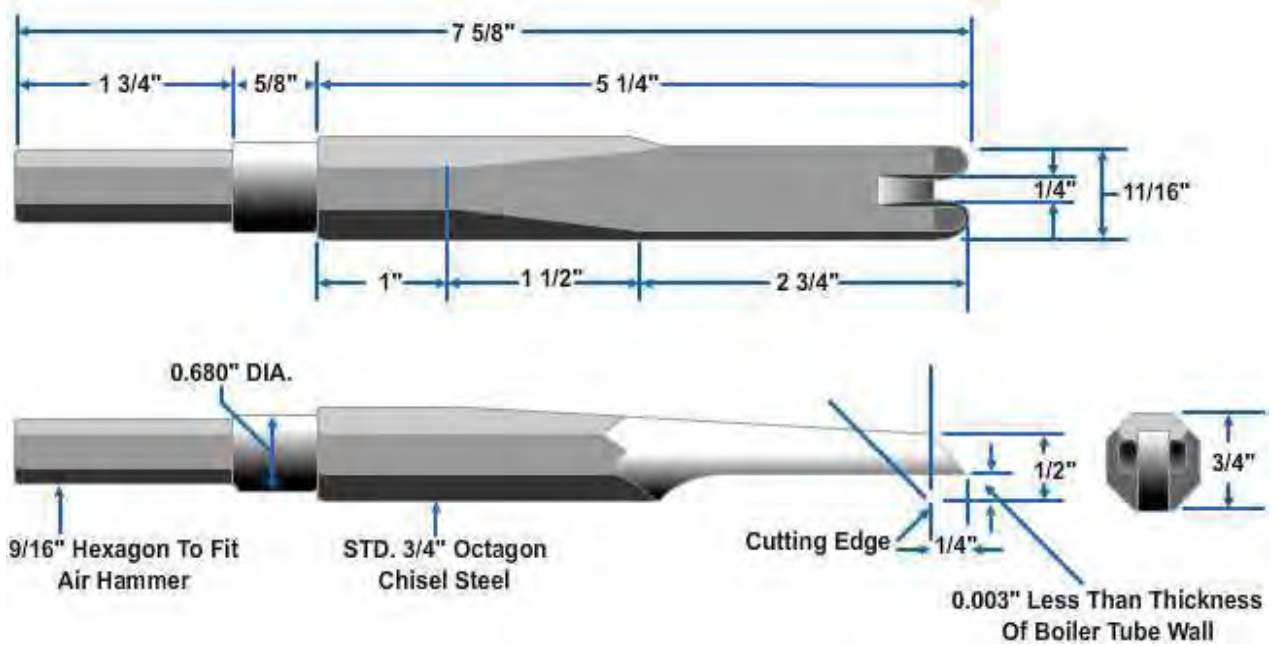
**Figure 9-40 - Side-cutting chisel.**

After removing the main part of the tube from the boiler, use a safety ripping chisel of the type shown in *Figure 9-41* to make a cut on the inside of the remaining portion of the tube. The safety ripping chisel is designed so it cannot cut entirely through the tube; therefore, it cannot score the tube sheet.

After cutting the tube approximately three-fourths of the way along the tube sheet, crimp the edges of the tube and drive out the stub with a blunt chisel. If the tube is a large one, you may have to make two cuts with the safety ripping chisel instead of one; the cuts should be about an inch apart.

If a safety ripping chisel is not available, you can remove the tube by the following method:

1. Split the ends of the tube with a flat chisel from the end of the tube to the drum or header at two places about 3/4 inch apart.
2. Force the 3/4-inch piece upward with a bar until it has been raised off its seat and has curled into the tube.
3. Split the tube to a point beyond the other side of the tube seat with a tool ground to conform to the tube hole. Be careful not to damage the tube hole.
4. Break in the ends of the tube with a crimping tool, and then drive out the stub.



**Figure 9-41 -Safety ripping chisel.**

Arc welding equipment can be used as an aid to the tube removal on some boilers. This procedure requires running two beads, 3/4 inch apart, through the entire tube sheet, quenching with water, and then using a backing-out tool. Do NOT use this method of tube removal if the drums or headers are made of 4-6 chromium steel.

Technology updates have made the removal of tubes much easier since the invention of the chisel. Figure 9-42 shows one option, the tube tigger. It is the simplest one to operate and will make this job easier for the UT. Be sure to follow the manufacturer's instructions as to the use of the tool. The basic operation of the tool is as follows:

1. Thread the spear into the tube using an impact drive or by hand.



**Figure 9-42 -Tube tigger in operation.**

2. Secure the tube tigger to the counter balance.
3. Position the tigger over the spear and hold against the tube sheet.
4. Initiate the stroke of the tigger, when it has reached its maximum stroke; initiate the return stroke, keeping the tigger in contact with the tube sheet. Repeat until the tube end is visible from the back of the collet holder.
5. Once the spear has passed through the collet jaws, stop the tigger and remove the spear from the tube.
6. Continue the extraction until the tube is fully extracted from the vessel.

### **9.2.4 Cleaning Tubes**

Replacement tubes must be thoroughly cleaned to remove all scale, dirt, and preservatives. One way of cleaning a tube is to push a kerosene-soaked rag through it and wipe the outside of the tube with a similar rag. Diesel oil may also be used. If a large enough tank is available, boiler tubes may be cleaned by immersing them in an approved cleaning solution, such as a saturated solution of boiler compound in hot water, to which a small amount of kerosene has been added. Boiler tubes may also be cleaned with steam jets.

### **9.2.5 Preparing Tube Sheets**

The tube sheet holes must be prepared before replacement tubes are inserted. The best way is to use a piece of hardwood turned to a diameter slightly less than the diameter of the hole and covered with a medium fine-grit emery cloth. Pass the wooden piece in a circular motion, back and forth through the tube sheet or header holes to smooth the surface. Finish the job by using a fine emery cloth wrapped around your finger. Keep working until the hole is clean and smooth.

When preparing tube seats, check the size and trueness of the tube holes; use a tube nipple of corresponding size as a template. It is impossible to make tube seats tight if the tube holes are much enlarged or if they are too elliptical (out-of-round). To ensure the tightness of the tube seats, be sure that the maximum enlargement and the maximum ellipticity of the tube holes do not exceed known values.

### **9.2.6 Repairing Tube Sheets**

Out-of-round tube holes, small steam cuts, and other minor defects may, in some cases, be corrected by welding. NAVFAC approval is not required for this type of welding repair on drums and headers made of low carbon steel, carbon-molybdenum steel, or steel containing less than 1 percent chromium if a qualified welder uses approved welding procedures for the welding, filler metal, and position of welding under MIL-STD-248. Always check the blueprints for the material of the drums and headers before welding.

### **9.2.7 Preparing Tube Ends**

After the tubes have been thoroughly cleaned, prepare the tube ends inside and outside. Clean the ends with a wire brush and polish them with abrasive paper and a liquid cleaner until the tube ends are completely clean, free of burrs and mill scale, and thoroughly polished. Clean and polish the tube ends for a distance equal to the thickness of the tube seat plus 2 or 3 inches.

Round off the tube ends with a file so no square or sharp edges remain. If the tubes are not rounded off at the ends, the tubes may split when they are belled.

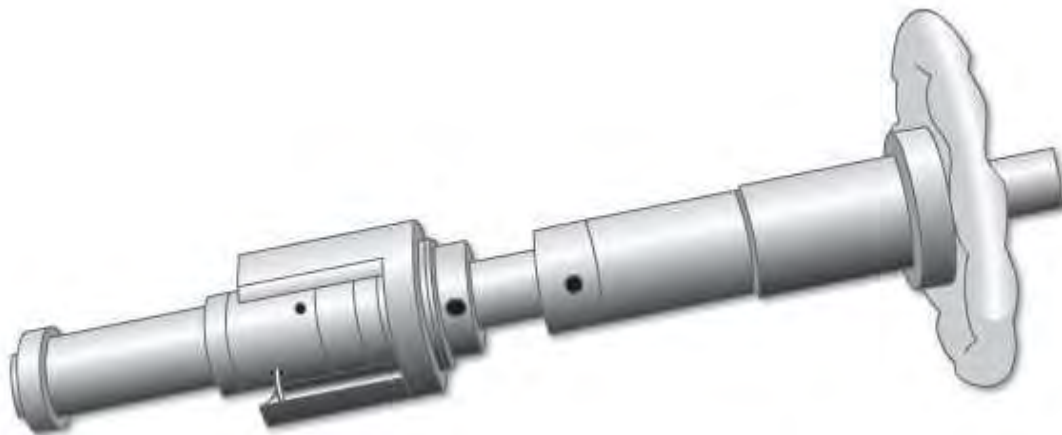
### 9.2.8 Fitting Tubes

When installing tubes, always fit the tubes into the steam drum before inserting the other end in the water drum or header. Inserting the tubes into drums and headers is not particularly difficult since all tube holes are drilled normal to the tube sheet.

If you are renewing a complete row of tubes, fit a tube at each end of the row and then work toward the middle. You may find slight differences in the lengths of tubes required if the boiler has been in service for some years. These differences are more likely to show up at the ends of the rows than in the middle.

When fitting tubes into drums or headers, be sure each tube extends far enough into the header or drum. Tubes up to (but not including) 2 inches in outside diameter (OD) should project  $3/16$  to  $5/16$  inch into the drum or header. Tubes 2 inches OD and larger should project  $5/16$  to  $7/16$  inch into the drum or header.

After you have fitted a tube and allowed for the amount it must project into the steam drum and into the water drum or header, remove the tube and cut off the excess. One of the tools you may use to cut the tube is the boiler tube cutter (*Figure 9-43*). You may be able to use one tube as a guide for cutting off the excess on several other tubes; if you recall, the tubes may vary slightly in length, particularly in older boilers. Do NOT use one tube to measure the rest of the tubes in a row if you believe there are big differences in tube lengths in the row. If your sample tube happened to be a little on the short side, you would end up with a whole row of tubes that were too short, and therefore could not be used.



