Generation-Oahu Division
Operator Trainee Training Program

Section 10
BOILER FUNDAMENTALS

OBJECTIVES:

1. Identify the parts of a typical boiler and describe their basic function in successful boiler operation. To include assembly and construction.
2. Discuss the two separate cycles of a typical boiler, waterside and fireside.
3. Describe natural circulation and forced circulation.
4. Describe the basic functions of the superheater, the reheater, the economizer, and the furnace.

Section 10

BOILER FUNDAMENTALS

BOILER FUNDAMENTALS

The steam generator, or boiler, as it is more commonly known, is the largest and most expensive piece of equipment in a plant. The initial step in the energy conversion process takes place in the boiler. The chemical energy in the fuel is converted to heat by the combustion process and this heat is transferred to the water in the boiler, converting it to steam. This section will discuss the basic theoretical considerations in the design of a boiler.

The construction of a typical boiler lends itself to a discussion in two separate parts or cycles. The waterside, which includes all the parts that contain water and/or steam, and the fireside, which includes all the spaces and passages in which combustion takes place and through which the flue gases pass. There is never any contact or mixing between the fluids flowing through each side of the boiler.

BOILER WATERSIDE

It is essential that a continuous flow of water and/or steam be maintained throughout all parts of the boiler during operation. If flow were to cease there would be no way of removing the heat being transferred from the fireside to the waterside and severe overheating of the boiler tubes would result. Flow through the boiler may be natural or forced circulation, as in boilers provided with drums. A forced circulation system has a pump in the closed flow loop between the Boiler Drum and the lower header. The pressure difference created by the pump helps to control the flow rate. All the boilers at Hawaiian Electric (Oahu) are natural circulation boilers.

NATURAL CIRCULATION

Consider the simple boiler circuit shown in Figure 10-1. This boiler consists of a drum at the top, a downcomer, a lower header and water wall tubes that return to the drum. Heat from the fire is transferred to the fluid in the water wall tubes. No heat is added to the fluid in the downcomer and it contains water at essentially saturation temperature. The heat addition in the water wall causes the water to expand and converts or boils some of the water to steam. Conversion of water to steam

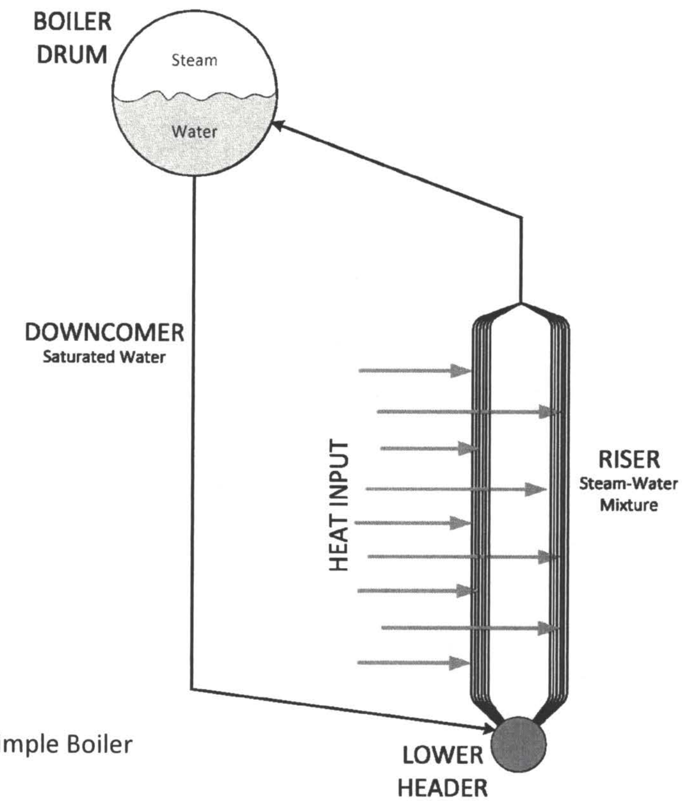

Figure 10-1 Simple Boiler

produces a large volume increase and a corresponding large density decrease.

Under operating conditions the downcomer is filled with water having a fairly high density while the water wall is filled with a water-steam mixture having a much lower density. This difference in density of the two columns times the height of the unit is a measure of the pressure available to cause natural circulation. The pressure produced in this manner must be great enough to overcome the friction losses of the system. There are several factors that influence the magnitude of the force causing natural circulation.

