•••POWER ENGINEERING

Fourth Class

Edition 3.5

Introduction to Boiler Designs

Part A

Unit A-11

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Partner in Education

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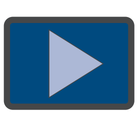
MEDIA 	Media icons show that some form of supporting medium is available. These media may include videos, animations, 2D and 3D models, multi-views of cutaways, simulations, and more. Media elements are available to registered textbook purchasers online via MyPower Study.
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4th Class Edition 3.5 • Part A

UNIT A-11

INTRODUCTION TO BOILER DESIGNS

Unit Introduction

Boilers are the main pieces of equipment operated by Power Engineers. Industries that use boilers are so varied in their process fluid requirements that it would be impossible to design one boiler to meet all their needs. These needs vary in terms of fluid type (steam or hot water), pressure (high or low, sub- or super-critical), capacity (kW or kg steam per hour), steam quality (superheated, saturated), and temperature. For this reason, there are boilers designed to meet practically every specification.

The design and development of boilers has proceeded over a few hundred years. Advances in design and technology have led to the present modern-day boiler. These historical advancements inform present-day boiler design. Today's rugged and reliable boiler designs reflect principles first established in the 1800s.

This unit examines the historical development of boilers and the different boiler varieties available today.

Unit Rationale

A person with a driver's license can drive a car without knowing how cars are designed or assembled. However, those with this knowledge have the potential to be great drivers. These drivers understand design limitations, and can anticipate when the limitations are being approached. They understand how important maintenance is, and can ensure their cars stay in peak condition. They understand when car parts need replacement, because of how their cars behave. The ability to recognize when things are working like they should, and what car designs can and cannot do, are traits of good drivers.

The same is true of Power Engineers. The greater the knowledge of the equipment being operated, the better the operator. Power plant knowledge begins with boilers. Knowing how they are designed, constructed, installed, maintained, and operated makes good Power Engineers better. This is the difference between being certified and competent.

CHAPTER 1

Introduction to Boilers

Learning Outcome

When you complete this chapter you should be able to:

Describe the historical development of boilers, boiler design, components, and configuration.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Describe the history of boiler applications, boiler design, and modern boiler improvements.*
2. *Describe packaged boilers.*
3. *Describe the construction of shop-assembled and field-erected boilers.*
4. *Describe components and design aspects common to all boiler vessels.*

Chapter Introduction

Steam boilers have been in use for thousands of years. The ancient Greeks and Romans used them extensively for heating buildings and public baths and had even invented a simple steam turbine by the first century AD.

According to the **American Boiler Manufacturers Association (ABMA)**, a boiler is "a closed vessel in which water is heated, steam is generated, steam is superheated, or any combination thereof, under pressure or vacuum by the application of heat." The operation, maintenance, inspection, and repair of boilers and their related systems has developed over centuries into the near exclusive domain of Power Engineers.

In theory, the production of steam is simple and relatively safe. However, when steam is produced under pressure, it can unleash great amounts of energy. Properly controlled, this energy powers all of society. If uncontrolled, this energy has proven to be highly destructive. If nothing else, history has demonstrated the need for efficient, safe, and reliable boilers.

There are many different boiler designs. Each has been developed to suit specific needs. To safely operate boilers, Power Engineers must understand how they are designed and built. This chapter is a broad overview of different types of boilers, their design, and construction.

Objective 1

Describe the history of boiler applications, boiler design, and modern boiler improvements.

History of Boilers

If one were to trace the "genealogy" of Power Engineers, it would lead back to great men like Thomas Savery, Thomas Newcomen, James Watt, and Richard Trevithick. They were important figures in the Industrial Revolution with regard to the development of steam boilers.

The Industrial Revolution was a major turning point in history, in large part due to the harnessing of steam power. This power was the driving source that brought society to previously unimagined levels of prosperity and productivity. New technologies were invented, older ones improved upon, and great technological leaps were made possible.

