



Chapter 14

Boilers



Objectives

After completing this chapter, you will be able to:

- 14.1** Identify the components of boilers and the purpose of boilers in the process industries. (NAPTA Boilers 1, 3-5*) p. 292
- 14.2** Identify the common types of boilers and their applications. (NAPTA Boilers 2) p. 296
- 14.3** Explain the operating principles of boilers. (NAPTA Boilers 6) p. 298
- 14.4** Identify potential problems associated with boilers. (NAPTA Boilers 11) p. 302
- 14.5** Describe safety and environmental hazards associated with boilers. (NAPTA Boilers 7, 10) p. 303
- 14.6** Describe the process technician's role in safe boiler operation, maintenance, and operator qualification. (NAPTA Boilers 8, 9) p. 304
- 14.7** Identify typical procedures associated with boilers. (NAPTA Boilers 7) p. 304

* North American Process Technology Alliance (NAPTA) developed curriculum to ensure that Process Technology courses will produce knowledgeable graduates to become entry level employees in process technology. Objectives from that curriculum are named here in abbreviated form. For example, "(NAPTA Boilers 2)" means that this chapter's objective relates to objective 2 of the NAPTA curriculum about boilers).

Key Terms

- Air registers**—devices that control the flow of air to the burners to maintain the correct fuel-to-air ratio and to reduce smoke, soot, or NO_x (nitrogen oxide) and CO (carbon monoxide) formation, **p. 297.**
- Blowdown**—the process of taking water out of a boiler to reduce the concentration level of impurities. There are two types of blowdown, continuous and intermittent, **p. 293.**
- Burners**—devices that introduce, distribute, mix, and burn a fuel (e.g., natural gas, fuel oil, or coal) for heat, **p. 297.**

- Coagulation**—a method for concentrating and removing suspended solids in boiler feedwater by adding chemicals to the water, which causes the impurities to cling together, **p. 301**.
- Condensate**—condensed steam, which often is recycled back to the boiler, **p. 294**.
- Damper**—a movable plate that regulates the flow of air or flue gases in boilers, **p. 297**.
- Deaeration**—removal of air or other gases from boiler feedwater by increasing the temperature using steam and stripping out the gases, **p. 301**.
- Demineralization**—a process that uses ion exchange to remove mineral salts; also known as *deionization*. The water produced is referred to as deionized water, **p. 301**.
- Desuperheated steam**—superheated steam from which some heat has been removed by the reintroduction of water. It is used in processes that cannot tolerate the higher steam temperatures, **p. 300**.
- Desuperheater**—a system that controls the temperature of steam leaving a boiler by using water injection through a control valve, **p. 297**.
- Downcomers**—tubes that transfer water from the steam drum to the mud drum, **p. 297**.
- Draft fan**—a fan used to control draft in a boiler, **p. 297**.
- Economizer**—the section of a boiler used to preheat feedwater before it enters the main boiler system, **p. 293**.
- Filtration**—the process of removing particles from water or some other fluid by passing it through porous media, **p. 301**.
- Firebox**—the area of a boiler where the burners are located and where radiant heat transfer occurs, **p. 296**.
- Fire tube boiler**—a device that passes hot combustion gases through the tubes to heat water on the shell side, **p. 298**.
- Igniter**—a device (similar to a spark plug) that automatically ignites the flammable air and fuel mixture at the tip of the burner, **p. 292**.
- Impeller**—a fixed, vaned device that causes the air/fuel mixture to swirl above the burner; different from an impeller in a turbine or pump, **p. 292**.
- Knockout pots**—devices designed to remove liquids and condensate from the fuel gas before it is sent to the burners, **p. 292**.
- Mud drum**—the lower drum in a boiler; also called the water drum; serves as a settling point for solids in the boiler feedwater, **p. 293**.
- Pilot**—an initiating device used to ignite the burner fuel, **p. 297**.
- Premix burner**—a device that mixes fuel gas with air before either enters the burner tip, **p. 297**.
- Radiant tubes**—tubes containing boiler feedwater that are heated by radiant heat from the burners and boiled to form steam that is returned to the steam drum, **p. 297**.
- Raw gas burner**—a burner in which gas has not been premixed with air, **p. 297**.
- Refractory lining**—a bricklike form of insulation used to reflect heat back into the box and protect the structural steel in the boiler, **p. 296**.
- Reverse osmosis**—method for processing water by forcing it through a membrane through which salts and impurities cannot pass (purified bottled water is produced this way), **p. 301**.
- Riser tubes**—tubes that allow water or steam from the lower drum to move to the upper drum, **p. 297**.
- Saturated steam**—steam in equilibrium with water (e.g., steam that holds all of the moisture it can without condensation occurring), **p. 300**.
- Softening**—the treatment of water that removes dissolved mineral salts such as calcium and magnesium, known as hardness in boiler feedwater, **p. 301**.
- Spiders**—devices with a spiderlike shape that are used to inject fuel into a boiler, **p. 292**.
- Spuds**—devices used to inject fuel into a boiler, **p. 292**.

Stack—an opening at the top of the boiler that is used to remove flue gas, p. 297.

Steam drum—the top drum of a boiler where all of the generated steam is collected before entering the distribution system, p. 293.

Steam trap—a device used to remove condensate or liquid from steam systems, p. 294.

Superheated steam—steam that has been heated to a very high temperature so that a majority of the moisture content has been removed (also called *dry steam*), p. 300.

Superheater—tubes located near the boiler outlet that increase (superheat) the temperature of the steam, p. 297.

Waste heat boiler—a device that uses waste heat from a process to produce steam, p. 297.

Water tube boiler—a type of boiler that contains water-filled tubes that allow water to circulate through a heated firebox, p. 296.

14.1 Introduction

Steam has many applications and a long history in the process industries. Steam provides efficient heat transfer and contains a high amount of latent heat. It is used to heat and cool process fluids, power and purge equipment, fight fires, facilitate distillation, and induce other physical and chemical reactions.

Boilers are an important source of energy in the process industries because they supply steam to operate process equipment and produce the steam used throughout the process facility. Examples of process equipment that uses steam includes turbines, reactors, distillation columns, stripper columns, and heat exchangers.

General Components of Boilers

Boilers are devices in which water is boiled and converted into steam under controlled conditions. Boiler components can vary, but the most common components include a firebox, burners, drums, tubes, an economizer, a steam distribution system, and a boiler feedwater system.

Firebox

Like other process furnace and direct-fired heater fireboxes, boiler fireboxes have a refractory lining, burners, a convection-type section, a radiant section, fans, air flow control, a stack, and dampers. The boiler firebox is insulated to reduce the loss of heat and enhance the heat energy being transferred to the boiler's internal components.

Burners

Burners inject air and fuel through a distribution system that mixes them in proper concentrations so combustion can occur. Most boilers use natural gas, fuel oil, or coal burners to provide heat to the boiler.

The key components of natural gas burners include pilots, impellers, spuds, spiders, and igniters. **Knockout pots** remove liquids and condensate from the fuel gas before it is sent to the burners. Dampers regulate the flow of air to the burner. Impellers in boilers are not the same as impellers in turbines or pumps. **Impellers** are fixed, vaned devices that cause the air/fuel mixture to swirl above the burner. Spuds or **spiders** (devices with a spiderlike shape) are used to inject fuel into the boiler (Figure 14.1). **Igniters** automatically ignite the flammable air and fuel mixture at the tip of the burner.