1) The difference in elevation between the drum and the lower headers is directly proportional to the force causing circulation. The higher the boiler the more force available. This is one reason why boilers are so tall.
2) The operating pressure of the boiler also has an important role in determining the force available for circulation. As pressure is increased the difference in specific volume and density between water and steam gets progressively smaller. This fact can be seen by looking at the steam tables shown in Section 2 of this manual.

The steam table data is presented graphically in Figure 10-2. In this figure the distance between the curves is the difference in density between steam and water. As pressure increases the difference in density gets smaller and smaller until at the critical pressure of 3206 psia there is no difference. Boilers operating above this pressure are known as supercritical units and must have forced circulation or forced flow since there is no density difference to cause natural circulation. Natural circulation boilers are normally limited to a maximum pressure of 2700 psia since above this pressure the density difference is too small to provide adequate circulation.

3) The third factor that determines the available circulating force is the rate of heat input to the water wall tubes.

This is basically the same as the firing rate of the boiler. As more heat is added there is a greater rate of steam formation and therefore a lower density in the water wall tubes. This lower density in the water wall tubes causes a greater natural circulation rate. As the firing rate or load on a boiler increases, the circulation rate also increases. This is a very desirable condition from the heat transfer standpoint.

The three factors discussed all contribute to determining the circulating force that is available. This force must be sufficient to overcome the frictional losses resulting from the circulating flow. Under steady conditions the flow will increase until the friction losses exactly balance the circulating force and flow will stabilize at this point. Since a high rate of circulation is desirable, the boiler designer takes care to insure that the friction losses are held to a minimum.

The factors that determine the boiler circulation are the height of the unit, the operating pressure, the heat input rate and

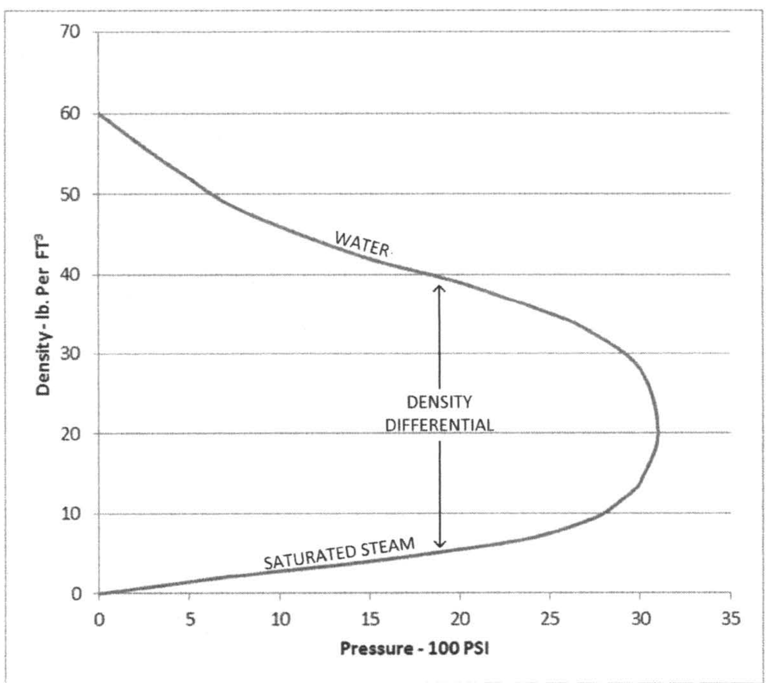

Figure 10-2 Steam-Water Density

the friction losses. Two of these, namely the height and friction losses, are fixed by the design and are beyond the control of the operator. The other two factors, operating pressure and heat input rate, have specified design values but may be operated under other conditions and are then under control of the operator. The two most common conditions under which the boiler may be operated are:

1) chemical boil out following initial installation or acid cleaning and,
2) controlled startup and shutdown operations.

During boil out, the boiler is not supplying any steam, heat input is very low and maximum circulation is required to insure that the chemicals are well mixed and contact all surfaces. To accomplish these purposes, the boil out is performed at reduced pressure where the difference in density between water and steam is much greater. In general the boil out pressure will be between 1/4 and 1/2 of normal operating pressure. It has been found, by experience, that a pressure in this range will produce sufficient circulation even at the low heat input rate.