Early Shell-Type Boiler Designs

In the late 1600s, steam was generated in containers that resembled brewer's kettles more than they resembled modern steam boilers. These early boilers were inefficient and weak, and had limited industrial application. One of those applications came about in the early 1700s. At that time, coal mines had become so deep that they were filling with ground water. To solve this problem, in 1702, Thomas Savery invented an "engine" that could be used to pump the water out and to a safe location.

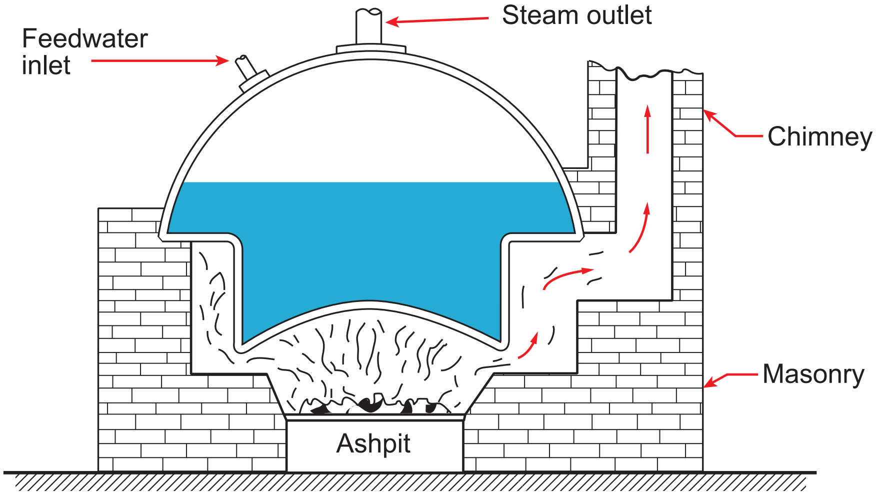
In 1712, Thomas Newcomen developed an atmospheric pressure steam engine. It was based upon Savery's principles, but it could do more than merely pump water. This engine is recognizable to modern eyes, because like today's engines, it had a cylinder with a movable piston. Newcomen's engine developed power by harnessing the difference between the atmospheric pressure on one side of the piston, and the vacuum formed by condensing steam within the cylinder.

James Watt improved upon Newcomen's engine between 1763 and 1775. He reasoned that using boiler pressure acting against a vacuum could develop greater power, and would be more efficient in operation.

Savery, Newcomen, and Watt all harnessed the energy of very low-pressure steam. Each were concerned that even moderately pressurized boilers were unsafe, due to the numerous boiler explosions during that era.

A typical steam boiler in the time of Savery, Newcomen, and Watt consisted of a single, enclosed, riveted copper container. An example of this early design was the Haycock Boiler of around 1720 (Figure 1). The boiler shell was partially filled with water, and enclosed within a brick setting that supported the shell and formed the furnace.

Figure 1 – Cross-Section of an Early Boiler Design (Haycock Boiler)



The fuel was burned below the vessel. The lower part of the shell was exposed to flames and hot gases as they travelled towards the rear of the boiler on the way to the chimney. The heat was conducted through the lower half of the shell, and heated up the water inside. When the water reached its saturation temperature, steam was generated and collected in the upper part of the shell.

The part of a boiler through which heat is transferred from combustion gases to boiler water is called the **heating surface**. The heating surface can be further divided into the **fireside** and the **waterside**. The fireside is the heat transfer surface exposed to radiant heat or the products of combustion. The waterside is the heat transfer surface covered with water, steam, or both. In this early boiler, the heating surfaces consisted only of the lower half of the shell. Because the furnace was located outside the shell, this type of boiler is classified as **externally fired**.

This boiler design was very inefficient because the heating surface was small, and the hot gases did not spend much time in contact with the heating surface. Most of the heat generated by the combustion of the fuel went up the chimney instead of being absorbed by the boiler water. Also, a large amount of heat was lost through the brick walls of the furnace.