Knockout pots devices designed to remove liquids and condensate from the fuel gas before it is sent to the burners.

Impeller a fixed, vaned device that causes the air/fuel mixture to swirl above the burner; different from an impeller in a turbine or pump.

Spiders devices with a spiderlike shape that are used to inject fuel into a boiler.

Igniter a device (similar to a spark plug) that automatically ignites the flammable air and fuel mixture at the tip of the burner.

Spuds devices used to inject fuel into a boiler.

Did You Know?

Low NO_x formation burners use nozzles, called **spuds**, to inject fuel into a boiler.

Spuds promote better combustion than traditional burners.

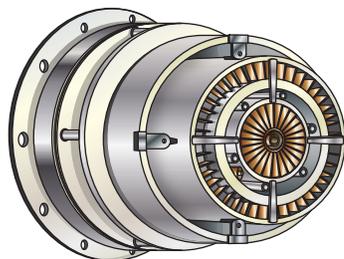
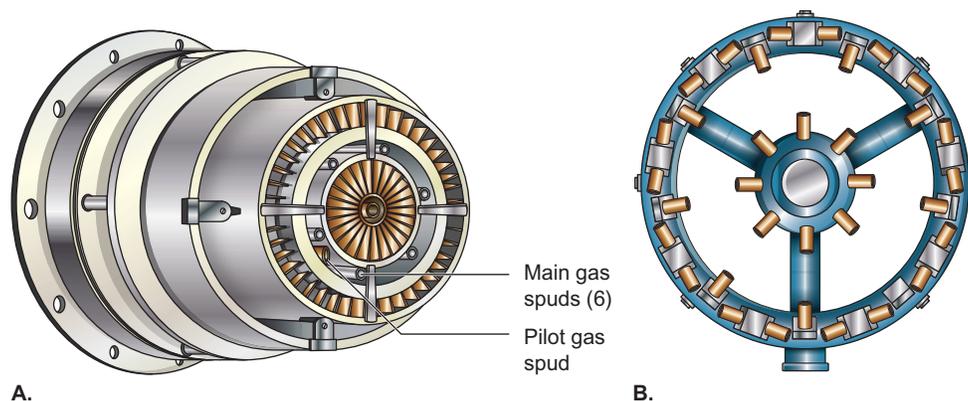


Figure 14.1 Fuel injection devices. A. Spud. B. Spider.



Drums

The drums that comprise a water tube boiler resemble a large water distribution header connected by a complex network of tubes. The **mud drum** is the lower drum in a boiler. The **steam drum** is the upper drum of a boiler where all of the generated steam is collected. The mud drum and water tubes are filled completely with water, while the steam drum is only partially full. Maintaining this vapor space in the upper drum allows the saturated steam to collect and pass out of the header.

Feedwater to the boiler is treated to achieve the required chemical composition. Water lost in the boiler is replaced through a makeup water line. Sediment accumulates in the bottom of the mud drum and is removed through blowdown. **Blowdown** is the process of removing small amounts of water from the boiler to reduce the concentration of impurities. Blowdown can be either continuous or intermittent. Continuous blowdown is the constant removal of a small quantity of boiler water from the steam drum to remove suspended solids and salts that could concentrate in the steam drum. Intermittent (or *bottoms*) blowdown is the occasional opening of a valve on the bottom of the mud drum to remove solids that have settled.

Economizer

The **economizer** is the section of a boiler used to preheat feedwater before it enters the main boiler system. Preheating the water increases boiler system efficiency. This heat exchanger transfers heat from the stack gases to the incoming feedwater. The economizer is usually located close to the stack gas outlet of the boiler. Economizers can be supported from overhead or from the ground. The feedwater line that serves the boiler is piped into and travels through the economizer. No additional feedwater control valves or stack gas dampers are required.

An economizer is similar to the convection section in a direct-fired heater. Both operate under the energy-saving concept of recovering some of the heat from the hot flue gases before they are lost out of the stack. The typical improvement in efficiency of a boiler with an economizer is 2 to 4 percent.

Steam Distribution System

The steam distribution system consists of valves, fittings, piping, and connections suitable for the pressure of the steam being transported. Steam exits the boiler at sufficient pressure required for the process unit or for electrical generation. For example, when steam is used to drive steam turbine generators to produce electricity, the steam must be produced at a much higher pressure than that required for process steam. The steam pressure can then

Mud drum the lower drum in a boiler; serves as a settling point for solids in the boiler feedwater.

Steam drum the top drum of a boiler where all of the generated steam is collected before entering the distribution system.

Blowdown the process of taking water out of a boiler to reduce the concentration level of impurities. There are two types of blowdown, continuous and intermittent.

Economizer the section of a boiler used to preheat feedwater before it enters the main boiler system.

Condensate condensed steam, which often is recycled back to the boiler.

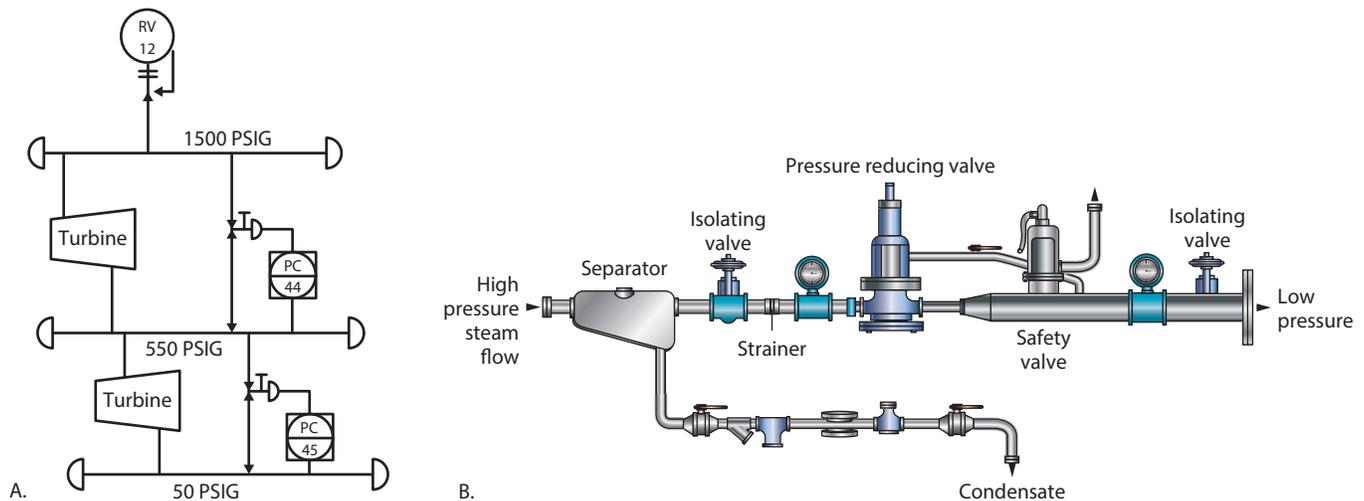
be reduced for the turbines that drive process pumps and compressors that require lower pressure steam.

Most steam used in a process facility is ultimately condensed to water. **Condensate** is typically returned through condensate return systems and reused as boiler feedwater. This saves the plant considerable money because the condensate, which has already been treated with chemicals, reduces the cost of boiler feedwater treatment.