**Figure 9-43 - Tubing cutter.**

Each tube must be carefully aligned with the other tubes. Use a plywood batten about  $1/2$  inch thick, 3 feet long, and 3 inches wide to align tubes in the generating bank. After positioning the tubes, check them with the batten. Then place small, wooden wedges to hold the tubes in place until they have been expanded into the tube sheets. Be sure to remove the batten and the wedges before starting work on the next row. These wooden pieces cannot be left in the boiler. You will have a real job on your hands if, after installing five or six more rows of tubes, you suddenly discover that you have overlooked the batten or one of the wedges.



### 9.2.9 Expanding Tubes

The basic joint in boiler construction is an expanded joint that must not leak or lack holding power. Leakage, if permitted to go uncorrected, leads to deficiency of holding power because of deterioration of the tube seat. Slight leakage itself should not be taken as cause for alarm, but rather as evidence to correct the fault as soon as possible. Deficiency of holding power causes the tube to pull out of its seat. In most cases, the tubes are installed within the furnace of the boiler, and any danger to personnel, if the tubes pull out of the seat, is reduced since the steam will be discharged up the stack. For this reason, tubes 1 inch outside diameter (OD) up to and including 2 inches OD are expanded by "boilerman's feet," as only a small amount of expansion is required to hold the tubes firmly in place. With tubes 3 inches OD and larger and all external downcomers, special precautions must be taken to ensure the tubes are properly expanded in the tube seat. Through a series of tests, the point of maximum holding power for various sizes of tubes has been found and is expressed in terms of standard diameters that should be measured after the tube has been expanded in place. In new construction or replacement of tubes where the tube and hole measurements can be obtained, the correct amount of expansion can be found by using the following formulas:

For tubes in drums: Diameter of tube hole minus OD of tube, plus 0.012 inch per inch OD of tube.

For tubes in headers for boiler design pressure under 500 psi: Diameter of tube hole minus OD of tube, plus 0.015 inch per inch OD of tube.

For tubes in headers for boiler design pressure over 500 psi: Diameter of tube hole minus OD of tube, plus 0.020 inch per inch OD of tube.

The figure arrived at by using the above formulas should be added to the OD of the tube as measured to give the required OD of the tube after rolling.

If it is impossible to reach the outside of the tubes in drums to gauge them, the inside diameter (ID) of the tube must be measured. Since the plastic deformation of the tube wall varies with tube wall thickness, the ID of the tube for different wall thickness will vary. Where the outside of the tube is inaccessible, the following formula is used in the expansion of a tube:

- The ID of the tube, plus the tube hole diameter minus the OD of the tube plus the expansion increase factor.

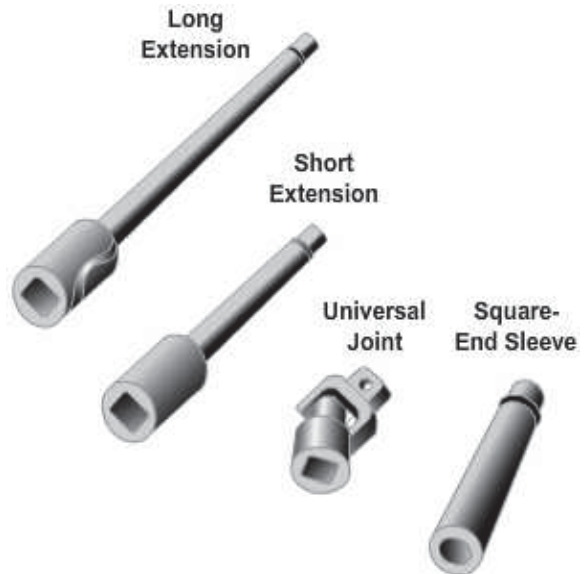
Boiler tubes should be expanded with the expanding equipment furnished to the shop. Select expanders of the proper size for the tube size and the seat thickness and expanders proper for the operation to be performed. There are two types of expanders: roller-type and ball-drift type. Roller-type expanders are furnished for use by the shop labor force. Roller-type expanders are shown in *Figure 9-44*. A series of adapters are furnished for use if tube holes are not readily accessible. Some of these adapters are shown in *Figure 9-45*.



**Figure 9-44 - Roller type tube extenders.**

Tube expanders are operated by air motors. The air, at about 100 psi, enters through a controlling handle and goes into the motor housing where it drives an air turbine. The turbine is attached to the shaft of the motor. The controlling handle can be turned clockwise or counterclockwise. A chuck with a tapered shank engages the shaft of the air motor, thus transmitting the power of the motor to the rollers used for expanding tubes into the tube sheet.

Both the air motors and the chucks are available in various sizes. The large sizes of motors and chucks are used for expanding the larger sizes of tubes. *Figure 9-46* shows a tube expander in use.



**Figure 9-45 - Adapters for tube expanders.**



**Figure 9-46 -Expanding a tube.**

Tube expanders must be used carefully to avoid damage to the expanders and to prevent injury to personnel. The centrifugal force developed by the air turbine is great, so the air motor must be gripped firmly with both hands. If the roller-mandrel combination should bind, the force of the air motor could break the mandrel and quite possibly cause injury to the operator. Always have a person stationed nearby to give immediate assistance if necessary. If you run into any trouble, your safety person maybe able to crimp the hose quickly and thus keep the mandrel from breaking.

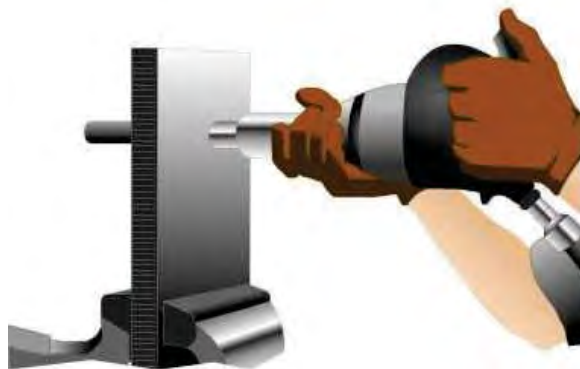
### 9.2.10 Belling Tubes

Most tubes are expanded and belled. However, check the drawing to determine if any specific instructions are shown. Some tubes in 1,200 psi boilers are lightly expanded or belled before welding; some are directly butt-welded to the studs. A roller-type or a drift-type belling tool is used. The drift-type tool is shown in *Figure 9-47*.

When belling a tube, be careful not to overdo the operation. Tubes up to, but not including 2 inches OD should be belled at least 1-15 inch but no more than 1/8 inch. Tubes 2 inches OD and larger should be belled at least 1/8 inch, but no more than 3/16 inch. The increase is to be measured over the outside tube diameter at the end of the tube. *Figure 9-48* shows the process of belling a tube.



**Figure 9-47 - Belling tool.**



**Figure 9-48 - Belling a tube.**

Some expanders are fitted with belling rolls. When these expanders are used, the tubes are expanded and belled at the same time; thus, there is no need for a separate belling job.

### 9.2.11 Renewing Welded Tubes

In some boilers of recent design, the super heater tubes and the economizer tubes are welded after they have been expanded. The renewal of these tubes is more complicated than the renewal of ordinary tubes. Procedures for renewing welding tubes are given in the appropriate manufacturer's technical manual.

### 9.2.12 Plugging Boiler Tubes

As an emergency measure, it is sometimes necessary to plug defective boiler tubes until they can be replaced.

 **CAUTION** 

Any tube that is plugged must have a hole drilled in it to prevent pressure buildup in the tube when the boiler is steamed.

Various sizes of tube plugs are carried in the supply system. The plugs are tapered to the required shape and are usually drilled and threaded at the larger end so they may be removed with a tube plug extractor.

Tubes must be plugged at each end. Before driving a tube plug into position, be sure the plug and the inside of the tube are absolutely clean so the plug makes good metal-to-metal contact with the tube. Drive the plug far enough in to ensure it will hold, but donot drive it so far in that it damages the tube sheet.

In plugging super heater tubes, use an offset driver to drive in the plugs when the tube holes do not fall in line with the handhole opening. When a super heater tube is plugged, it will eventually burn away after a period of service. When tubes have burned away (or when they have been removed) so much that they leave a gas lane more than three tube rows wide through the entire super heater tube bank, plug the gas lane with a plastic or castable refractory. If the lane cannot be plugged, the firing rate of the boiler must be restricted to avoid overheating the super heater tubes next to the gas lane.

When a sidewall tube needs to be plugged, cut the tube 3 to 4 inches above the sidewall heater and 3 to 4 inches below the steam drum. The space left exposed after removal of the tube should be packed with plastic refractory to protect the pressure parts previously cooled by the plugged tube. Do not plug more than two tubes next to each other since an exposed area wider than this cannot be effectively protected for an extended operation. Sidewall tubes that have been plugged should be replaced at the earliest opportunity.

When a rear wall tube needs to be plugged, cut the tube 3 to 4 inches from the headers or at other cutoff points specified in the manufacturer's technical manual. Use a plastic refractory to plug casing openings in order to cover exposed areas not protected by firebrick or high-temperature castable refractory, and to cover the exposed pressure parts previously cooled by the plugged tube. Rear wall tubes that have been plugged should be replaced at the earliest opportunity.