The Haycock boiler and its successors were limited to low pressures, due to the inherent design and manufacturing weaknesses. Despite being limited to low pressure applications, these boilers exploded with alarming frequency, because early boilers did not have the safety devices found on modern boilers.

James Watt's engine created the preconditions for the development of high-pressure boilers. Instead of applying atmospheric pressure against a vacuum, Watt's engine applied boiler pressure. It was only a matter of time for other engineering pioneers to realize the potential power increase from using higher boiler pressure.

First High-Pressure Designs

In the early 1800s, Richard Trevithick created several high-pressure boiler designs, including the one shown in Figure 2. These boilers contained many innovative features still found in modern boilers:

a) An **internal furnace** that reduces heat losses.

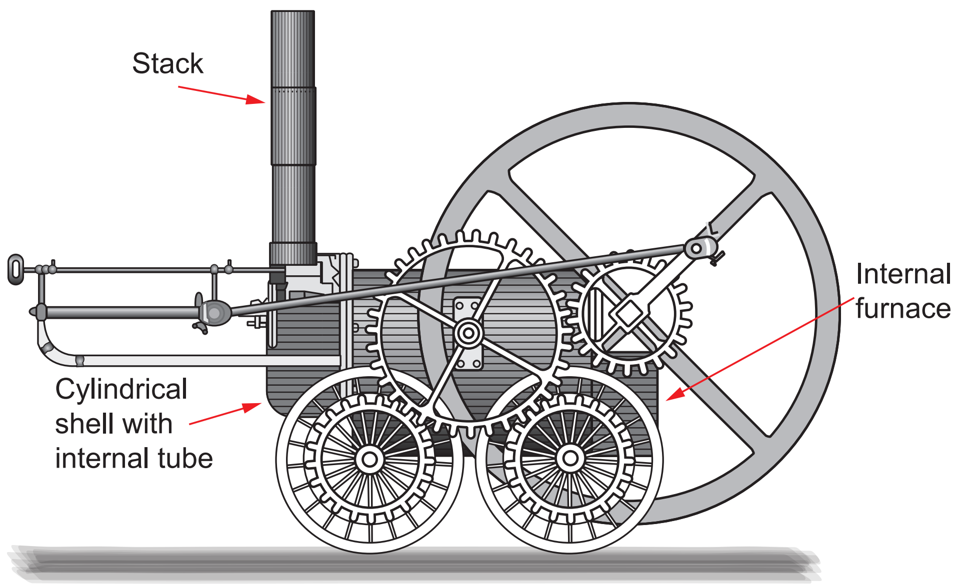
b) A chimney (or stack) that improved combustion.

c) A cylindrical shell with a dished end that was stronger than previous enclosures, and increased the heating surface of the boiler.

d) An internal tube that was surrounded entirely by water. This allowed the combustion gases more opportunity to transfer heat. Later more tubes were added, that aided heat transfer and strengthened the boiler. These internal tubes are called **firetubes.**

A drawing of the 1802 Trevithick Coalbrookdale boiler is shown in Figure 2. This was one of the first steam locomotives. It combined his advanced boiler design with a high-pressure steam engine, which drove wheels through toothed gears.

Figure 2 – Trevithick Boiler circa 1802



These early engines led to improved steam cycles. This led to better boilers, improved transportation, and large-scale electric power generation. These developments incorporated the technological underpinnings of today's sophisticated plant machinery.

Firetube Boilers

Trevithick's boiler was the first to include submersed firetubes. For this reason, Trevithick is credited with making the first firetube boiler.