During a controlled start-up the boiler is in service supplying steam at a pressure much lower than design. The boiler may be operated under these conditions for some time until the silica concentration is reduced sufficiently to allow raising pressure. It would appear that circulation would be quite high under these circumstances since pressure is low and heat input is high. This is not the case and it is necessary to limit the heat input rate at reduced pressures.

In this type of boiling, small steam bubbles are formed on the tube wall and are swept away as fast as they form. This allows the

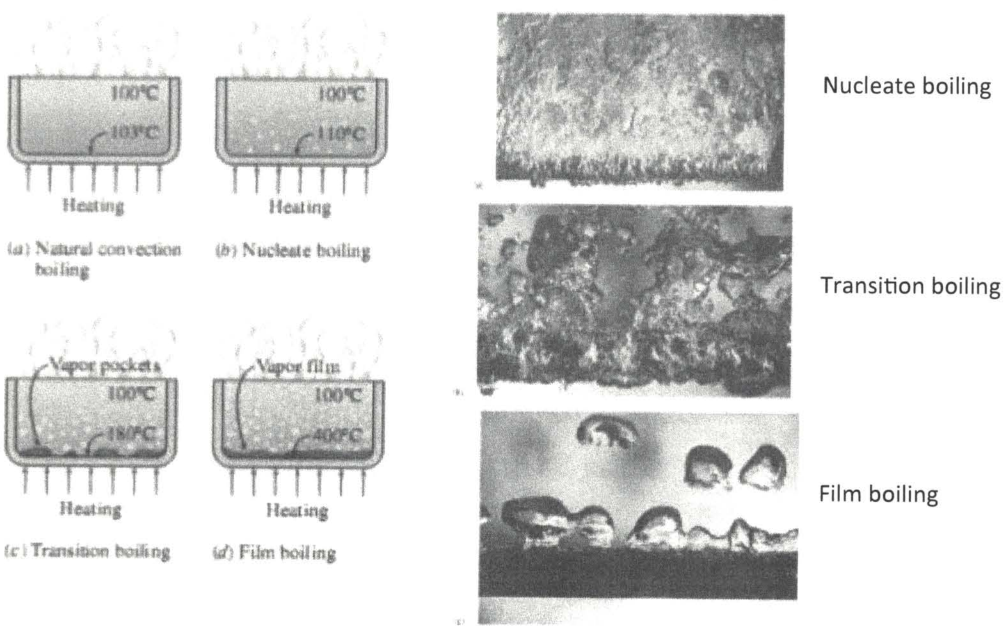

Figure 10.-3—Types of Boiling

water to continually cool the tube surface. If heat input is increased, the steam formation changes to film boiling in which the tube surface is blanketed by steam and is not adequately cooled. This type of operation can result in overheated and ruptured tubes. Film boiling will not occur if the steam flow versus pressure curve is followed. In some of the newer high pressure boilers a design error allowed film boiling to occur under normal operating conditions. In these cases, special tubes with internal rifling were installed. The rifling causes the steam water mixture to have a rotating or swirling motion which moves the steam to the center of the tube and keeps water in contact with the tube surface. The various types of boiling are illustrated in Figure 10-3.

SUPERHEATERS

The initial separation of steam and water occurs as the mixture leaves the riser and enters the drum. The steam bubbles separate at the water level in the drum. The steam bubbles carry some water along with them and several stages of mechanical separators are installed in the drum to remove this moisture. Essentially dry steam leaves the drum near the top and enters the superheater. The superheater is a once through circuit where all the steam that enters it from the drum also leaves it. The superheater usually consists of several separate banks or groups. These are given names such as primary or secondary. In general, the flow is countercurrent, with the steam flowing opposite to the direction of the flue gases. Heat transfer in the superheater is quite critical. A high velocity of flow must be maintained in order to keep the surface steam film thickness to a minimum. Special alloys which maintain their strength at elevated temperatures must be used for superheater tubes. Most boilers have thermocouples installed on the superheater tubes to indicate the metal temperature and insure that temperature limits are not exceeded. Final steam temperature is usually controlled by spraying feedwater into the steam to reduce its temperature. Spraying is accomplished early in the circuit, usually after the primary or first stage superheater. This practice reduces the temperature throughout the rest of the superheater and permits the use of less costly alloys for the tube metal. It is of utmost importance that no contamination of the steam takes place. Contamination can occur from carry-over of water droplets from the drum or from spraying for temperature control with contaminated feedwater. If a condenser tube leak occurs, it may be necessary to reduce load to a point where spraying is not required in order to prevent introducing contamination into the superheater.