A facility's steam system is usually composed of two or three piping systems with different pressure steam headers. There are different methods of maintaining several steam headers operating at different pressures. One method is through a letdown valve or a reducing station in which a pressure control valve is used. In this type of arrangement, a pressure drop across the valve equalizes with the pressure contained in the lower pressure steam header. In many instances, the steam header itself has another letdown valve that repeats the same function, supplying steam to yet another, lower pressure steam header.

Another method of supplying steam to headers of different pressures is by piping the exhaust of steam turbines into headers. For example, a steam turbine that operates at 1,500 psig pressure might exhaust into a 550 psig steam header. The turbine that uses the 550 psig steam then might exhaust into a 50 psig header. A letdown valve or reducing station (see Figure 14.2) offers the advantage of maintaining a steam header at an interim pressure that might not be suitable for all steam turbines.

Figure 14.2 A. Diagram of a letdown station. B. Letdown station with pressure-reducing valve, safety valves, and separator.



Some process plants are supported by a cogeneration plant, in which electricity and steam are generated in the same unit. Steam is brought to a very high temperature and pressure. This high-pressure steam is used to turn a turbine that turns an electrical generator. The exhaust from the turbine goes into a lower pressure steam header. In this way, a cogeneration plant supplies the process facility with both electricity and steam.

Steam trap a device used to remove condensate or liquid from steam systems.

An important component used in steam systems is a steam trap. **Steam traps** are used to remove condensate or liquid from steam systems. There are several steam trap designs. The most common, however, are the mechanical trap (Figure 14.3) and the thermostatic trap (Figure 14.4). See also Figures 4.18 and 4.19.

Mechanical traps operate based on the density difference between steam and condensate. Internal floats attached to mechanical linkages are found inside most mechanical traps. As the condensate levels rise, the linkage causes the valve to open. As the levels drop, the valve closes. Inverted bucket and float traps are both common examples of mechanical traps.

Figure 14.3 Examples of different designs for mechanical steam traps. **A.** Inverted bucket trap. **B.** Float trap.

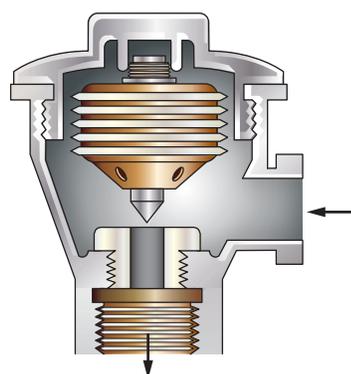
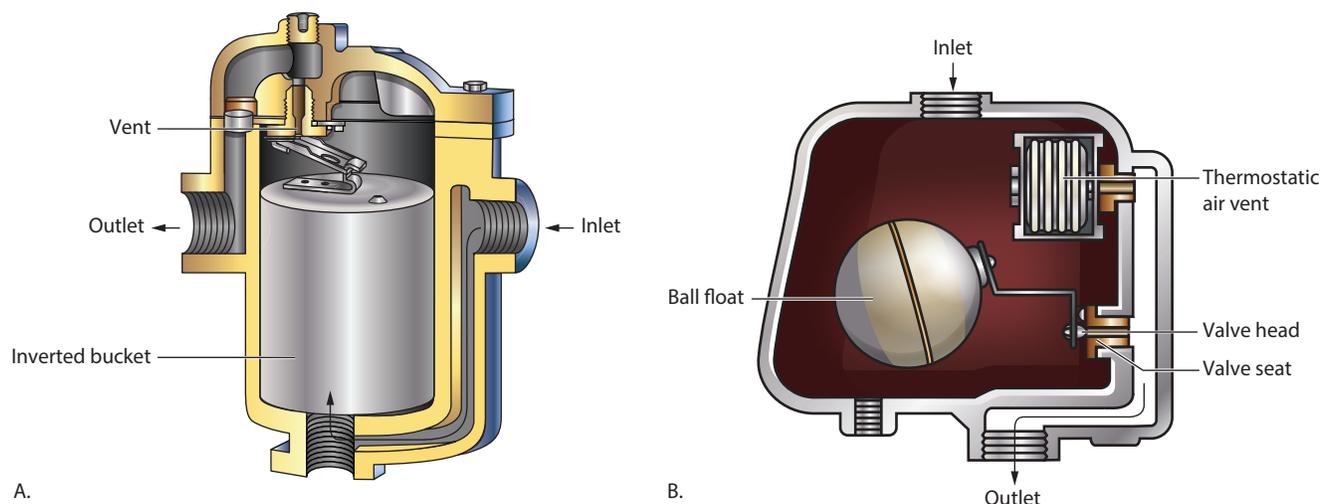


Figure 14.4 Example of a type of thermostatic steam trap (Bellows).

Thermostatic traps operate on the principle of temperature change (steam is hotter than condensate). These traps contain valves that are opened or closed by thermal expansion and contraction. Bimetallic and bellows traps are examples of temperature-operated traps. Condensate will cause the bellows to collapse or bimetallic element to move, releasing the condensate. When the condensate is removed and steam is present, the bellows expands or the bimetallic element moves the opposite way, and the steam trap closes.

Boiler Feedwater System

The boiler feedwater supply is a critical part of steam generation. There must always be as many pounds of water entering the system as there are pounds of steam leaving.

The water used in steam generation must be free of contaminants such as minerals and dissolved impurities that can damage the system or affect its operation. Suspended materials such as silt and oil create scale and sludge, and must be filtered out. Dissolved gases such as carbon dioxide and oxygen cause boiler corrosion and must be removed by deaeration and other methods of treatment. Because dissolved minerals cause scale, corrosion, and turbine blade deposits, boiler feedwater must be treated with lime or soda ash to precipitate these minerals from the water. Recirculated condensate must be deaerated to remove dissolved gases.

Depending on the individual characteristics of the raw water, boiler feedwater can be treated by clarification, sedimentation, filtration, ion exchange, deaeration, membrane processes, or a combination of these methods. Boiler feedwater treatment is discussed in greater detail in the following section.

14.2 Water Tube, Waste Heat, and Fire Tube Boilers

Many factors are considered when selecting a boiler. These factors include the pressures and temperatures required, total capacity, number of generating tubes, number of drums, type of circulation (natural or forced), superheating and desuperheating requirements, tube configuration, and cost. The most common types of boilers used in the process industries are water tube, waste heat, and fire tube boilers.

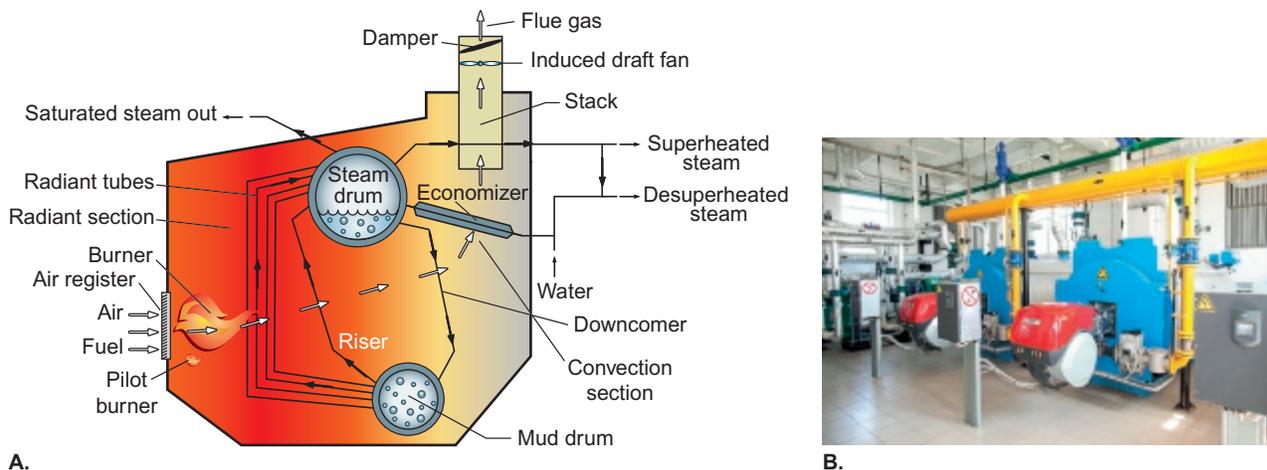
Water Tube Boilers

Water tube boiler a type of boiler that contains water-filled tubes that allow water to circulate through a heated firebox.