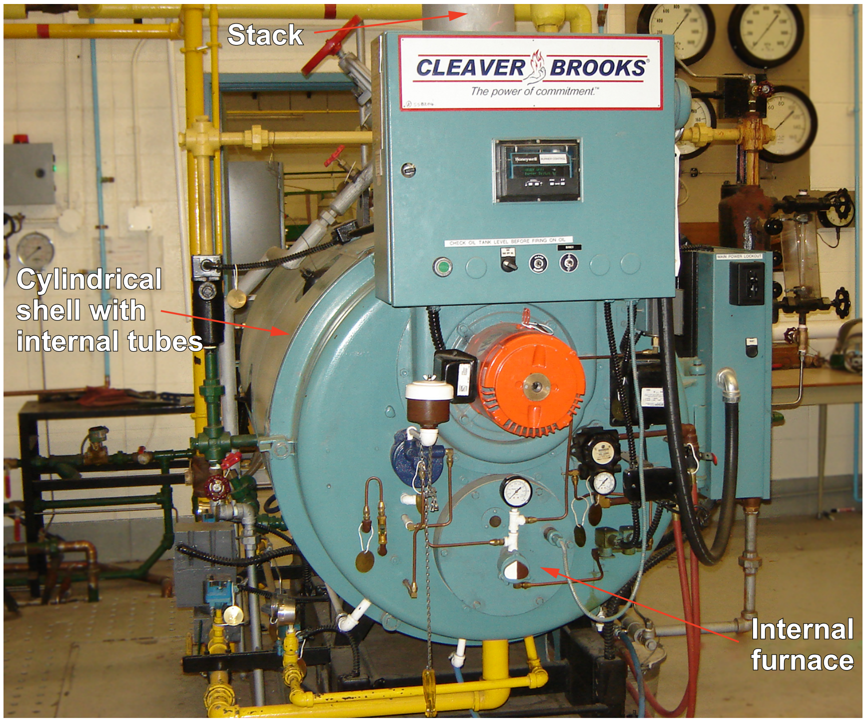
The introduction of firetubes was an important stage in boiler evolution. Until then, all designs were essentially shell-type kettles placed atop fires. Firetubes are significant for two main reasons:

1. The addition of firetubes increased the ratio between boiler heating surface and water volume. This allowed firetube boilers to produce steam more quickly, and consume less fuel than shell-type boilers.

2. Firetubes stiffened the boiler structure. This allowed boilers to safely support higher internal pressures.

Figure 3 shows a modern firetube boiler, similar in appearance and operation to Trevithick's boiler. This boiler incorporates all of Trevithick's technological advances, and more. It has a submerged furnace and multiple firetubes to increase the strength and efficiency of the shell. However, modern firetube boilers are made of better materials, assembled with better methods, and designed according to modern engineering practice.

Figure 3 – Modern Firetube Boiler



Watertube Boilers

Straight Tube Designs

In 1856, Stephen Wilcox patented a boiler considered to be the first **watertube** design. These boilers feature drums and headers that are connected by water-filled tubes. The combustion gases travel over the outside surfaces of these tubes, and transfer their heat to the water within.

Wilcox called his boiler the "Safety Boiler" for two reasons. The boiler had:

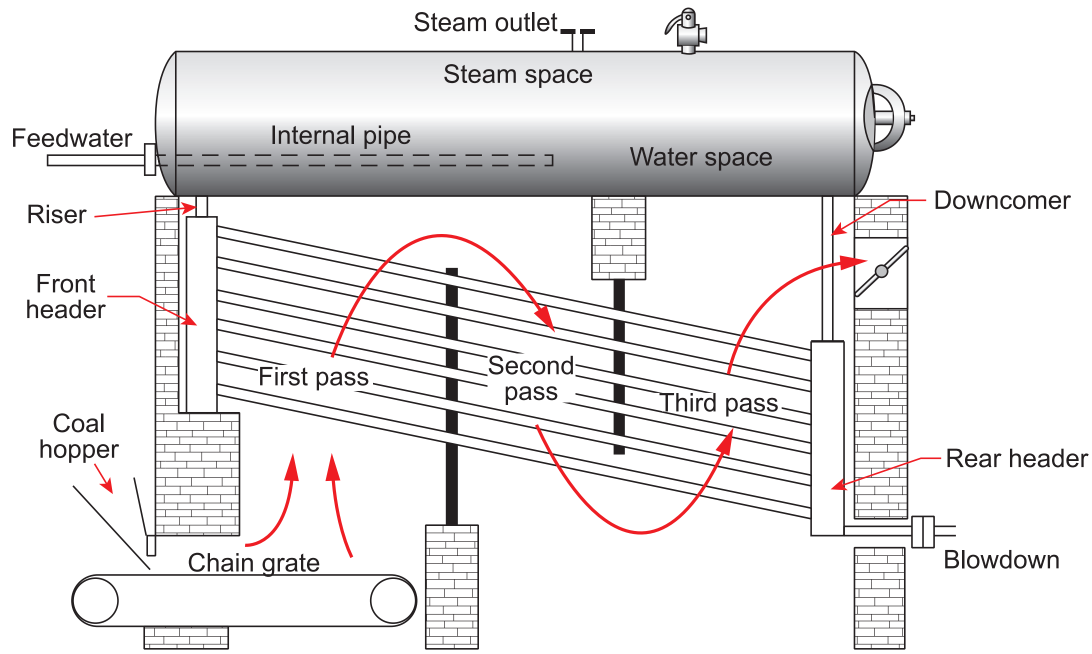
1. A small internal water volume
2. Small diameter pressure parts

If made of the same material and thickness, smaller diameter pressure parts can withstand higher pressure than larger diameter parts. As well, the explosive potential for a boiler is proportional to the mass of saturated water within the shell. Small diameter parts have less water volume, and so have less explosive potential.

Wilcox's design was considered far safer than the firetube boilers of its time. In 1867, Stephen Wilcox and George Babcock formed Babcock and Wilcox (B&W), and released an inclined straight-tube watertube boiler design similar to that shown in Figure 4.

Because water treatment chemistry was not yet developed, boilers had a tendency to develop waterside scale and other conditions that made boilers unsafe and inefficient. The tubes in the early Babcock and Wilcox designs were kept straight to facilitate mechanical waterside cleaning, which was done regularly.