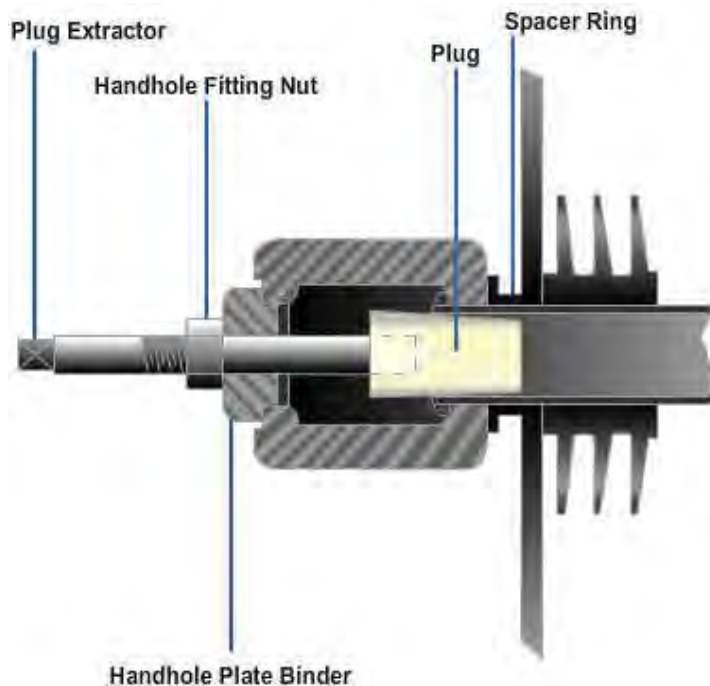
Super heater screen 1 1/2 and 2 inches in outside diameter should, in general, be replaced, rather than plugged, when tube failure occurs.

In plugging generating tubes 1 inch and 1 1/4 inches in outside diameter behind the super heater tube bank (in single-furnace boilers) and behind the 2-inch tubes (in double-furnace boilers), consider gas laning and drum protection. Any complete lane through the tube bank more than three tube rows wide should be re-tubed, especially if such a lane is bounded by the boiler casing. Any drum area greater than 4 inches square should have refractory protection over the drum or, if this is not practicable, have blind nipples replace the failed

tubes instead of just plugging the failed tubes. The blind nipples give greater protection to the drum than plugged tubes.

If an economizer element develops a leak, the ends of the element should be plugged at the inlet header and at the outlet header. To install a tapered plug in an economizer element, screw the plug extractor into the plug and insert the plug into the tube. Unscrew and remove the extractor from the plug. Drive the plug securely into position by holding one end of a piece of pipe against the plug and striking the pipe on the other end.

Figure 9-49 shows how to remove a plug from an

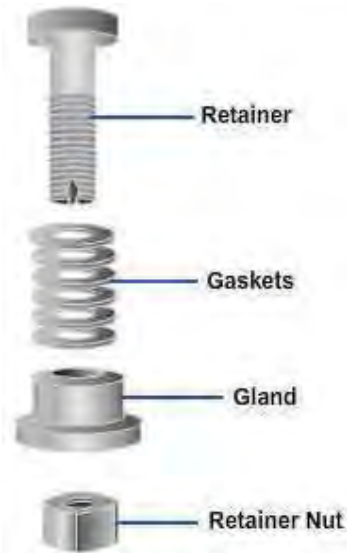


**Figure 9-49 - Removing plug from economizer element.**

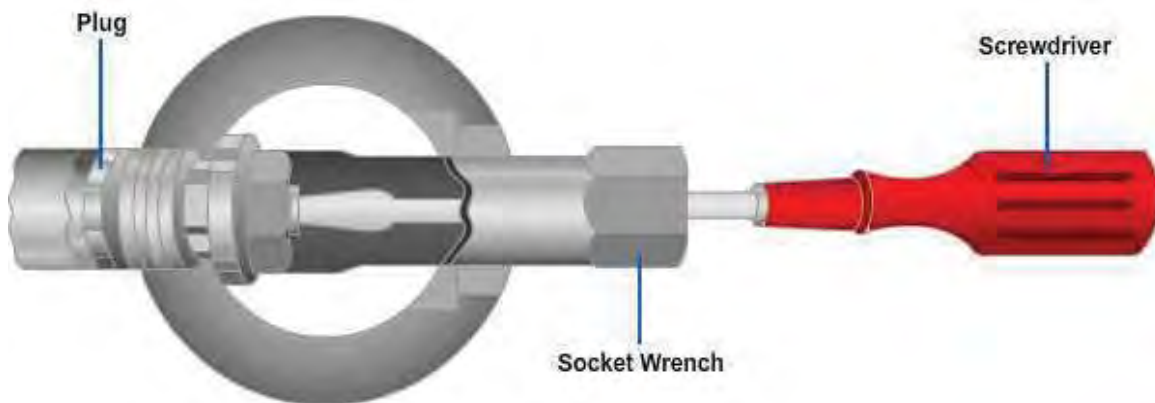
economizer element. Screw the plug extractor into the plug. Place the handhole plate binder in position over the extractor, and then thread on the handhole fitting nut. As you tighten the handhole fitting nut, the plug pulls out.

Some activities using boilers of recent design are furnished with expandable gasketed plugs for plugging economizer elements. One of these plugs is shown in *Figure 9-50*.

The installation of the expandable plug is shown in *Figure 9-51*. After inserting the plug assembly into the tube, hold a screwdriver in the slot of the retainer stem to keep the plug from turning as you tighten the nut. As you tighten the nut using an open-end wrench or a socket wrench, the gaskets expand radially as they are compressed axially.

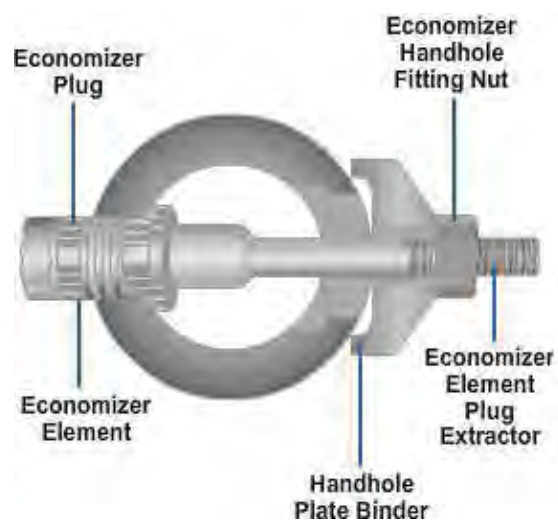


**Figure 9-50 - Expandable gasketed plug.**



**Figure 9-51 - Installing expandable plug in economizer element.**

The removal of an expandable plug is shown in *Figure 9-52*. Insert a socket wrench or an open-end wrench through the handhole and remove the retainer nut. Insert the economizer plug extractor and then thread it onto the retainer. Place the handhole plate binder in position over the extractor and the thread on the handhole fitting nut. As you tighten the nut, the plug pulls out.



**Figure 9-52 - Removing expandable plug.**

### 9.3.0 Repairing Boiler Refractories

Furnaces are built with high-grade, fire-resistant materials that take a lot of punishment. Sooner or later, however, repairs become necessary. Furnace walls or floor may need repairing. The procedure for this repair is as follows:

First, mix the mortar, using a Navy-recommended fire clay or fire cement and freshwater. Do not add anything else. Make the mortar rather thin and free of lumps.

Inspect the bricks for flaws and evenness. Choose the best edge for the furnace side. Dip the brick in fresh water and allow the excess water to drip off.

Now, dip one end and side of the brick into the mortar, using an edgewise motion to prevent air bubbles from forming. Lift the brick from the mortar and allow the excess mortar to drip off. Do not place any mortar on the wall or brick with a trowel. The mortar sticking to the brick is all that is used.

If the mortar is too thick, you will not get the thin joints that you want. The mortar should be a little thinner than the usual wall plaster. You can feel the proper thickness with your hand. Some mortar will stick to your hand as you lift it away from the mortar. Add more clay or water as necessary, and stir the batch often to keep the mortar at the desired consistency.

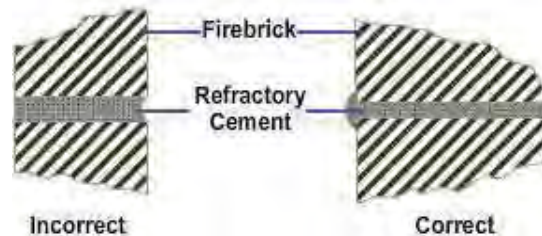
Place the brick quickly in position in the wall and pound it in place with a wooden mallet until no mortar can be forced out of the joints. With high-grade brick, joints can be made less than 1/32 inch thick. Joints should never exceed 1/16 inch.

With a small trowel, fill in any unevenness in the furnace side of the seam and bead over the joints (*Figure 9-53*). Be sure that no edges of the brick are exposed. The wall should be laid up evenly and smoothly. Any excess mortar that protrudes from the joints should be smoothed off with a small trowel so the corners of the brick are protected.

Allow the wall to dry for about 12 hours with the burner shutters open to allow circulation of air, which permits the escape of some of the water added to the mortar. As soon thereafter as practicable, light the burner under the boiler and slowly bring the furnace up to operating temperature to bond the mortar to the adjacent brickwork.

When inspecting the boiler, you may find cracks or holes in the furnace lining. To make necessary repairs, mix some of the fire clay you used for brick mortar into a thick mixture. Use more mortar than you used for the brick mortar mix. Use a trowel to apply this wash.

While standard firebrick generally is used for normal refractory work, plastic firebrick is recommended for emergency patches and for building up furnace openings. Plastic firebrick is unfired firebrick in a stiff plastic condition. It offers a particular advantage in that, because of its plastic nature, it can be pounded into places where otherwise a firebrick of special shape would be required. The fusion point of plastic firebrick is practically equal to that of standard firebrick. Because of the moisture in the plastic



**Figure 9-53 - Cementing block.**

material, however, a greater degree of shrinkage takes place. This factor prevents its general use for sidewalls. It provides an excellent material, though, for repairing brickwork, topping off side and back walls, repairing and constructing the burner openings and, in general, for any part of the furnace not exposed to temperatures in excess of 2000°F. It is particularly adapted for use in place of specially formed brick of complicated shapes.

Plastic firebrick material, as received from the factory, ordinarily contains enough moisture for working. Avoid the addition of water or any foreign material. In laying up, chunks of plastic just as taken from the can should be rammed tightly into place (preferably in horizontal layers). In general, the more solidly the section of plastic is rammed up, the better it will be.