Water tube boilers (shown in Figure 14.5) are so-called because they contain water-filled tubes that allow water to circulate through a heated firebox. Water tube boilers have upper and lower drums connected by tubes. The upper drum is the steam drum, and the lower drum is the mud drum. Chemicals are added to the boiler feedwater that enters these drums in order to prevent fouling and corrosion.

Figure 14.5 A. Diagram of water tube boiler components. B. Water tube boiler.

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Heat is generated in the boiler through a direct-fired heater with a natural gas, oil, or combination burner. The heat from the burner is transferred to the water tubes. As water flows through the tubes, the combustion gases heat the water and produce steam. This steam is collected in the upper drum, while combustion gases exit the boiler stack as flue gas.

Several types of tubes are found inside the boiler. Generating tubes are attached to the upper and lower drums. Water flows through the tubes from the upper (steam) drum down to the lower (mud) drum and back up to the steam drum. The *downcomer tube* is the cold water line between the upper and lower drums. The *riser tube* is the hot water/steam line between the lower and upper drums. *Superheater tubes* are tubes where steam is removed from the steam drum and heated to remove moisture content without an increase in pressure.

The water level in a water tube boiler is controlled in the steam drum. The water level in this drum must be maintained for safety reasons and for compliance with standard operating procedures. Loss of water level can damage boiler equipment. Excessively high water levels can result in carryover, which can cause steam to become saturated with water containing chemicals, which in turn can result in fouling in the steam system. An even greater risk is that water carryover will result in wet steam, which can cause operational upsets.

WATER TUBE BOILER COMPONENTS The heating portion of a boiler is similar to that of a furnace. Like furnaces, boilers contain a **firebox** where the burners are located and radiant heat transfer occurs. A special **refractory lining** (a bricklike form of insulation) is used to reflect heat back into the box and protect the structural steel in the boiler.

Firebox the area of a boiler where the burners are located and where radiant heat transfer occurs.

Refractory lining a bricklike form of insulation used to reflect heat back into the box and protect the structural steel in the boiler.

Located in the firebox area of the boiler are radiant tubes. **Radiant tubes** and riser tubes both contain boiler feedwater that is heated by radiant heat from the burners and boiled to form steam that is returned to the steam drum.

Burners are devices that introduce, distribute, mix, and burn a fuel (e.g., natural gas, fuel oil, or coal) for heat. **Pilots** are used to light burners. A burner can be a **premix burner** (fuel gas and air mixed before either enters the burner tip), a **raw gas burner** (gas not premixed with air), or a combination.

Air registers control the flow of air to the burners to maintain the correct fuel-to-air ratio and to reduce smoke, soot, or NO_x (nitrogen oxide) and CO (carbon monoxide) formation.

A **draft fan** is used to control draft in a boiler. Depending on the design of the boiler, the draft fan either forces the air through the boiler (*forced draft*) or pulls the air through the boiler (*induced draft*). In some boilers, a combination of the two is used (*balanced draft*).

Water tube boilers have a **stack** at the top of the boiler to remove flue gas. Contained within the stack is a **damper** for regulating the flow of flue gases.

A steam drum at the top of the boiler is where all generated steam gathers before exiting the boiler. Depending on the boiler design, water enters the steam drum or the mud drum from the economizer.

At the bottom of the boiler is the mud drum, where sediment accumulates. This sediment is removed by intermittent blowdown, which is done manually.

Downcomers are tubes that transfer water from the steam drum to the mud drum. As cooler water descends from the steam drum and flows through the downcomers, it picks up heat from the firebox and replenishes the water supply to the mud drum. **Riser tubes** allow water or steam from the lower drum to move to the upper drum.

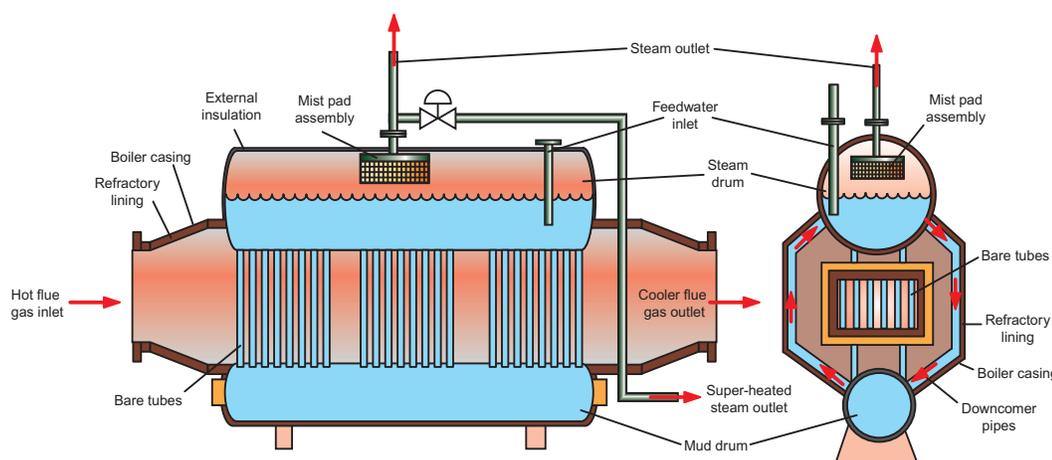
The **superheater** is a set of tubes located toward the boiler outlet that increases (superheats) the temperature of the steam flow. The steam drum usually is connected to the superheater through a coil or pipe.

A **desuperheater** is a temperature control point at the outlet of the boiler steam flow that maintains a specific steam temperature by using boiler feedwater injection through a control valve. The purpose of the desuperheater is to lower the temperature of the steam.

Waste Heat Boilers

Waste heat boilers use excess or waste heat from a process to produce steam. Waste heat boilers have two functions: to produce steam and to provide cooling for a process in order for it to proceed or to recover heat that would otherwise be released to the atmosphere, losing a tremendous amount of usable energy. Figure 14.6 shows a waste heat boiler that can be used to recover waste heat energy and cool the flue gas stream from a turbine exhaust.

Figure 14.6 Diagram of a waste heat boiler.



Radiant tubes tubes containing boiler feedwater that are heated by radiant heat from the burners and boiled to form steam that is returned to the steam drum.

Burners devices that introduce, distribute, mix, and burn a fuel (e.g., natural gas, fuel oil, or coal) for heat.

Pilot an initiating device used to ignite the burner fuel.

Premix burner a device that mixes fuel gas with air before either enters the burner tip.