Figure 4 – Early Watertube Boiler Design

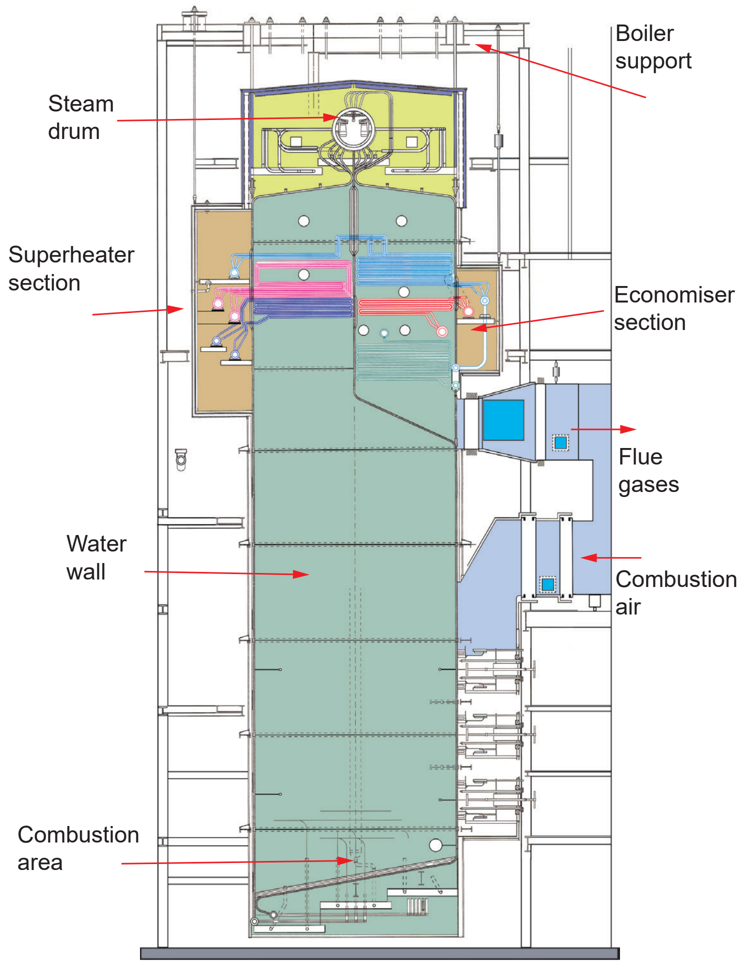


Bent Tube Designs

Watertube boilers came to dominate the world of steam production. Part of this reason is that these boilers can be designed to be extremely large capacity high-pressure units, for generating electric power.

Some of the largest watertube boilers stand over 10 stories tall. They produce over 2 million kilograms of steam per hour, at pressures of over 20 MPa, and steam temperatures near 600°C. A steam generator similar to this description is shown in Figure 5. In comparison, the 150-year-old straight-tube watertube boiler could only produce about 5000 kilograms of steam per hour, at about 1000 kPa, and around 180°C.

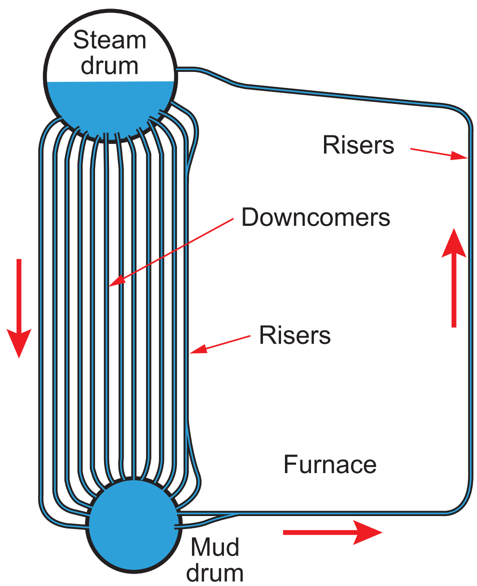
Figure 5 – Modern Steam Generator (Watertube Boiler)



To permit the development of such large-scale boilers, water treatment chemistry needed to be developed and perfected. When boiler manufacturers were confident that boiler water treatment techniques could keep watersides clean, they began making bent watertubes. Bent tubes could be attached radially to boiler drums. This greatly increased the heat transfer area, and allowed more boiler parts to be placed in close proximity to the furnace heat. Bent tube construction was the last major technical achievement that led to the creation of very large steam generating units.

Figure 6 shows a modern design of watertube boiler. Compare it to the straight-tube watertube boiler in Figure 4. Note that in Figure 6, the watertubes are bent so they can be attached radially to the drums. The bent watertubes also surround the furnace, thus absorbing more radiant heat.

Figure 6 – Bent Tube Watertube Boiler



Other significant advancements in boiler design include:

a) Water-cooled furnaces, whereby the furnace is completely surrounded with heat transfer surface.

b) Internal steam/water separation devices.

c) All-welded construction, with weld joints as strong as the parent metal.

d) Improved draft equipment, to supply combustion air and remove flue gas.

e) Improved combustion equipment, including burners and burner controls.