As the next step, the plastic section should be vented with 3/16-inch holes. Ensure that the holes extend clear through the plastic and are not more than 2 inches apart. This positioning allows deeper heat penetration during the baking-out process. It also permits ready escape of the steam formed from the moisture in the plastic. Do NOT trowel the surface of a new plastic section. This tends to prevent the escape of steam during baking out.

The plastic section should be held in place with as many anchor bolts as would have been provided had standard firebrick been used instead of plastic. The plastic section should be air-dried. This takes from 48 to 72 hours, depending upon the atmosphere. As soon as practicable after air drying, the furnace should be fired with a small fire and gradually brought up to operating temperature to complete baking out. Plastic requires a temperature of about 2900°F to 3000°F for baking out. If small shrinkage cracks open up, they should be filled with fire clay. If large cracks occur, they should be filled with plastic.

When used for patches, as in the case of brick falling out, the hole should be cleaned out to give at least 4 inches of body thickness to the plastic brick. In building up furnace openings, the use of a metal form is desirable. However, it is not absolutely necessary if care is exercised in making openings of the proper shape and concentric with the atomizer at every point. If furnace openings, as built, have a smooth surface, they should be roughened with a stiff wire brush before baking out.

The following ways to maintain newer boilers are recommended. The boiler is normally shipped with a completely installed refractory. This consists of the rear head, the inner door, and the furnace liner (*Figure 9-54*). Follow the instructions in the manufacturer's manual for the boiler you are maintaining. Where specific directions or requirements are furnished, follow them.

Normal maintenance requires little time and expense and prolongs the operating life of the refractory. Preventive maintenance through periodic inspection keeps the operator informed of the condition of the refractory and helps guard against unexpected downtime and major repairs.

Frequent wash coating of refractory surfaces is recommended. A high-temperature bonding, air-dry type of mortar diluted with water to the consistency of light cream is used for this purpose. Recoating intervals vary with operating loads and are best determined by the operator when the heads are opened for inspection.

Maintenance consists of occasional wash coating of the entire liner. Face all joints or cracks by applying high-temperature bonding mortar with a trowel or use your fingertips. This should be done as soon as the cracks are detected. Should segments of the liner become burned out or broken, replace the entire refractory. Any refractory that may





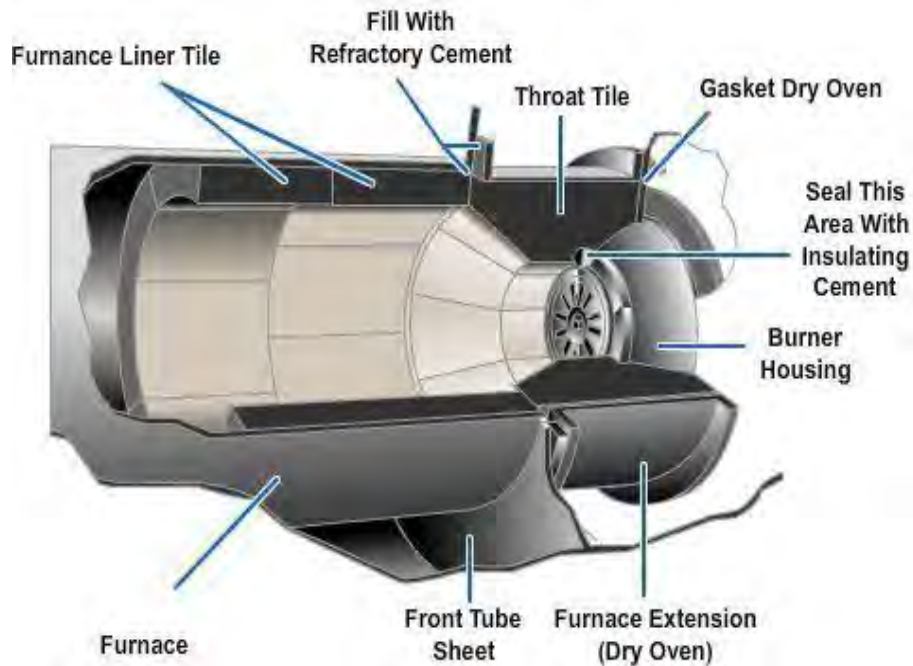
**Figure 9-54 - Front and rear doors open on a gas-fired boiler.**

break out should be removed as soon as detected so it will not fuse to the bottom of the furnace and obstruct the burner flame.

Remove the existing refractory and thoroughly clean that portion of the furnace covered by the liner to remove all old refractory cement or other foreign material to ensure the new liner seats firmly to the steel. Inspect all furnace metal for soundness. There may be metal clips welded in the furnace at the extreme end of the liner. These clips were installed to prevent shifting during original shipment and serve no other purpose. They are tack-welded in place and can be removed when you are installing the new liner. If they are not removed, make sure the liner has clearance between this clip and the end of the refractory to allow for expansion in this direction.

Depending upon the design pressure of the boiler, the furnace may be of the corrugated type. Although it is not necessary to fill in the depressions for convenience of installation, some or all of the corrugation valleys may be filled with insulating cement. The liner tile should be fitted tightly against the crown of the corrugations.

The furnace extension of the boiler or a dry oven is shown in *Figure 9-55*. The throat tile should be installed flush with the front of the oven and should fit tightly against its sides. The two rows of furnace tile should be fitted tightly against the furnace wall. It is not necessary to allow for expansion.



**Figure 9-55 - Furnace liner refractory.**

It is recommended that the tile be dry fitted, match marked, removed, and then reinstalled with the proper amount of refractory cement. Thin joints are desirable. Generally, it is necessary to shave a portion from one or more tiles to obtain a fit. If a fillpiece is required, cut it to fit and install this piece at the bottom of the furnace. It is important to have a good seal between the burner housing and the throat tile. Liberally coat the sealing area with an insulating pulp cement or equivalent mixed with water before swinging the burner housing into place.

The rear door is a steel shell containing horizontal baffle tiles and lined with insulation material and a castable refractory (*Figure 9-54*).

Burned or discolored paint on the outer surface of the door does not necessarily indicate refractory trouble but may be an indication of other conditions such as the following:

- Leaking gaskets
- Improper seal
- Door-retaining bolts insufficiently or unevenly tightened
- Air line to the rear sight tube is blocked or loose
- Repainted with other than heat-resistant paint

Therefore, before you assume the refractory requires re-working, check the following:

- Condition of the tadpole gasket
- Condition of the insulating cement protecting the tadpole gasket.
- Horizontal baffle tile for large cracks, breaks, chipped corners, and so forth

- Cracks in the castable refractory at the ends of the baffle tile
- Tightness of door bolts
- Air line to the sight tube to ensure it is clear and all connections are tight. If necessary, blow it clear with an air hose.

It is normal for refractories exposed to hot gases to develop thin "hairline" cracks. This by no means indicates improper design or workmanship. Since refractory materials expand and contract to some degree with changes in temperature, they should be expected to show minor cracks because of contraction when examined at low temperature. Cracks up to approximately 1/8 inch across may be expected to close at high temperature. If there are any cracks that are relatively large (1/8-inch to 1/4-inch width), clean and fill them with high-temperature bonding mortar. Any gap that shows between the castable refractory and the baffle tile should be filled in a similar fashion.

After opening the rear door, clean off the flange surface of the door with a scraper or wire brush. Clean the surface of the refractory carefully with a fiber brush to avoid damaging the surface. Clean the mating surfaces of the baffle tile and the boiler shell. Remove all dried-out sealing material. Wash coat the lower half of the rear door refractory before closing it. The upper half of the door contains a lightweight insulating material similar to that used in the inner door. A thin wash coat mixture applied gently with a brush is helpful in maintaining a hard surface.

The front inner door is lined with a lightweight castable insulation material. Thin "hairline" cracks may develop after a period of time; however, these cracks generally tend to close because of expansion when the boiler is fired. Here again, a thin wash coat mixture is helpful in maintaining a hard surface. Minor repairs can be accomplished by enlarging or cutting out affected areas, making certain they are clean, and then patching as required.

Should the entire installation require replacement, remove existing material and clean to the bare metal. Inspect the retaining pins and replace if necessary. Reinforcing wire suitably attached may also be used. The recommended insulation is known as Vee Block Mix and is available in 50-pound bags. Mix the material with water to a troweling consistency. Mixing should be completely uniform with no portion either wetter or drier than another. Trowel this mixture into any areas that are being patched. If replacing complete insulation, begin at the bottom of the door and apply the mixture to a thickness equal to the protecting shroud. With a trowel, apply the mixture horizontally back and forth across the door in layers until the required thickness is reached. Allow the mixture to air-dry as long as possible. If immediate use of the boiler is required, fire as slowly as possible to avoid rapid drying of the material.

Whenever the front or rear door is opened for inspection, the head gasket should be checked for hardening and brittleness. Doubtful gaskets should be replaced. Coat the gasket with an oil and graphite mixture before closing the door. Make certain all gaskets retaining rivets are in place. The flange of the door should be clean and free of any hardened cement, scale, and so forth. Check the condition of the rope gasket used as a baffle seal. Replace if necessary. If the rope is in good condition, liberally coat it with an insulating pulp before closing. Make sure the rope is properly positioned.

If it is necessary to replace the rope, wire brush the tube sheet area to remove all of the old sealing material. Place a new piece of 1 1/2-inch-diameter rope gasket on the lip of the baffle tile. Hold it in place with furnace cement or an adhesive.

### NOTE

Earlier models have several steel bar segments tack-welded across the tube sheet to serve as a gasket retainer for 5/8-inch-diameter rope. It is suggested that these bars are removed and 1 1/2-inch-diameter rope be used.

Generously apply a seal, consisting of a pulp mixture of insulating cement and water, around the entire rear door circumference. Place the pulp around the inside diameter of the head gasket. Also coat the tube sheet area adjacent to the baffle tile. When the door is closed, the pulp compresses to protect the tadpole gasket and to form a seal between the refractory surface and the tube sheet. The insulating pulp seal is not needed or used on the front head. Make sure the gaskets are in position when closing.