There are some special operations which can result in contaminating the superheater if care is not taken. During forced cooling of the boiler, the drum is flooded to equalize temperatures. Care must be taken to insure that the drum is not overfilled and that no drum water is allowed to enter the superheater. A similar situation arises when filling the boiler for a hydrostatic test. The superheater must be filled separately with pure distilled water to insure that contamination does not take place.

When starting up a boiler there is a period of time when there are fires in the boiler and very little steam flow through the superheater. Since steam flow is what cools the superheater tubes a condition where there is no cooling results. It is quite possible to overheat and damage the tubes during this period. To prevent this occurrence, most boilers are provided with start-up furnace probes. These probes contain thermocouples which are connected to indicating or recording instruments in the control room. The probes are installed in the boiler ahead of the superheater. During start-up, the flue gas temperature leaving the furnace area as indicated by the probes should not be allowed to exceed 900°F. If this limit is adhered to it will not be possible to overheat the superheater tubes. The probes should be removed before the unit is on the line or they will be damaged by the increased temperature.

REHEATERS

The construction and operation of the reheater is essentially the same as for the superheater. The flow is usually countercurrent with the reheater arranged in banks or sections similar to the superheater. The major difference is that the reheater is handling steam at much lower pressures.

This permits the use of less expensive alloy metals or the use of larger diameter tubes to produce a lower pressure loss due to friction. The possibility of contaminating the reheater is much lower. The only normal way this can occur is through spraying for reheat temperature control. Reheat sprays are usually a backup reheat temperature control and, as such, are seldom used. The same precautions apply when spraying in the reheater as with the superheater.

ECONOMIZERS

Most boilers are provided with an economizer, the purpose of which is to reclaim low temperature energy from the flue gas and use it to heat the incoming feedwater before it enters the drum. The economizer is a counter-current flow heat exchanger which makes use of relatively small diameter tubes. Friction loss is not important since flow is insured by the feedwater pump. The flue gases have been cooled to a reasonable temperature by the time they enter the economizer section and ordinary carbon steel can be used for these tubes. Heat transfer is usually not a problem in the economizer due to the low temperature of the flue gases and the forced water flow. One exception to this occurs during start-up. At this time there are fires in the boiler, however, there is no flow through the economizer since no water is being added. It is possible to boil the economizer dry and overheat the tubes. To eliminate this possibility most units are provided with an economizer recirculation line. This line connects the economizer to the boiler water walls and permits natural circulation to take place. The recirculation line should be shut off as soon as water is being supplied to the boiler.

BOILER FIRESIDE

Air is supplied to the boiler by forced draft fans which force the air through large ducts to an enclosure on the boiler known as the wind box. The wind box is designed so that it provides essentially equal air pressure at each burner. The wind box is connected to the furnace by openings for each burner. The fuel is supplied to each burner through appropriate connections that penetrate the wind box. Each burner is usually provided with a register which gives the air a swirling motion to assist in mixing with the fuel. The register is also used to adjust or control the amount of air supplied to each burner. Proper setting of the registers is essential for safe and efficient operation of the boiler. The opening between the wind box and the furnace is known as the burner throat and is usually lined with refractory material. The throat aids in heating the air and swirling it for better mixing with the fuel.

FURNACE

Combustion takes place in the volume enclosed by the water walls and known as the furnace. The fuel and air enter the furnace through the burners. In the design of the boiler there are two primary considerations that determine the size of the furnace.

1. The furnace volume must be large enough to permit complete combustion to take place without undue impingement of the flames on the boiler tubes.
2. There must be sufficient water wall surface to insure reasonable values of heat input per unit of area to the tubes.

These considerations generally lead to very large furnace volumes and consequently very high boilers. In some of the larger boilers additional heating surface in the form of furnace division walls is installed to permit using a smaller overall boiler size.