Raw gas burner a burner in which gas has not been premixed with air.

Air registers devices that control the flow of air to the burners to maintain the correct fuel-to-air ratio and to reduce smoke, soot, or NO_x (nitrogen oxide) and CO (carbon monoxide) formation.

Draft fan a fan used to control draft in a boiler.

Stack an opening at the top of the boiler that is used to remove flue gas.

Damper a movable plate that regulates the flow of air or flue gases in boilers.

Downcomers tubes that transfer water from the steam drum to the mud drum.

Riser tubes tubes that allow water or steam from the lower drum to move to the upper drum.

Superheater tubes located near the boiler outlet that increase (superheat) the temperature of the steam.

Desuperheater a system that controls the temperature of steam leaving a boiler by using water injection through a control valve.

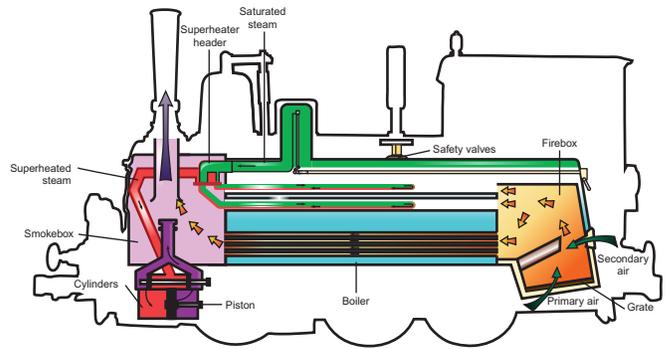
Waste heat boiler a device that uses waste heat from a process to produce steam.

Did You Know?

Steam locomotives and home water heaters are both examples of fire tube boilers.



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Waste heat boilers improve efficiency and save money by allowing steam to be produced through the use of waste gases. Use of waste gases as a heat source reduces the amount of money spent on burner fuels and reduces environmental impact.

Because of the duty required of waste heat boilers, construction is usually thick-walled and designed to withstand high pressures and temperatures. Waste heat boilers usually are single-pass, floating-head type heat exchangers that experience a considerable amount of expansion and contraction of the tubesheet.

In many furnaces, the waste heat boiler is on the outlet of the furnace. This design recovers heat by generating steam and thus cooling the flue gas stream exiting the furnace stack. Because of this, waste heat boilers are sometimes referred to as *steam generators*.

Fire Tube Boilers

Fire tube boiler a device that passes hot combustion gases through the tubes to heat water on the shell side.

Fire tube boilers pass hot combustion gases through the tubes to heat water on the shell side of the boiler. In this type of boiler, combustion gases are directed through the tubes while water is directed through the shell. As the water begins to boil, steam is formed. This steam is directed out of the boiler to other parts of the process, and makeup water is added to compensate for the fluid loss. In this type of system, the water level within the shell must always be maintained so that the tubes are covered. Otherwise, the tubes could overheat and become damaged. Figure 14.7 shows examples of fire tube boilers.

Figure 14.7 Fire tube boilers.

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A.



B.

14.3 Principles of Operation of Boilers

Boilers use a combination of radiation, convection, and conduction to convert heat energy into steam energy. Proper boiler operation depends on controlling many variables, including boiler feedwater quality, water flow and level in the boiler, furnace temperatures and pressures, burner efficiency, and air flow.

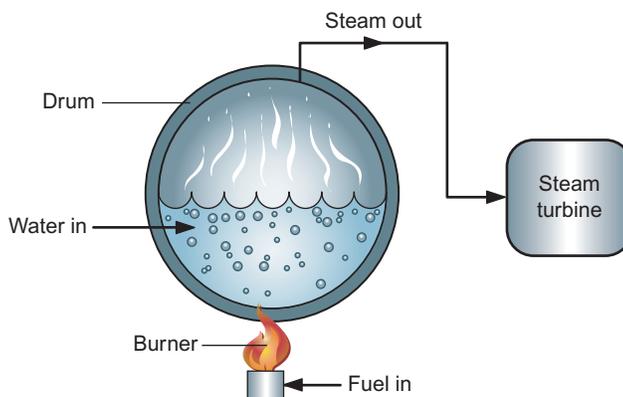


Figure 14.8 Simple boiler.

To illustrate how boilers work, consider the simple boiler shown in Figure 14.8. Simple boilers consist of a heat source, a water drum, a water inlet, and a steam outlet. In this type of boiler, the water drum is partially filled with water and then heat is applied. Steam forms after the water is heated sufficiently. As the steam leaves the vessel, it is captured and sent to other parts of the process (e.g., used to turn a steam turbine, or sent to a heat exchanger to heat a process fluid). Makeup water is then added to the drum to compensate for the liquid lost as steam.

Boilers use the principle of differential density when it comes to fluid circulation. For boilers to work properly, they must have adequate amounts of heat and water flow. Factors that affect boiler operation include pressure, temperature, water level, and differences in water density. As fluid is heated, the molecules expand and the fluid becomes less dense. When cooler, denser water is added to hot water, convective currents are created that facilitate water circulation and mixing.

Water Circulation

The circulation of boiler water (shown in Figure 14.9) is based on the principle of convection. A fluid that is heated expands and becomes less dense, moving upward through heavier, denser fluid. Convection and conduction transfer heat through pipe walls and water currents, resulting in unequal densities. Cold water flows through the downcomer to the bottom of the mud drum and then flows upward through the riser (water wall tubes) as it is heated.

In a water tube boiler, circulation occurs because the temperature of the fluid in the downcomer is always lower than the temperature in the boiler and generating (riser) tubes. Steam bubbles are formed as the liquid temperature continues to increase. These bubbles increase

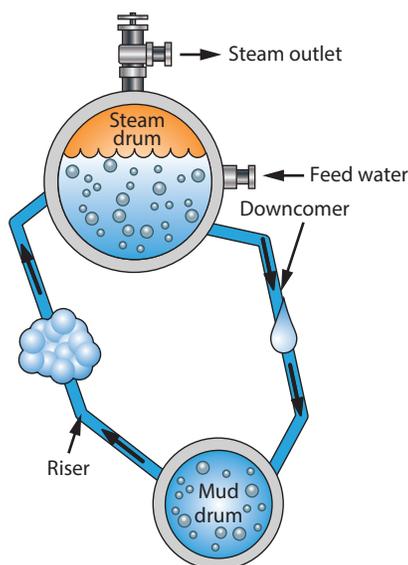


Figure 14.9 Water circulation.

the circulation as they move up the riser tubes. The pressure builds as the water vapor collects in the upper drum. Each time the water passes through the tubes, it picks up more heat energy. As the pressure increases, the boiling point of the water increases. When the target pressure is achieved, steam is delivered to the steam header. To maintain this pressure, makeup water must be added, heat must be continually applied, and circulation must be controlled. In a fire tube boiler, the water level in the boiler shell must be maintained above the tubes to prevent overheating of the tubes.

Superheated Steam

Saturated steam steam in equilibrium with water (e.g., steam that holds all of the moisture it can without condensation occurring).

Saturated steam is steam in equilibrium with water (e.g., steam that holds all of the moisture it can hold and still remain a vapor). Saturated steam can be used to purge process equipment or perform other functions, or it can be superheated.

As long as the steam and water are in contact with each other, the steam is in a saturated condition. Saturated steam cannot absorb additional water vapor, but the boiler can continue to add heat energy to it. Steam that continues to take on heat energy or get hotter is known as superheated steam.