When you are closing the door, bolts should be snug and tightened evenly to avoid cocking the door and damaging the gasket. Start tightening at the top center bolt and alternate between the top center bolt and the bottom center bolt until both are drawn-up tight. Do not over-tighten. Continue the tightening sequence along top and bottom, tightening the bolts alternately until the door is secured and gas-tight. After the boiler is back in operation, retighten the bolts to compensate for any expansion.

### NOTE

Proper sealing of the doors is essential to avoid leakage of combustion gases and loss of heat and operating efficiency.

## 9.4.0 Boiler Operation

The operation of a boiler consists of seven major phases: (1) pre-watch assumption checks, (2) pre-operating checks, (3) lining up of systems, (4) operating procedures, (5) operating checks, (6) securing procedures, and (7) boiler emergencies.

### 9.4.1 Pre-Watch Assumption Checks

The pre-watch assumption checks are often neglected by boiler watch standers. Before you assume the responsibility of a boiler watch stander, you must complete specified checking procedures to ensure that the equipment in service is in sound operating condition and is functioning satisfactorily. When the watch is relieved, the watch stander coming on duty inspects the instrument readings and charts, visually inspects all equipment, and exchanges information with off-going watch standers. Oncoming watch standers should complete the following inspections and tests before assuming duty:

- Visually inspect the setting and casting.
- Observe the furnace and firing conditions.
- Inspect the charts, logs, controls, and so forth on equipment performance during previous watch.
- Inspect the fans, dampers, damper drives, and other driven auxiliaries.
- Test the water columns and gauge glasses.
- Obtain information from the watch standers on duty on the boiler operating condition and any unusual event or trouble that occurred during the previous watch.

Immediately after accepting the operational responsibility, you should make a complete inspection of all auxiliary equipment as follows:

- Inspect all electric motor drives for abnormal temperature, condition of bearings, and so forth.
- Inspect the fan and pump bearings for overheating and adequacy of lubrication.
- Visually inspect the boiler and all associated equipment; listen for unusual sounds, friction, vibration, and other abnormal conditions.
- Inspect the burners, fuel supply, pilot systems, and other fuel supply components.
- Review the log sheets to obtain information on past operating conditions and unusual events.

### 9.4.2 Pre-Operating Checks

The pre-operating checks should be completed before lining up and lighting off a boiler. These checks are performed to ensure that the plant and associated equipment are in a safe and efficient operable condition. The major pre-operating procedures applicable to boilers in general, as well as additional procedures for gas-fired and oil-fired boilers, are shown in *Tables 9-4, 9-5, and 9-6* below.

**Table 9-4 - Pre-operating checks for boilers.**

Equipment	Check/Action
Boiler room	Remove rags, paint cans, oil spots from deck.
	Stow tools and equipment.
Furnace/Gas passages	Must clean and clear; all doors must fit tight.
	Must be in good repair and purged.
	No oil/tools in combustion chamber.
Valves	Good operating condition.
	Missing/broken handwheels or bent stems.
Piping	Inspect piping for leaks.
	Check for proper support.
Electrical systems	Oil-soaked or frayed wiring.
	Damaged or loose conduit.
	Improperly secured control boxes.
Guards	Tight and in proper position.
Water gauge glass	Well lighted and not stained.

**Table 9-5 - Additional pre-operating checks for gas-fired boilers.**

Equipment	Checks
Pilot and main gas cock	Operate smoothly.
Copper tubing	Has no restrictions, such as kinks or flat spots.
Air shutters	Operate freely.
	Linkage must not have too much loose motion.
Burner and main gas valve	Must be firmly supported.
Boiler room	Has no free gas. Ventilate if present and test all piping with soap solution.

**Table 9-6 - Additional pre-operating checks for oil-fired boilers.**

Equipment	Checks
Strainers	Inspect and clean.
Burners	Must be clean.
	Nozzle must be clean.
	Inspect and test electrodes.
	Check all fittings for leaks.
	Check operation of burner safety switch.
Oil system	Inspect for leaks, and repair.

### 9.4.3 Lining Up Systems

After you have completed the pre-operating checks, your next job is to line up the boiler systems. The procedure used in lining up boiler systems (fuel, water, steam, and electrical) vary with different types and kinds of boilers. Always follow the manufacturer's instructions for the boiler being used. Before lining up a boiler, complete the following basic tasks:

1. Fuel oil
  - a. Measure with a stick or gauge.
  - b. See that the proper valves are open.
  - c. Remove any excess accumulation of water in the tank.
2. Gas
  - a. Check the pressure.
  - b. Check for leaks.

3. Gas-fired unit
  - a. Check and regulate the water level and line up the feed system.
  - b. Examine the burner, control valves, and safety shutouts for proper working condition before lighting off.
  - c. Purge air out of the gas lines by external vents before lighting off.
  - d. Check the draft devices and purge the combustion chamber.
  - e. Light the pilot and set the flame.
  - f. Open the main gas cock.
  - g. Close the burner controls switches to light the burner.
  - h. Maintain the fuel-air ratio for complete combustion.
4. Oil-fired unit
  - a. Check and regulate the water level. Line up the feedwater system. Check the operation of the feed pump.
  - b. Line up the fuel oil system.
  - c. Purge the combustion chamber.
  - d. Close the burner control switch; if automatic, the burner should light off.
  - e. Should ignition fail, the furnace must be purged before a second attempt is made.
  - f. Do not allow oil to impinge on brickwork or part of the boiler.
  - g. Maintain the proper air-fuel ratio.

In general, the basic lighting off procedures for most boilers are as follows:

1. Close the following valves:
  - a. All blowdown valves and boiler drains
  - b. Chemical feed valves
  - c. Boiler non-return
  - d. Main steam stops
  - e. Soot blower header (steam system) and all soot blowers
  - f. All burner fuel valves
  - g. Water column and feedwater regulator drains
  - h. Auxiliary valves, as necessary
2. Open the following valves:
  - a. Vent valves on boiler drums and super heaters
  - b. Super heater drain valves
  - c. Recirculating line valves in economizer, if so fitted
  - d. Feedwater stop and check
  - e. Drum steam gauge connection
  - f. Water column gauge connections

- g. Water column gauge glass valves
  - h. Auxiliary valves, as necessary
3. Start filling the boiler with properly treated water at a temperature close to the temperature of the pressure parts. The temperature difference should not be greater than 50°F to avoid severe temperature stresses. Fill the boiler to level just below the middle of the glass on the water column.
  4. Close the induced draft fan dampers (or other flue gas control dampers).
  5. Start the induced draft fan.
  6. Close the forced draft fan dampers (or other air control dampers).
  7. Start the forced draft fan.
  8. Start the air heater rotor if a regenerative type of air heater is installed.
  9. Light off the boiler under the manufacturer's instructions and maintain a firing rate so the water temperature in the boiler is raised 100°F per hour until operating pressure is reached. On new boilers, check expansion movement to see that no binding or interference occurs.
  10. When burning oil, prevent incomplete combustion in the furnace: Unburned oil is deposited on the cooler surfaces in the back of the unit, such as the economizer and air heater, and this creates a potentially dangerous condition.
  11. When the steam drum reaches about 25 psig, close the vent valves on the boiler drum. Check the steam pressure gauge now to be sure that it is registering.
  12. Ease up on the stem of the main steam stop valve to prevent any serious expansion stresses. If there is no steam on either side of the main steam stop valve, gently lift and reseal it to make sure that it is not stuck. Open the drain valve on the boiler side of the main steam stop valve.
  13. Observe the water level carefully to ensure that no water is carried over into the super heater. Maintain a normal water level in the drum by blowing down or feeding water as may be required.
  14. Operate the vent and drain valves in the super heater headers and economizer by following the manufacturer's instructions. In general, drain valves in the super heater inlet header are closed first, followed by the drains in the super heater outlet header. In any case, the super heater outlet header drain and vent valves must not be completely closed until enough steam flow through the boiler outlet valve is assured.
  15. Check for leaking gasket joints. If a leaking gasket is discovered, shut down the boiler and tighten the joints.
  16. If the gasket still leaks, drop the pressure again, replace the gasket, and repeat the lighting off sequence.

Before cutting in the boiler, proceed as follows:

1. Open all drain valves between the boiler and the header, especially the drains between the boiler and the two stop valves.
2. Warm up the steam line between the boiler and the header by back feed through the drip line or by means of the bypass valve.



3. When the steam line is thoroughly heated and at header pressure, open the bypass valve.
4. When the boiler pressure almost reaches line pressure, open the bypass line around the main steam stop valve to equalize pressures and temperatures in the piping; then slowly open the main steam stop valve. As the boiler reaches line pressure and is actually steaming, slowly raise the non-return valve stem to the full open position.
5. After the boiler is on line, close all super heater drains.
6. Inspect the entire boiler, and close any drain valves that are not discharging condensate.
7. Close the economizer-recirculating valve when an adequate continuous feedwater flow is established.
8. Close the drain valve at the non-return valve.
9. Close the bypass valve around the non-return valve.
10. A boiler with a pendant (non-drainable) super heater has a slightly different operation. Super heaters of this type trap condensate in the loops that must be boiled off before the firing rate can be increased and the steam flow started.
11. Maintain a constant firing rate. The strength of thick steam drums may be impaired by excessive temperature differentials between the top and the bottom of the drum if the proper firing rate is not maintained. Tubes may start leaking at rolled seats and the super heater tubes may overheat.
12. On boilers generating saturated steam, follow the above instructions for removing air and condensate.

#### **9.4.4 Operating Procedures**

Success in operating boilers depends largely upon the operator's performance. No fixed set of rules can be established to fit all conditions. Consequently, the operator must see and interpret all prevailing operating conditions and, if necessary, take action to control, modify, or correct them. To be able to do this, the operator must be thoroughly familiar with the characteristics and standard operating procedures for the boiler for which the operator is responsible. This section acquaints you with some of the basic operating procedures that generally apply to most, if not all, boilers you will be assigned to operate. For specific operating instructions, consult the manufacturer's manual for the boiler concerned.