Heat generated in the combustion of fuel appears as sensible and latent heat in the products of combustion. Approximately 50% of the total heat generated is absorbed in the furnace enclosure walls. The primary heat transfer method involved in the furnace is radiation. Approximately 75% of the heat transferred to the furnace walls is by radiation. For this reason the furnace area is known as the radiant section of the boiler. The approximate temperature in the furnace is 3000°F.

CONVECTION SECTION

The flue gases leave the furnace and pass into the convection section of the boiler. This section is so named because most of the heat transfer takes place by the convection method. Located in this section are the superheater, reheater and economizer. These three sections are located in the flue gas space so that the gases pass completely around all the tubes.

The walls which enclose the convection section are generally water walls which combine with the furnace water walls to generate the required steam flow. The flue gas temperature entering the convection section is usually about 2200°F. This temperature is reduced to approximately 700°F when the gas leaves the economizer. At these lower temperatures ash and soot can accumulate on the tube surfaces and restrict heat transfer. This results in much hotter flue gas leaving the economizer and therefore, lesser boiler efficiency. To eliminate this condition the convection section is provided with soot blowers. These blowers remove the accumulated soot and ash and thereby restore normal heat transfer.

AIR PREHEATERS

Practically all boilers are equipped with an air preheater whose function is to reclaim low temperature heat energy from the flue gas by transferring it to the incoming combustion air. Due to the relatively low temperatures involved, the air preheater must have a large surface area for heat transfer. The air preheater may be an integral part of the boiler in which case it is part of the convection section. Older air preheaters are of the tubular design. Most of the newer units have separate rotary regenerative air preheaters which are considered as boiler accessories. The flue gases leaving the air preheater are discharged to atmosphere through the stack.

BOILER CONSTRUCTION

All large boilers, such as those used in steam power plants, are shipped from the manufacturer's plant completely disassembled. The boiler is then put together or erected on the plant site. A large steel framework is erected first and the boiler is then hung or suspended from this structure. In this way the boiler is free to expand downward as it heats up. A large boiler may expand as much as 8 - l0 inches while going from cold to hot. The exterior of the boiler is referred to as the casing and usually consists of a thin layer of sheet metal backed up by 2 - 3 inches of insulation. This insulation keeps radiation to air losses to a minimum.

The furnace and convection sections of the boiler fireside may be operated either at a slight negative pressure (draft) or at a slight positive pressure (pressurized).·When designed for draft, an induced draft fan is provided to remove the products of combustion from the boiler. In this type of unit the boiler casing does not have to be air tight since any leakage will be inward. Air in leakage does result in reduced efficiency, however, it is not a hazardous condition. In the pressurized system no induced draft fan is provided and the entire boiler fireside is under a positive pressure. In this case the boiler casing must be completely air tight since leakage will consist of hot flue gas leaving the boiler which can result in damage to equipment and present a hazard to personnel. See Figure 10-4 and Figure 10-5 for examples of the furnaces.