Superheated steam steam that has been heated to a very high temperature so that a majority of the moisture content has been removed (also called *dry steam*).

Superheated steam, which is produced downstream of the steam drum (typically in the firebox), is steam that has been heated to a temperature above its saturated temperature. Superheated steam is typically 200 to 300 degrees F (93 to 149 degrees C) hotter than saturated steam. Typical uses for superheated steam include:

- Driving turbines
- Catalytic cracking
- Product stripping
- Maintenance of steam pressures and temperatures over long distances
- Producing steam for systems that require dry, moisture-free steam.

Desuperheated Steam

Superheated steam might not be the best choice for heat transfer in some heat exchangers because the amount of energy given up by superheated steam is relatively small compared to the energy given up by saturated steam. Also, some facility processes cannot tolerate the high temperatures of superheated steam. The process of cooling the superheated steam is called desuperheating. **Desuperheated steam** is superheated steam from which some heat has been removed by the reintroduction of boiler feedwater. Typically, desuperheating does not occur at the boiler but at specific points in the process where boiler feedwater is injected into superheated steam.

Desuperheated steam superheated steam from which some heat has been removed by the reintroduction of water. It is used in processes that cannot tolerate the higher steam temperatures.

Boiler Feedwater

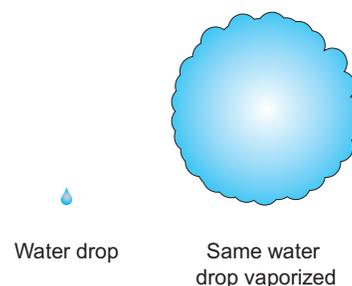
Boiler feedwater levels and flows are critical to proper boiler operation. If feedwater flow is reduced and the water level decreases to the point where the boiler runs dry, the tubes will overheat and fail. If the boiler water level becomes too high, excess water will be carried over into the steam distribution system. This negatively affects process facility steam consumers and can damage turbines and other equipment.

During the boiling process, most suspended solids stay in the water section of the drum while steam is sent to the distribution system. Suspended solids are removed from the steam drum by sending a small amount of the feedwater, called continuous blowdown, to a blowdown tank. This continuous blowdown is usually released to a waste water treatment processing unit. Boilers utilize both continuous and intermittent blowdown systems to remove suspended solids from the steam drum and solids that have settled from the mud drum. Blowdowns limit the scale buildup that can negatively affect turbine blades and superheater tubes.

Feedwater must be free of contaminants that could affect boiler operation. As a general rule, the higher the steam pressure, the stricter the feedwater quality requirements will be. Important feedwater parameters include pH (alkalinity or acidity of the water), hardness (amount of mineral content in the water), oxygen and carbon dioxide concentration, presence of silicates, dissolved or suspended solids, and concentration of organics. Water treatment techniques include reverse osmosis, ion exchange, deaeration, membrane contactors, and electrode ionization or demineralization.

Did You Know?

When a volume of water is converted to steam, the volume increases more than 1,600 times its original volume. This is why steam generation is a dangerous part of industrial processes.



Water Treatment Methods

Raw water can come from a variety of sources, such as lakes, rivers, or wells. Each water source has its own components and treatment requirements. In general, however, the water chemistry required for steam production must meet standards. The water needs to be filtered and have minerals and oxygen removed. Raw water goes through the following steps to become boiler feedwater.

1. Clean the water. This step removes suspended solids. Depending on water source this could include:
 - a. Coagulation/sedimentation
 - b. Filtration
2. Remove minerals. This step is done to the clean water (from step 1) to remove minerals that could build up on steam turbines or other process equipment. Depending on the water source, this step could be one or more of these processes:
 - a. Softening
 - b. Demineralization (ion exchange)
 - c. Reverse osmosis (membrane)
3. Remove the oxygen. Dissolved oxygen and other gases (primarily CO₂) in boiler feedwater are major causes of boiler system corrosion. While oxygen results in localized corrosion (pitting), CO₂ forms carbonic acid and damages condensate piping. This step could include:
 - a. Deaeration
 - b. Oxygen scavenging

Coagulation adds chemicals to reduce coarse suspended solids, silt, turbidity, and colloids through the use of a clarifier. The impurities gather together into larger particles and settle out of the chemical/water solution (*sedimentation*).

Filtration removes coarse suspended matter and sludge from coagulation or from water softening systems. Gravel beds and anthracite coal are common materials used for filter beds.

Softening is the treatment of water to remove dissolved mineral salts such as calcium and magnesium, known as hardness, in boiler feedwater. Softening methods include the addition of calcium carbonate (lime soda), phosphate, and/or zeolites (crystalline mineral compounds).

Demineralization is the removal of ionized mineral salts by ion exchange. The process is also called *deionization*, and the water produced is called deionized water.

Reverse osmosis uses pressure to remove dissolved solids from boiler feedwater by forcing the water from a more concentrated solution through a semipermeable membrane to a less concentrated solution.

Deaeration removes oxygen or other gases from boiler feedwater by increasing the temperature, using steam, to strip out the dissolved gases.

Coagulation a method for concentrating and removing suspended solids in boiler feedwater by adding chemicals to the water, which causes the impurities to cling together.

Filtration the process of removing particles from water or some other fluid by passing it through porous media.

Softening the treatment of water that removes dissolved mineral salts such as calcium and magnesium, known as hardness in boiler feedwater.

Demineralization a process that uses ion exchange to remove mineral salts; also known as *deionization*. The water produced is referred to as deionized water.

Reverse osmosis method for processing water by forcing it through a membrane through which salts and impurities cannot pass (purified bottled water is produced this way).

Deaeration removal of air or other gases from boiler feedwater by increasing the temperature and stripping out the gases.

Specific terms describe the water as it moves through these steps. Water starts as raw water and becomes demineralized water, then deaerated water, and finally boiler feedwater.

Steam that has been condensed (*condensate*) is already clean and can be fed back into the system at the deaerator. This saves the cost of treating more raw water, making it practical to recycle any used steam condensate.

Burner Fuel

Boilers use a single fuel or a combination of fuels, including refinery gas, natural gas, fuel oil, and powdered coal. In some complexes, scrubbed off-gases are collected from process units and combined with natural gas or liquefied petroleum gas in a fuelgas balance drum. The balance drum establishes a constant system pressure and fairly stable BTU (British thermal unit) content. It also provides for separation of suspended liquids in the gas vapors to prevent large slugs of liquid from being carried over into the fuel distribution system. As the scrubbed gases enter the balance drum, heavier liquids fall to the bottom along with any gases that have condensed into liquid. The lighter gas leaves the top of the balance drum and goes to the fuel distribution system. The fuel oil system delivers fuel to the boiler at the required temperatures and pressures. The fuel oil is heated to pumping temperature, sent through a coarse suction strainer, pumped to a temperature-control heater, and then pumped through a fine mesh strainer before being burned.

14.4 Potential Problems

Boiler system operations have a direct and immediate impact on the operation of other process equipment, such as distillation columns and turbines. The boiler must be operating properly to produce steam energy at steady pressures. Failure to maintain normal boiler operation can result in loss of production, compromised product quality, and high costs to repair or replace failed or damaged components. Table 14.1 lists problems associated with boilers.