##### **9.4.4.1 Normal Operation**

During normal operation of boilers, the operators have two major responsibilities. The first is to maintain proper water level at all times. If the water level is too low, tubes may overheat, blister, and rupture. If water level is too high, carry-over of water to the super heater tubes may damage the super heater elements and the turbine. The second is to prevent loss of ignition when burning fuel is in suspension. Maintain safe and efficient combustion conditions in the furnace and correct fuel-air ratios.

##### **9.4.4.2 Blowdown**

Establish definite intervals for blowing down the boiler, depending on the type of operation and chemical analysis of the boiler water. During regular operation, never

blow down economizers or water-cooled furnace walls. Blowdown valves on this type of equipment serve only as drain valves.

Blowdown should be at reduced or moderate rates of steam for low point drains or blowdown valves. When the water glass is not in full view of the operator blowing down a boiler, another operator should be temporarily assigned to observe the water glass and signal the operator handling the valves. For control of water conditions when working, use continuous blowdown to maintain the proper concentration at all times and to prevent blowing down large quantities of water while the boiler is operating at a high capacity.

#### **9.4.4.3 Boiler Makeup Water**

Use only properly treated water for makeup, and maintain the boiler water conditions as specified in water treatment instructions. Make an accurate water analysis at specified intervals. Carefully control the blowdown and the addition of treatment chemicals to meet the manufacturer's specifications.

#### **9.4.4.5 Soot Removal**

Remove soot from hoppers and pits at definitely established intervals, as necessary.

#### **9.4.4.6 Instrument Readings**

Establish definite intervals for observing and recording the readings on all important instruments and controls. Be sure you obtain accurate readings and see that the readings are recorded properly on the log sheet or other required record.

#### **9.4.5 Operating Checks**

To help ensure efficient operation of the boiler, operators should ensure that proper operating checks are done during boiler operations. Operating checks, as shown in *Table 9-7*, apply to most, if not all boilers.

**Table 9-7 - Operational checks for boilers.**

Equipment	Action/Check
Water level	Check frequently; water expands during the heating up period.
Main steam stop bypass (if installed)	Open if the boiler is to be cut in on a coldline.
	Main steam stop can be opened when there is no other boiler on the same steamline.
Air cock	Close after steam has formed and has blown all air from the boiler.
Steam pressure	Raise slowly, usually 1/2 to 2 1/2 hours, depending upon type and size.
	Temperature of water should be raised at a rate of 100°F per hour.
Safety valve	Manually lifts when pressure is at least 75% of the valve setting.
	Make sure valves reseal properly; if valves fail to reseal, lift them a second time.
Boiler feedwater	Commence feeding boiler.
Firing	Gas: Maintain ignition; maintain air-fuel ratio; there should be no soot formation.
	Oil: Maintain ignition; observe flame and adjust dampers; check accuracy by flue-gas analysis.
Water level	Blow down gauge glass and water column.
	Keep at proper level.
	Determine true level of water frequently.
Boiler blowdown	Watch and monitor gauge glass.
	Frequency depends on water tests.
Cutting in boiler	If closed, open main steam stop valve.

Keys to efficient boiler operation and performance are as follows:

1. Flue-gas temperature
  - a. Keep the temperature low.
  - b. Temperature should be about 150 degrees higher than temperature of steam produced.
2. Flue-gas analysis
  - a. Take periodically.

- b. Maintain proper CO<sup>2</sup> level for fuel used.
- 3. Flame
  - a. Should be long and lazy.
  - b. Must not enter the tubes.
  - c. Should not be dark and smoky.
  - d. Have a light brown haze from stack, except gas.
  - e. When the fuel is oil, have a yellow flame with dark or almost smoky tips.
- 4. Draft
  - a. Usually 0.03 to 0.06 inches of water.
  - b. Check the manufacturer's recommendations.
- 5. Makeup feed
  - a. Maintain low rate.
  - b. Avoid excessive boiler blowdown.
- 6. Insulation
  - a. Ensure boiler and lines are well insulated.
- 7. Water treatment
  - a. Carry out prescribed treatment of boiler water.

#### **9.4.6 Securing Procedures**

The recommended procedures for securing boilers are as follows:

1. Reduce the load on the boiler slowly, cutting out the fuel supply by proper operation of the fuel-burning equipment.
2. Maintain normal water level.
3. When the boiler load is reduced to about 20% of rating, change the combustion control and the feedwater control to manual operation.
4. Before securing the final fuel burner, open the drain valves at the steam and non-return valve and the drain valve on the super heater outlet header. Be sure the bypass valve around the non-return valve is closed.
5. Secure the final fuel burner when the load has been reduced sufficiently.
6. Continue operating the draft fans until the boiler and the furnace have been completely purged.
7. Shut down the draft fans.
8. Close the dampers, including the air heater and super heater bypass dampers, when provided.
9. Follow the manufacturer's instructions for the rate of cooling the boiler. A thermal strain may occur if the change is too fast.
10. When the boiler pressure has started to drop, close the steam stop and non-return valve.
11. When the boiler no longer requires any feed and the non-return valve is closed, open the valve in the recirculating connection of the economizer, if provided.

12. Let the boiler pressure drop by relieving steam through the super heater drain valve and the drain valve at the non-return valve. If the boiler is losing pressure at a rate faster than specified by the manufacturer, throttle the drain valves as necessary to get the proper rate. Do not close the valves completely
13. When the drum pressure drops to 25 psig, open the drum vent valves.
14. If a regenerative type of air heater is used, the rotor may be stopped when the boiler exit gas temperature is reduced to 200°F.
15. The boiler can be emptied when the temperature of the boiler is below 200°F. Before sending someone into any part of the boiler, close and properly tag all controls, valves, and drains or blow down valves connected with similar parts of other units under pressure at the time. This move prevents any steam or hot water from entering the unit. The tags are to be removed only by the authorized person who tagged out the boiler and must remain in place until the work is completed. Ventilate the boiler thoroughly and station a person outside. Inside, use only low voltage portable lamps provided with suitable insulation and guards. Even 110 volts can kill under the conduction conditions inside a boiler. All portable electrical equipment should be grounded; electric extension cords should be well insulated, designed to withstand rough usage, and maintained in good condition.

#### **9.4.7 Boiler Emergencies**

Typical emergency situations encountered with the operation of boilers are (1) low water, (2) high water, (3) serious tube failure, (4) flarebacks, (5) minor tube failure, and (6) broken gauge glass. *Table 9-8*, lists the safe procedures to follow.

**Table 9-8 - Procedures for Boiler Emergencies.**

EMERGENCY	TASK	KEY POINTS
Emergency One: Low water condition indicated by no water level in the gauge glass.	Secure the boiler; secure electrical switches, steam stop, and feed stop. Provide water level by opening try cocks. Cool the boiler until the water temperature is 200°F. Secure all sources of draft. Check controls. Find out the cause for failure. Correct the trouble. After correction, add water to correct water level.	Do NOT add water to the boiler to raise the water level in the gauge glass column. Stay away from the discharge. Do not force cool.
Emergency Two: High water condition indicated by gauge glass full of water.	Prove water level by opening the try cocks. Blowdown the boiler by opening the blowdown valves. Find cause of failure. Correct the trouble. Secure the boiler if pump controls operate improperly.	Stay away from discharge. Check blowdown pit. Watch the gauge glass until normal level is reached. If control operates properly, continue to operate the boiler.
Emergency Three: Serious tube failure making it impossible to maintain water level.	Secure the boiler by securing the electrical, steam, and fired systems. Add water to the boiler until the ruptured tube level is reached and the boiler is cooled to a temperature of 200°F. Open boiler to replace the tube.	For large boilers: Water should be fed to the boiler until properly cooled. Mark the gauge glass if within its range. Observe level by whatever means available.
Emergency Four: Flareback caused by an explosion within the combustion chamber.	Secure the boiler. Find the cause of flareback and correct. Check for sufficient fuel and type of fuel contamination. Check the burner.	Ensure that a slug of water did not interrupt flame with a re-fire before pre-purge.
Emergency Five: Minor tube failures indicated by trouble maintaining water level under normal steam demand.	Secure the boiler if it is possible to remove it from the line for sufficient time to make necessary repairs. Secure electrical switches. Open the steam stop and feed stop if additional water is not needed.	If unable to secure boiler because of steaming requirements and you can maintain the water level, continue to operate. If unable to maintain the water level and/or supply, secure the boiler.
Emergency Six: Broken gauge glass on water column.	Secure top and bottom valves. Replace gauge glass. Use chains to prevent injury to personnel.	Boiler may be kept on line. Check the boiler water level by using the try cocks.