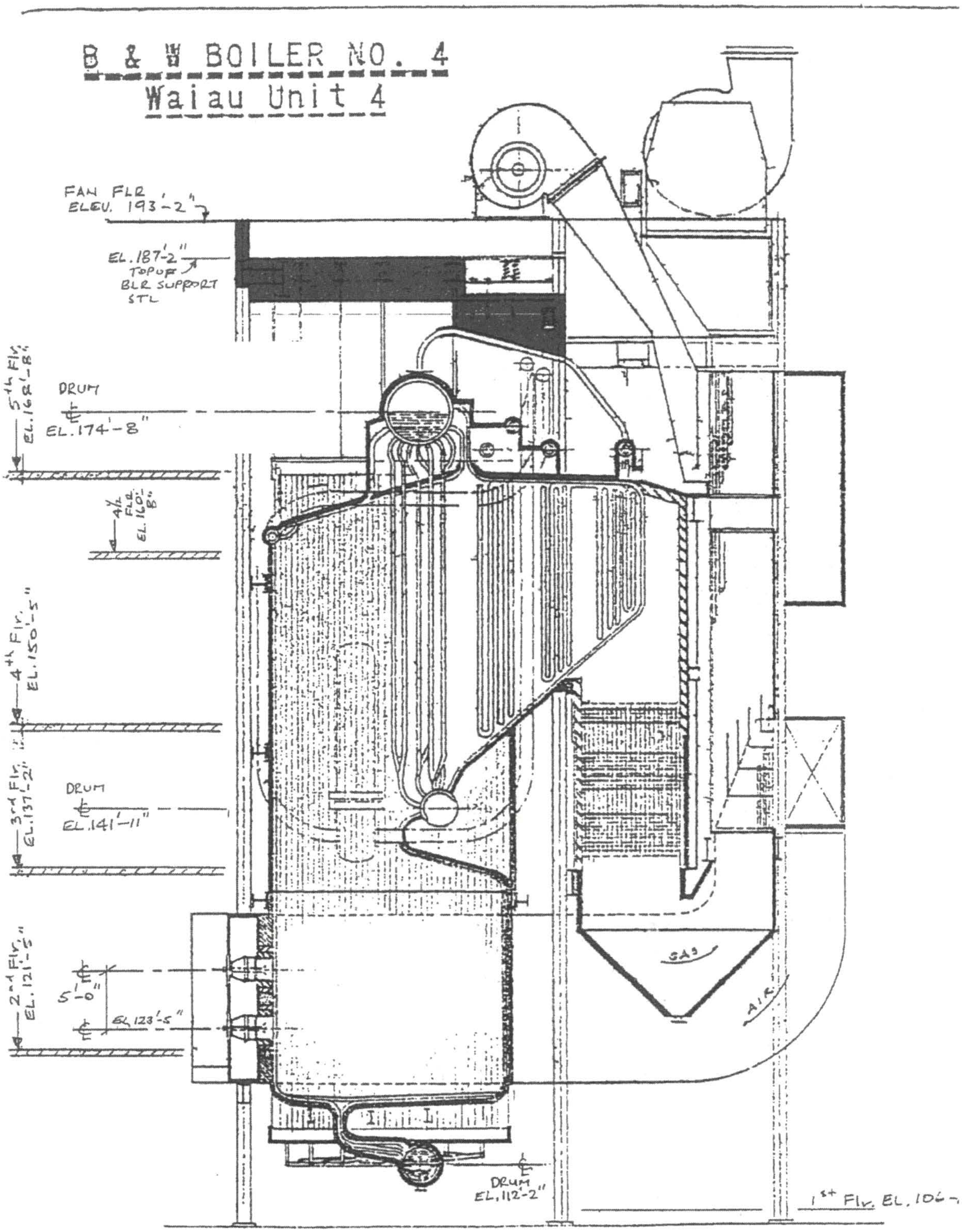

Figure 10-4—Waiau 4 operates under negative pressure.