Table 14.1 Problems Associated with Boilers

Condition	Problem
Burner flame impingement or poor flame distribution	Overheating and failure of the tubes
A change in the fuel flow	Creates or increases soot deposits on the tubes, causing excessively high temperature on the tube walls
A change in the composition of the fuel	Creates or increases soot deposits on the tubes, causing excessively high temperature on the tube walls
Loss of boiler feedwater flow	Allows the steam drum to run dry, causing the tubes to overheat and fail and leading to catastrophic equipment failure and potential injuries
A high water level in the steam drum	Causes water to carry over into the steam distribution system, which can damage equipment downstream
Poor control of feedwater treatment	Creates formation of scale in the tubes, resulting in a loss of boiler efficiency and can cause tube failure
Power outage	Loss of pumps and draft fans

Contributing Factors

Several factors can contribute to problems in boiler operation, including the design and age of the equipment, instrument problems, fouling, tube temperatures, and external factors.

EQUIPMENT AGE OR DESIGN The types of boiler equipment that are most subject to failure from aging include boiler feedwater pumps, blowdown valves, and system piping. In addition, linkages on stack dampers can wear out from inadequate lubrication or from the collection of dust and grit. Freezing and earth movements can crack concrete equipment foundations and cause external corrosion of structural components. Worn or damaged tube supports can create stress problems for the boiler tubes.

WATER AND OTHER CONTAMINANTS Water and contaminants can contribute to instrument malfunctions and other problems that can activate boiler interlocks and trip a boiler. For example, water can condense in the pressure sensing leads in the firebox and cause faulty pressure readings, automatically shutting down the boiler.

Tube life in a boiler can also be significantly affected by the quality of the feedwater. For example, improper feedwater treatment can create salt deposits inside the tubes. These salt deposits cause tube corrosion and/or hot spots, leading to premature tube failure.

EXTERNAL FACTORS Other factors that contribute to boiler problems include interrupted water supply, electrical failure, cold weather, and downstream process upsets. For example, if a large steam user suddenly stops taking steam, steam header pressure can increase, causing abrupt pressure swings and instrument sensing problems faster than the boiler firing controls can respond. Another factor is cold weather, which can cause water in the process and utility lines to freeze and plug the line. Upsets in the upstream processing units can cause off-spec fuel to be sent to the boiler.

14.5 Safety and Environmental Hazards

Hazards associated with both normal and abnormal boiler operation can negatively affect personal safety, equipment, and the environment. Process technicians must always take proper safety precautions when working around boilers. Table 14.2 lists some of the hazards associated with improper operation of boilers and possible effects.

Table 14.2 Hazards Associated with Boiler Operation

Improper Operation	Possible Effects			
	Individual	Equipment	Production	Environment
Opening header drains, vents, and peepholes	Burns and eye injuries			
Failing to purge the firebox (startup)	Possible burns or injuries	Explosion in the firebox; damage to the internal components of the boiler	Process facility upset; lost steam production; downtime for repairs	Exceeding regulatory limits for opacity (the amount of light blocked by a medium)
Poor control of excess air and draft control		Flame impingement	Reduced boiler efficiency	Exceeding opacity limits
Loss of boiler feedwater	Possible burns or injury	Tube rupture; loss of downstream equipment use	Lost production because of downtime for repairs	
Loss of fuel gas or oil		Loss of downstream equipment use	Lost steam production	

NO_x and Smoke Emissions

Excessive smoke or nitrogen oxide (NO_x) emissions from boiler operation have a negative impact on the environment. Both are considered air pollutants and can lead to emissions violations. To keep NO_x emissions under control, the burner air registers and fuel valves must always function properly. Understanding and controlling oil burner operations allows the right balance for complete combustion and control of smoke emissions. Process technicians should also be cautious when handling chemicals to reduce environmental impact.

Fire Protection and Prevention

The most potentially hazardous operation in steam generation is boiler startup. During startup, a flammable mixture of gas and air can build up as a result of flame loss at the burner during *light-off* (when the pilot flame is ignited). Each type of boiler requires specific

startup and emergency procedures, including purging before light-off and after misfire or loss of burner flame.

Hazardous Operating Conditions

Hazards exist during both normal and abnormal boiler operation. For example, there is a potential for exposure to feedwater chemicals, steam, hot water, radiant heat, and noise. Alternate fuel sources might be available onsite in the event fuel gas is lost because of a process unit shutdown or emergency.

Personal Safety

Process technicians must always follow safe work practices and wear appropriate personal protective equipment when working around boilers or performing process sampling, inspection, maintenance, or turnaround activities. Process technicians should also avoid skin contact with boiler blowdown because it can contain hazardous chemicals.

14.6 Process Technician's Role in Operation and Maintenance

Process technicians are responsible for performing specific procedures to safely operate and maintain boiler system equipment. Starting up a boiler, for example, requires filling the drum with water, lighting the burner, bringing the boiler up to pressure, and then placing the boiler online. Each of these steps requires that the process technician perform a number of tasks and follow specific procedures, which vary according to the site and boiler type. When monitoring and maintaining boilers, process technicians must always remember to look, listen, and check for all the factors listed in Table 14.3. Failure to perform proper maintenance and monitoring could affect personal safety as well as the process and could result in equipment damage.

Table 14.3 Process Technician's Role in Operation and Maintenance

Look	Listen	Check
<ul style="list-style-type: none"> ■ Look at firebox for flame impingement on tubes ■ Observe burner flame color and pattern ■ Observe for wall hotspots (external and internal) ■ Look at draft balance (pressures) ■ Look at temperature gradient ■ Monitor burner balance (fuel and air) ■ Inspect controlling instruments (water level, fuel flow, feedwater flow, pressure, steam pressure, and temperature) ■ Look at the boiler stack for smoke ■ Watch for proper steam flow ■ Monitor the air flow and oxygen level, and adjust draft as needed ■ Ensure that the blowdown on the mud drum is operating efficiently 	<ul style="list-style-type: none"> ■ Listen for abnormal noise (e.g., fans, burners, water leaks, steam leaks, or external alarms) ■ Listen for huffing or puffing, either of which can indicate improper draft operation 	<ul style="list-style-type: none"> ■ Check for excessive vibration (fans and burners) ■ Check burner atomization for uniformity (if not uniform, burner tips on the atomization gun or the burner will require replacement) ■ Check firing efficiency (CO₂, CO, and O₂ in the stack) ■ Collect boiler feedwater samples and ensure proper chemical treatment ■ Check for burner wear, which can cause uneven flame or hotspots

14.7 Typical Procedures

Process technicians must be familiar with boiler procedures, including startup, shutdown, lockout/tagout, and emergency procedures. The procedures that follow are generic in nature. Process technicians should always refer to site-specific procedures before performing any work on their unit.

Startup

1. Inform control room personnel that the boiler is going to be put into service.
2. Use the peepholes to inspect the inside of the boiler and verify that it is free of debris (e.g., scaffold boards, rain suits, and tools) and that the refractory lining, tubes, and tube supports are all intact.
3. Inspect the outside of the boiler for loose flanges around inlet and outlet piping. Ensure that all blinds have been removed, valves are in their proper startup positions, and the pressure relief valve is properly lined up.
4. Inspect the condition of the draft fan, the damper, and the fuel gas system to ensure all are in satisfactory operating condition.
5. While in close communication with control room personnel, open the damper and start up the draft fan per standard operating procedures.
6. Fill the boiler to its normal water level to satisfy the interlock (control safety systems that have to be verified before boiler startup) for proper water level.
7. After the draft in the boiler is stable and has been purged for the required length of time, open the fuel gas supply to the burner and the pilot gas block valves.
8. Inform control room personnel that the pilot is being ignited.
9. After all of the pilots are lit and burning (confirmed through visual observation), open the primary and secondary air registers as required. Slowly open the main burner block valves one at a time until all burners are burning.
10. Remain in the boiler area to inspect the flames for proper flame patterns and general operation (e.g., draft fan and fuel supply).
11. Use the peepholes to inspect the inside of the boiler and look for uniform color of the tubes.