### 9.4.8 Boiler Operating Logs

The main purpose of boiler operating logs is to record continuous data on boiler plant performance. Logs become a source of information for analyzing the operation of the boiler for maintenance and repair. The daily operating log sheets provide the basic information around which maintenance programs are developed. The log is arranged for use over a 24-hour period divided into three 8-hour shifts. Log sheets vary among different activities, but you should have no difficulty in making log entries once you

understand what information is required. The types of information to be entered in the appropriate column of the log are as follows:

- Steam pressure. Based on steam gauge readings and indicates the performance of the boiler.
- Steam flow. Actual output of the plant, in pounds per hour, to obtain steam flow. The data from these entries are used to determine the number of boilers to operate for greatest efficiency.
- Feedwater heater pressure. Indicates whether the proper deaerating temperature can be maintained in the heater.
- Feedwater heater temperature. Shows the effectiveness of the feedwater heater. A drop in steam-supply pressure or insufficient venting may cause low heater temperature.
- Feed pump pressure. Indicates the effectiveness of the boiler feed pumps. If the feedwater supply fails, the pressure reading enables the operator to determine whether the trouble is in the feed pumps. Pumps are defective when the feed pump pressure reading is below normal.
- Last-pass draft. Indicates the actual draft produced by the stack or the induced-draft fan. A decrease in the last-pass draft with other conditions constant indicates leaking baffles. An increase shows gas passages are becoming clogged.
- Percent CO<sub>2</sub> flue gas. This value is a measure of relative quantities of air supplied with fuel. It is kept at a value that has been established as most satisfactory for the plant, fuel, firing rate, and other related factors. In plants not equipped with CO<sub>2</sub>-recording meters, this value is determined with a hand gas analyzer.
- Flue gas temperature. Shows the quantity of heat leaving the boiler with flue gases. This heat represents a direct energy loss in fuel. Dirty heating surfaces or leakage of baffles causes high flue gas temperatures. Excessive fouling of firesides of boilers increases draft loss, while leaking baffles decrease draft loss. Either condition raises the temperature of flue gas above normal.
- Fuel. Fuel oil quantities are determined by the use of a measuring stick and tables supplied with a given tank. Some tanks are equipped with gauges to show the fuel volume. Always determine the quantity of fuel used, as this represents a major operating cost.
- Outside temperature. The load on a heating plant is greatly influenced by outside temperature. Record this temperature for comparison with steam generated and fuel used. These comparative values are useful in finding abnormal fuel consumption and in estimating future requirements.
- Makeup water. Record the quantity of makeup water used to enable the operator to note an abnormal increase before a dangerous condition develops. Return all possible condensate to the boiler plant to save water and chemicals used to treat water.
- Water pressure. Indicates whether water is sufficient.
- Hot-water supply temperature. Insufficiently heated water can cause scaling or deposits in a boiler.

- Water softeners. Where softeners are used, a decrease in the quantity of time used for runs between regeneration indicates either an increase in hardness of incoming water or a deterioration of softening material.
- Total and average. Space is provided for recording the total and average quantities per shift. Steam flowmeter. The steam flowmeter integrator reading at the end of a shift and multiplied by the meter constant gives the quantity of steam generated. Dividing steam generated by fuel burned (gallons of oil) yields a quantity that shows the economy obtained. If a plant does not have a steam flowmeter, pumps can be calibrated for flow and a record kept of their operating time, or condensate and makeup water can be metered.
- Boiler feed pumps in service. Makes it possible to determine operating hours and to ensure that various pumps are used for equal lengths of service.
- Phosphate, caustic soda, and tannin added. Is valuable in keeping the correct boiler water analysis and in determining total chemicals used.
- Remarks. The Remarks column is used to record various types of information for which space is not provided elsewhere on the log sheet. Note irregularities that are found during inspections, dates boilers are drained and washed out, equipment to be checked daily, and so forth.
- Other personnel. Names of personnel responsible for specific tasks and data must be entered on the log sheet, if required.

### **9.5.0 Safety**

In servicing boilers, the need for safety cannot be overemphasized. Much progress has been made over the years in the development of safety devices for boilers. There are still many ways, however, in which serious accidents can happen around boilers. A boiler operator or serviceman who is careless on the job threatens the safety of everyone. Accidents somehow have a way of happening at a moment we least expect. All the more reason, therefore, for constant alertness and close attention to detail. Do not take chances! Be safety conscious!

Some of the major safety precautions to be observed by Utilitiesmen engaged in boiler operation and servicing are presented below.

As protection against toxic or explosive gases, boiler settings must be ventilated completely and tested for toxic or explosive gases before crews are permitted to enter.

The covers of manholes must be removed for ventilation before people enter the drum.

Before anyone enters a steam drum, mud drum, or other waterside enclosure, steam and feed lines connected to the headers under pressure should be isolated by a stop valve and a blank with an open telltale valve in between, or by two stop valves with a telltale valve opened in between.

A ventilating fan should be operating in the drum when someone is working in the boiler. Workers should not be inside the waterside of the boiler when pressure is being applied to test a valve that has not been under pressure.

Workers should wear protective clothing when making boiler water tests.

Boiler settings must be examined daily for external air leaks. Cracks, blisters, or other dangerous conditions in joints, tubes, seams, or blowoff connections are to be reported to your supervisor immediately.



Boilers should also be examined regularly for deposits on their heating surfaces and for grease or other foreign matter in the water. Boilers showing any such faults should be cleared at the first opportunity and should not be used until cleared.

Performing certain adjustments and repairs while pressure is up is prohibited. A complete absence of pressure is to be ensured by opening the air cock or test and water gauge cocks connecting with the steam space before fittings or parts subject to pressure are removed or tightened, and before manhole or handhole plate fittings are loosened on a boiler that has been under pressure.

Combustion control, feed control, and burner, stoker, or similar adjustments are permitted with the boiler steaming, since many adjustments can be made only when pressure is up.

When cleaning operations are performed, workers should wear the proper personal protective equipment. The following requirements apply:

- Hard hats and goggles must be worn.
- When a worker is chopping slag inside a furnace, a respirator must be worn.
- Safety-toed shoes or toe guards must be worn to prevent injuries from falling slag.
- When someone is working inside the furnace, a large warning sign, such as Caution-Man Working Inside, should be placed near the furnace entrance.
- The use of open-flame lights is prohibited in boilers. When cleaning where flammable vapors and gases may be present, workers are to use only explosion-proof portable lamps equipped with heavily insulated three-wire conductors, with one conductor connecting the guard to ground.
- Oil accumulated on furnace bottoms should be cleaned out immediately.
- The fuel-oil suction and discharge strainers should be cleaned at least every 8 hours and more frequently if necessary.
- Condensate pits in boiler rooms should have metal covers. If the pits must be opened for maintenance, adequate guards should be placed around them and warning signs posted.
- Wear goggles with dark lenses, Number 1.5 to 3 shade, and suitable fireproof face shields when working near or looking through furnace doors of boilers in operation.
- When firing a cold boiler, be sure that the air vents are open on the boiler proper and that the drains are open on the super heater; keep these open until steam is liberated from the openings. Super heater vents must remain open until the boiler is on the line.
- Be sure gas-fired and oil-fired boilers, whether manual or automatic, are cleared of combustible gases after each false start.

All semiautomatic (multi-burner) boilers and all fully automatic boilers should be equipped with a manually activated switch for pilot ignition and a control device to prove the pilot flame is on before the main fuel valve is opened. Do NOT use a hand torch to light off a boiler. If a hand torch is applied to a firebox filled with vaporized oil, a severe boiler explosion is likely to occur.

Prevent overheating of boilers equipped with super heaters by firing at a slow rate during the warm-up period and by allowing a small amount of steam to flow through the super heater.

When taking over a watch, blow the water gauges and note the return of the water in the glass. Be certain of the water level at all times. Do NOT be misled by a dirt marking on the gauge that may look like the surface of the water. Do NOT depend entirely upon automatic alarm devices and automatic feedwater regulators.

If the water goes out of sight in the bottom of the gauge glass, kill the fire with the quickest means available; immediately close the steam stop valve, and allow the boiler to cool slowly; then, drain the boiler completely and open it for inspection. Do NOT feed cold water to a boiler that has had low water until the boiler has cooled.

Check the water on steaming boilers by try cocks at least once each watch and before connecting a boiler to the line.

Check safety valves often to be sure they will pop at the correct pressure, as marked on the nameplate. Do NOT break the seal of a safety valve or change its adjustment, unless such action has been authorized. NEVER weight pop valves, relief valves, and so on, to increase the recommended steam pressure for which the boiler is approved.

Do not use oil from a tank in which a lot of water is mixed with oil unless a high suction connection is provided. When an atomizer sputters, shift the suction to the standby tank or another storage tank. A sputtering atomizer indicates water in the oil.

Reduce the fouling of oil heaters by using as few heaters as possible. Recirculate the oil through the used heaters for a short time after securing the burners. Maintain the prescribed fuel-oil temperature; do NOT exceed it.

If a large steam leak occurs in a boiler, shut off the burners, continue to feed water until the fire is out, close the steam stop valve, ease the safety valves, clear the furnace of gases, close the registers, and cool the boiler slowly.

Do NOT tighten a nut, bolt, or pipe thread, nor strike any part, nor attempt other adjustments to parts while the boiler is under steam or air pressure.

Take care to prevent lubricating oil, soap, or other foreign substances from getting into the boiler. Condensate from cleaning vats should be drained to waste and not returned to the boiler.

Close the furnace openings as soon as all fires have been put out and the furnace has been cleared of gases.

At shore installations, the handles on pull chains to boiler water-gauge cocks and water-gauge glass stop valves should be painted the following colors:

Opening water-gauge glass stop valves WHITE

Closing water-gauge glass stop valves RED

Top gauge cock YELLOW

Center gauge cock GREEN

Bottom gauge cock BLUE

Do NOT use water to put out an oil fire in the furnace.

When fires are banked, make certain the draft is enough to carry off flammable gas accumulations.

The following lists contain a number of actions to which you should ALWAYS be alert and a number of actions you should NEVER perform.

### **9.5.1 Safety Precautions**

Always study every conceivable emergency and know exactly what action to take.

Always proceed to proper valves or switches rapidly but without confusion in time of emergency. You can think better walking than running.

Always check the water level in the gauge glass with the gauge cocks at least daily—also at any other time you doubt the accuracy of the glass indication.

Always accompany orders for important operations with a written memorandum. Use a logbook to record every important fact or unusual event.

Always have at least one gauge of water before lighting off. The gauge cocks should check the level.

Always be sure the blowdown valves are closed, and proper vents, water-column valves, and pressure-gauge cocks are open.

Always use the bypass if one is provided. Crack the valve from its seat slightly and await pressure equalization. Then open it slowly.

Always watch the steam gauge closely and be prepared to cut the boiler in, opening the stop valve only when the pressures are nearly equal.

Always lift the valve from its seat by the hand lever when the pressure reaches about three quarters of popping pressure.

Always consult the officer in charge of the plant, your CPO, or other proper superior and accept his/her recommendations before increasing the safety-valve setting.

Never fail to anticipate emergencies. Do not wait until something happens before you start thinking.

Never start work on a new job without tracing every pipeline in the plant and learning the location and purpose of each and every valve regardless of size. Know your job!