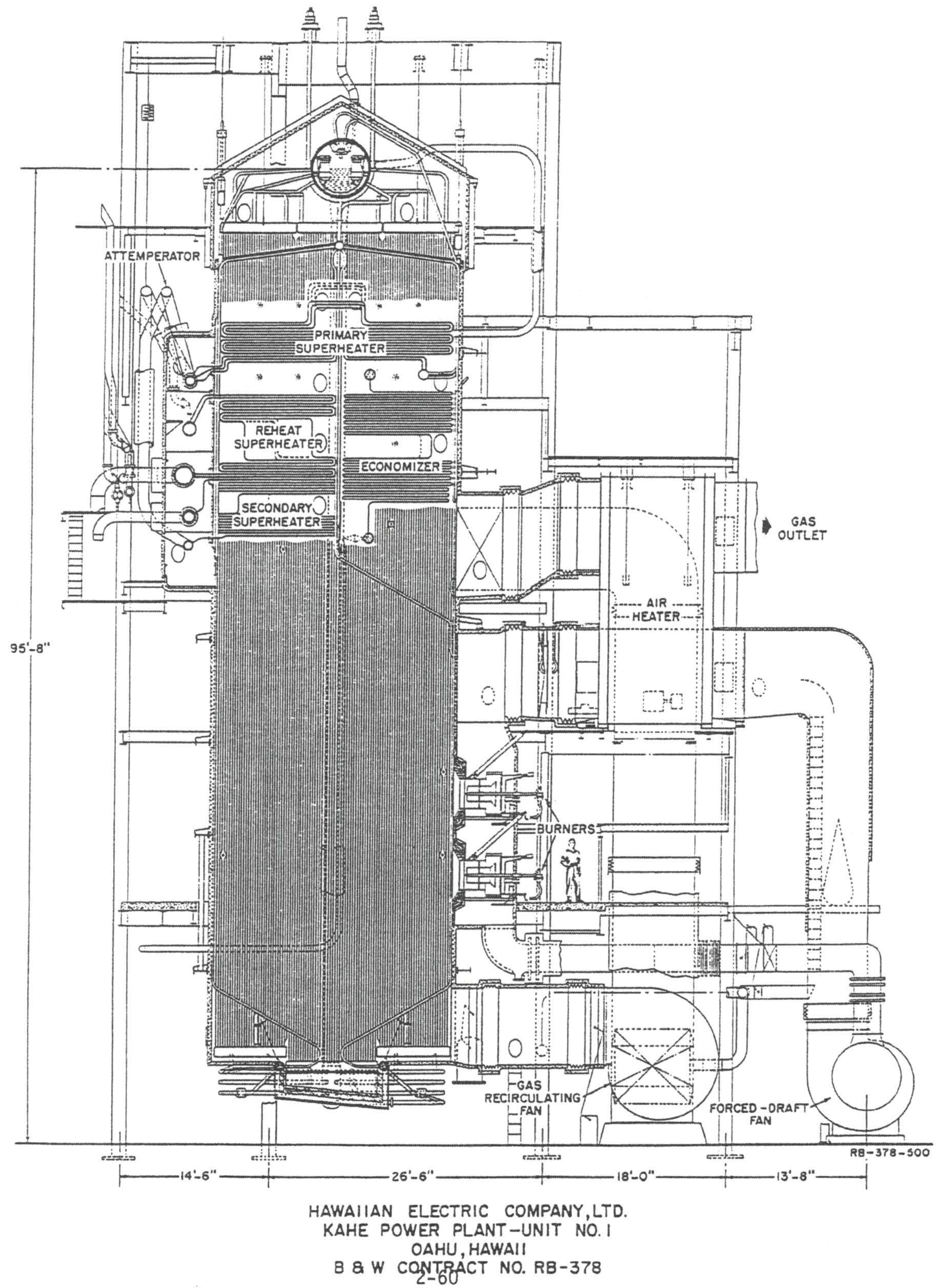

Figure 10-5—Kahe 1 operates under positive pressure.

Section 10
BOILER FUNDAMENTALS
Study Questions

1. The boiler is the first step in the ______________ ______________ process.

2. The two cycles of a typical boiler are:
   a. ______________________, which includes all parts that contain the flow of ______________________ and/or ______________________;
   b. ______________________, which includes spaces and passages where ______________________ takes place and through which ______________ gases pass.

3. Describe, briefly, what would happen should the continuous flow of water and/or steam through the boiler cease.

4. Identify the four factors that determine boiler circulation.
   a)
   b)
   c)
   d)

5. During acid cleaning and controlled startup and shutdown operations, which two of the four factors listed above would be under the control of the operator?
   a)
   b)

6. Which two are fixed by design and beyond the control of the operator?

   a)

   b)

7. How does natural circulation differ from forced circulation and forced flow?

8. Boiler walls are made up of riser tubes known as ______________________________ .

9. The construction and operation of the reheater and the superheater is essentially the same. The major difference is that the ___________________________ handles steam at much lower pressure.

10. What are some causes of steam contamination? List and describe at least two (2).

11. During start-up. the flue gas temperature leaving the furnace area should not be allowed to exceed ____________________________ .

12. Low temperature energy from the flue gas is reclaimed by the ________________.

13. This low temperature energy is used to heat the incoming ________________________ before it enters the ____________________________________.

14. Air is supplied to the boiler through large ducts to an enclosure on the boiler known as the _______________________________________ .

15. Each burner is usually provided with a ________________________ which give the air a swirling motion and adjusts the amount of air supplied to each burner.

16. The opening between the wind box and furnace is known as the ________________.

17. Combustion takes place in the area enclosed by the water walls and known as the _____________________ and the primary heat transfer method involved is _____________________.

18. The superheater, reheater, and economizer are located in the ____________________ section of the boiler.

19. Why is the convection section provided with soot blowers and what is their purpose?

20. Reclaiming low temperature heat energy from the flue gas by transferring it to the incoming combustion air is the function of the ____________________________ .

21. When erecting a boiler on a plant site, a steel framework is erected and the boiler is suspended from this structure. Why?

22. What determines whether or not a boiler casing should be air tight?