Note: Many of these steps are included in a boiler automated control system.

Shutdown

With some exceptions, boiler shutdown is the reverse of the startup procedure.

1. Gradually reduce load and firing rate.
2. Turn off fuel.
3. Shut steam header valve.
4. Shut down feedwater pump.
5. Open vents and drains.
6. Leave fans on to help cool boiler.

The control room operator should monitor conditions and inform the outside operator when it is safe to block in all the burners, shut down the fan, and close the damper.

Emergency

In an emergency, one fuel gas block valve (often referred to as the fireman) usually is designated as the main shutoff valve. Generally, the draft fan continues to run and the damper remains open. The only thing the outside operator does is block in the burners, block in the fuel, and stop all pumps.

Lockout/Tagout for Maintenance

Each company has its own lockout/tagout procedures. Process technicians must be familiar with these procedures before performing any maintenance.

Summary

Boilers convert water into steam, which is supplied to steam consumers throughout a process facility. The steam produced by boilers provides heat to other process equipment and supplies the steam energy to drive turbines and compressors.

Boilers use a combination of radiant, conductive, and convective methods to transfer heat. These devices consist of a number of tubes that carry the water-steam mixture through the boiler for maximum heat transfer.

The process industries use three types of boilers: water tube, waste tube, and fire tube. Water tube boilers are the most commonly used boilers in process operations. In water tube boilers, the water is circulated through tubes that run between the upper steam drum and the lower water collection drum (mud drum). Water circulation is created using the principles of differential density. The downcomer is the cooler water line that goes from the upper drum to the lower drum. The riser is the hotter water line that goes from the lower drum to the upper drum.

A fire tube boiler is similar to a shell and tube exchanger. A combustion tube equipped with a burner transfers heat through the tubes and out of the boiler. The tubes in a fire tube boiler are submerged in water and designed to transfer heat energy to the liquid through conduction and convection. Sediment accumulated in the bottom of the mud drum is removed by water blowdown. Steam from the upper drum can be superheated before entering the steam distribution system. Desuperheaters are used to lower the steam temperature for processes that cannot tolerate the higher steam temperatures.

Steam used in a process facility is usually condensed to water. This condensate can be reused as boiler feedwater.

Oil- or gas-fired burners provide the boiler heat. A damper is used to regulate combustion air flow. Combustion gases exit the boiler stack as flue gas.

The boiler feedwater supply is a critical part of steam generation. Feedwater is treated to remove contaminants that can damage system equipment or compromise its efficient operation. An economizer is used to preheat the feedwater as

it enters the boiler. Makeup water is added to maintain proper water levels in the system.

Proper boiler operation depends on controlling feedwater quality, maintaining a specific water level in the system, controlling boiler temperatures and pressures, and maintaining burner efficiency. Process technicians are responsible for monitoring boiler system operation and performing preventive maintenance on boiler system equipment. Typical tasks include checking the boiler stack for smoke; inspecting burners and flame patterns; checking burner fuel pressure, temperature, and air flow; and maintaining proper steam flows, temperatures, and pressures.

Problems associated with boiler operation include the impingement of burner flames on the tubes, loss of boiler feedwater, inadequate treatment of feedwater, or a high water level in the steam drum. A change in the flow or composition of the fuel can increase soot deposits and cause excessively high temperature on the tubes.

Some problems are a consequence of equipment age and design. Other problems are the result of instrument malfunctions, which can be caused by rain, dust, or moisture. Performing the required preventive maintenance, such as making sure that the damper linkages are properly lubricated, can prevent many problem conditions.

Boiler safety is built into procedures for operation. As is the case with all furnaces or direct-fired heaters, there is always the potential for fire or explosion in the boiler firebox. This is of greatest concern during boiler startup. Because of this, the boiler firebox must be purged of combustibles before light-off and in the event of misfire or loss of burner flame. Process technicians must always follow the specific startup and emergency procedures for the particular boiler in order to ensure personal safety as well as the safety of peers, the site, and the community.

Other potential hazards associated with boiler operation include the potential for exposure to feedwater chemicals, steam, hot water, radiant heat, and noise. Process technicians should wear appropriate personal protective gear and avoid skin contact with blowdown materials, which can contain hazardous chemicals.

Checking Your Knowledge

1. Define the following terms:
 - a. Superheated steam
 - b. Saturated steam
 - c. Blowdown
 - d. Fire tube boiler
 - e. Water tube boiler
 - f. Waste heat boiler
2. (True or False) Boilers deliver steam at a desired pressure and temperature that is used throughout the process facility.
3. List three examples of process equipment that use steam energy.
4. The common component(s) of a boiler is (are) (select all that apply):
 - a. radiant tubes
 - b. burners
 - c. a bridgewall
 - d. a firebox
5. Burners inject air and fuel through a distribution system. The key components of a natural gas burner include (select all that apply):
 - a. dampers
 - b. impellers
 - c. spuds or spiders
 - d. drums
6. (True or False) The economizer section is a fixed, vaned device that causes the air/fuel mixture to swirl above the burner.
7. Dissolved minerals in the boiler feedwater system include metallic salts and calcium carbonates that cause scale, corrosion, and turbine blade deposits. Boiler feedwater is treated with _____ to precipitate these minerals from the water.
 - a. lime
 - b. salt
 - c. lemon
 - d. ethanol
8. A water treatment method that uses ion exchange to remove all ionized mineral salts is:
 - a. deaeration
 - b. coagulation
 - c. reverse osmosis
 - d. demineralization
9. (True or False) Burner flame impingement or poor flame distribution can cause overheating and failure of the tubes.
10. When should a boiler be purged? (Select all that apply.)
 - a. Before light-off
 - b. After misfire
 - c. At the loss of burner flame
 - d. When flame impingement is present
11. (True or False) If atomization is not uniform, the burner tips on the atomization gun or burner require replacement.
12. What can be caused by burner wear? (Select all that apply.)
 - a. Uneven flame
 - b. Flame impingement
 - c. Hot spots
 - d. Loss of boiler feedwater flow
13. The _____ is a common name for the one fuel gas block valve that is designated as the main shutoff valve.

NOTE: Answers to Checking Your Knowledge questions are in the Appendix.

Student Activities

1. Write a one-page paper about the three boiler types and their functions. Include drawings of the boilers and label their components.
2. Research boiler accidents. Choose one and write a one-page paper about the causes of the accident and how this type of accident can be avoided in the future.
3. Within a group, select one type of water treatment method used in boiler feedwater. Research this treatment method and present what you learned to the class. Be sure to include drawings and explain how the water treatment can enhance productivity for the process unit.
4. With a partner, review the typical startup procedure mentioned in the chapter. After reviewing the procedure, decide what steps can be added to make the procedure safer for the individual, the equipment, the production goals, and the environment. Be prepared to present your information to the class.