Never leave an open blowdown valve unattended when a boiler is under pressure or has a fire in it. Play safe--your memory can fail.

Never give verbal orders for important operations or report such operations verbally with no record. Have something to back you up when needed.

Never light a fire under a boiler without checking all valves. Why take a chance?

Never open a valve under pressure quickly. The sudden change in pressure, or resulting water hammer, may cause piping failure.

Never cut a boiler in on the line unless its pressure is within a few pounds of header pressure. Sudden stressing of a boiler under pressure is dangerous.

Never bring a boiler up to pressure without trying the safety valve. A boiler with its safety valve stuck is the same as playing with dynamite.

Never increase the setting of a safety valve without authority. Serious accidents have occurred from failure to observe this rule.

In case of an oil fire in the boiler room, close the master fuel-oil valve and stop the oil pump.

Other than the above precautions, the following list contains a number of safe practices that you should try to follow in your work. It also contains a number of unsafe practices that you must avoid.

### **9.5.2 Safe Practices**

Always have the valve fitted with a new spring and re-stamped by the manufacturer for changes over 10 percent.

Always keep out loiterers, and place plant operation in the hands of proper persons. A boiler room is not a safe place for a meeting.

Always consult the officer in charge of the plant, your CPO, or other proper superior before making any major repair to a boiler.

Always allow the draft to clear the furnace of gas and dust for several minutes. Change draft conditions slowly.

Always consult someone in authority. Two heads are better than one.

### **9.5.3 Unsafe Practices**

Never allow unauthorized persons to tamper with steam plant equipment. If they don't injure themselves, they may injure you.

Never allow major repairs to a boiler without authorization.

Never attempt to light a burner without venting the furnace until clear. Burns could occur.

Never fail to report unusual behavior of a boiler or other equipment. It may be a warning of danger.

### **9.5.4 Lockout Devices**

A lockout device is a mechanism or arrangement that allows the use of key or combination locks (most commonly padlocks) to hold a switch lever or valve handle in the OFF position. Some switches and valves have lockout devices built in; others must be changed before locks can be used. As a UT, you may use lockout devices when working on potentially hazardous equipment, such as high-pressure steam lines, electrically operated equipment, and boilers. The use of a lockout device is a great advantage since the machine or equipment cannot be started up, energized, or activated while you are working on it. The examples in *Figure 9-56* will give you an idea of how devices may be used in locking out valves.



#### LOCKING OUT VALVES

Valves should accept locks or lockout adapters and should automatically bleed downstream pressure. Pneumatic valve at right meets these criteria.

Valve above is not designed to be locked out, so a lockout device (Wire Cable) has been improvised.

When equipment uses several power sources, each must be locked out. Combination disconnect valve at left facilitates the job.

**Figure 9-56 - Locking out valves.**

#### 9.5.4.1 Multiple Lock Adapter

It is often an advantage for a lockout device to accommodate more than one padlock. In this way, when you are working on a machine or an item of equipment with the valve locked off, another person can come along and use the padlock to do other hazardous work on the machine or equipment at the same time, rather than wait until you are finished.

Since most controls are not designed to accommodate more than one padlock at a time, multiple lock adapters, called lockout clamps or tongs, may be used (*Figure 9-57*). These adapters should be permanently chained to the control, or alternately, issued to all people with padlocks.



**Figure 9-57 - Multiple lock adapters.**

#### 9.5.4.2 Locks

Perhaps you are wondering what kind of lock should be used-key or combination. What person should have a lock? Who should be in possession of the keys or combinations? How should the lock be identified? The answers to these questions may vary from one activity to another, but some guidelines are as follows:

1. Key-operated padlocks are more commonly used than combination locks. Supervisors can control keys easier than combinations.
2. Locks should be issued to every person who works on closed-down equipment. No key (or combination) should fit more than one lock.
3. Only one key should be issued to a person authorized to use the lock. At some activities, the supervisor may be permitted to maintain a duplicate set of keys for locks under his/her control, or a master key. Some activities, however, may have only one lock-one key. In an emergency, bolt cutters may be used to remove a lock. As a word of caution: Keys and locks should never be loaned.

4. Locks should identify the user by name, rate, and shop. This information can be stamped into the lock case, stenciled on, or carried on a metal tag fixed to the shackle of the lock. In addition, locks may be color coded to identify the skill or rating of the lock folder, such as UT, Construction Electrician (CE), or Construction Mechanic (CM). The colors could also follow the hard hat color code.

#### 9.5.4.3 Lockout Procedures

If locks, lockout devices, and multiple lock adapters are to be effective, they must be used properly on every occasion where they are needed. Make sure that you follow the steps of the lockout procedure below.

1. Before any equipment is locked out, there should be agreement as to the specific machine or unit to be taken out of operation. The supervisor should oversee lockout procedures.
2. Turn off the point-of-operation controls. (Remember that disconnect switches should never be pulled while under load because of the possibility of arcing or even explosion.)
3. See that the main power controls (switch, breaker, or valve) are turned OFF. Where electrical voltages are involved, do NOT attempt this yourself but have it done by a CE.
4. After the switch has been opened or the valve closed, the person who will be doing the work should snap the locks on the control lever or multiple lock adapter. At this point, tag the switch, valve, or device being locked. Tags should indicate the type of work being done, approximately how long the job will take, and the name of the supervisor.
5. Try the disconnect or valve to make sure it cannot be moved to ON.
6. Try the machine controls as a test to ensure the main controls are really off.
7. As each person completes work, only that person should remove the lock and supplemental tag. The person removing the last lock should notify the supervisor that the work is finished and the equipment is ready to be placed back in operation.

#### Test your Knowledge (Select the Correct Response)

5. What color should the pull chain handle be painted for the center gauge cock?
  - A. White
  - B. Red
  - C. Yellow
  - D. Green

#### Summary

As a UT, you will be involved with the installation, operation, and maintenance of various types of boilers such as water-tube or fire-tube. You must understand the basic theory and operation of steam generation. You must have the understanding of the purpose, use, interface, and control of boiler fittings, automatic control mechanisms, instruments and meters associated with boilers. You also must be capable of identifying

and correcting water impurities problems associated with boilers by utilizing various water treatment and boiler cleaning procedures.

You will also be involved in the maintenance and repair of auxiliary equipment, boiler tubes, and refractories. As a UT, you will be responsible for the detailed boiler operations including pre-watch tours, pre-operating checks, operating procedures, operating checks, securing procedures, and the recording and upkeep of boiler operating logs. You will also be responsible for the immediate and effective casualty control over any type of boiler emergencies encountered. You must know and understand the numerous safe and unsafe practices associated with boiler operations including the use of local lockout procedures. Remember, you will be the first line of defense in the prevention against accidents and mishaps from occurring.



## **Trade Terms Introduced in this Chapter**

<b>British Thermal Unit (BTU)</b>	The amount of heat required to raise the temperature of 1 lb. of water 1°F.
<b>Saturated</b>	Soaked, impregnated, or imbued thoroughly; charged thoroughly or completely.
<b>Baffles</b>	An artificial obstruction for checking or deflecting the flow of gases.
<b>Water leg</b>	The tubing in which water flows through a boiler.
<b>Sediment</b>	The matter that settles to the bottom of a liquid.
<b>Flue</b>	Any duct or passage for air or gas.
<b>Bellows</b>	A device for producing a strong current of air, consisting of a chamber that can be expanded to draw in air through a valve and contracted to expel it through a tube.
<b>Ferrous</b>	Of or containing iron.
<b>Scale</b>	A coating or incrustation, as on the inside of a boiler, formed by the precipitation of salts from the water.
<b>Deaeration</b>	To remove bubbles from a liquid, as boiler feedwater, as by mechanical agitation in a vacuum or by heating at atmospheric pressure.
<b>Dispersant</b>	A liquid or gas added to a mixture to promote dispersion or to maintain dispersed particles in suspension.
<b>Precipitates</b>	A solid that is separated from a solution by chemical or physical changes.
<b>Reagents</b>	A substance used in a chemical reaction to detect, measure, examine, or produce other substances.
<b>Causticity</b>	Capable of burning, corroding, dissolving, or eating away by chemical action.
<b>Slag</b>	The glassy mass left as a residue by the smelting of metallic ore.

## **Additional Resources and References**

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

*Basic Machines*, NAVEDTRA 12199, Naval Education and Training Professional Development and Technology Center, Pensacola, FL, 1994.

*OSHA Regulations (Standards - 29 CFR)*

*Naval Construction Force Manual, NAVFAC P-315*, Naval Facilities Engineering Command, Washington, D.C., 1985.

*Facilities Planning Guide*, NAVFAC P-437, Volumes 1 and 2, Naval Facilities Engineering Command, Alexandria, VA, 1982.

*Fluid Power*, NAVEDTRA 12964, Naval Education and Training Professional Development and Technology Center, Pensacola, FL, 1994.

*National Standard Plumbing Code-Illustrated*, National Association of Plumbing-Heating-Cooling Contractors, Washington, DC, 2006.

*Safety and Health Requirements Manual*, EM-385-1-1, Department of the Army, U.S. Army Corps of Engineers, Washington, DC, 1992.

MIL-STD-17-1, Mechanical Symbols

*International Plumbing Code 2009*, International Code Council

*International Mechanical Code 2009*, International Code Council

R. Dodge Woodson, *Plumber's Quick-Reference Manual Tables, Charts, and Calculations*, 1<sup>st</sup> edition, McGraw-Hill, NY, 1996.

*Water Testing Kit, Chemical Agent: M272, Technical Operations Manual, TM 3- 6665-319-10*, Department of the Army, Washington, DC, 1983

*Boiler Care Handbook*, Cleaver-Brooks Division of Aqua-Chem. Inc., Milwaukee, WI, 1985.

COMFIRSTNCDINST 3500.1, Operational Risk Management (ORM).

COMFIRSTNCDINST 5100.2, Naval Construction Force Occupational Safety and Health Program.

UFC 3-430-07, Inspection and Certification of Boilers and Unfired Pressure Vessels.