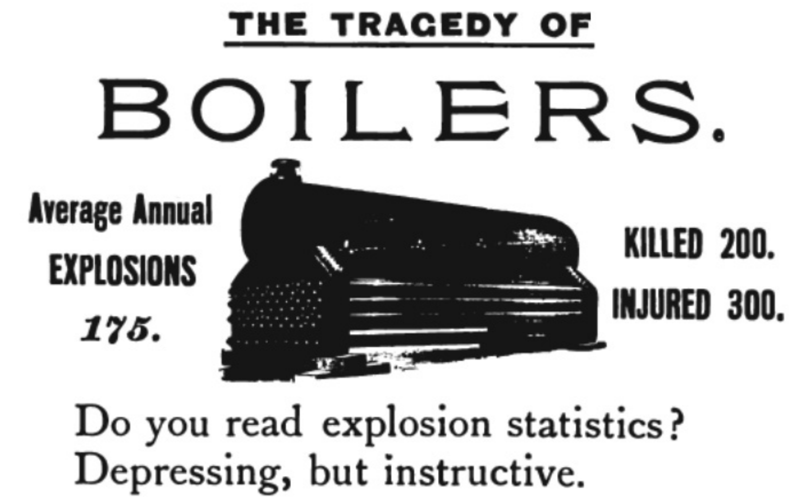
f) Addition of components to extract more heat from the combustion gases, such as economizers, air heaters, and superheaters.

Boiler Design and Manufacturing

Origins of the Boiler and Pressure Vessel Code

In the mid to late 1800s, boiler explosions were so common that monthly trade publications listed the locations and severity of explosions over the prior month. Figure 7 shows part of an advertisement of a boiler manufacturer in an 1893 edition of *The Safety Valve*. The manufacturer used this headline to draw attention to how their boiler designs were safer than others.

Figure 7 – Boiler Advertisement circa 1893



Three significant causes of boiler explosions were:

1. Inconsistent and inadequate boiler design
2. Inconsistent and inadequate methods of construction
3. Poorly trained and unskilled operators

On March 20, 1905, a massive boiler explosion at a Brockton Massachusetts shoe factory killed 58 and injured 117 others. As a result, in 1905 Massachusetts became the first US jurisdiction to enact formal rules for the design and construction of boilers.

In 1911, manufacturers and users from several US states appealed to the **American Society of Mechanical Engineers (ASME)** to develop consistent, unified rules for the design and construction of power boilers. After the release of the ASME **Boiler and Pressure Vessel Code (BPVC)**, several US and Canadian jurisdictions adopted ASME codes as law. Within a few years, nearly all US states and Canadian provinces followed suit. As the codes became law, all boiler manufacturers were compelled to use the same design calculations, similar materials of construction, and consistent manufacturing methods.

All boilers currently manufactured in Canada and the USA are designed and built according to the ASME BPVC. These codes contain rules for design, fabrication, and inspection of boilers and pressure vessels, as well as, guidance for their operation.

ASME BPVC

Boilers may be designed to produce either steam or hot water, at high or low pressure, and at high or low temperature. The ASME BPVC calls high pressure, high temperature designs **power boilers**. The low pressure, low temperature designs are called **heating boilers**. Different ASME codes are used for the design and construction of power boilers and heating boilers. Though designed according to different rules, power and heating boiler operation is quite similar.

Refer to Table 1. Power boilers are designed and constructed according to **Section I** of the **ASME BPVC**. Power boilers, if designed to produce steam, are built to operate at greater than 100 kPa gauge pressure. If designed to produce hot water, power boilers are built to operate at a temperature greater than 120°C, at a pressure greater than 1.1 MPa, or both.

Heating boilers, on the other hand, are low-pressure boilers. If designed to produce steam, heating boilers are built to operate at pressures not exceeding 100 kPa. If designed to produce hot water, they are built to be operated at pressures not exceeding 1.1 MPa, and at a temperature not exceeding 120°C. Heating boilers are designed and constructed according to **Section IV** of the **ASME BPVC.**

Table 1 – Comparison of Power and Heating Boilers

	Power Boilers	Heating Boilers
Design Pressure (Steam)	> 100 kPa	<= 100 kPa
Design Pressure (Hot Water)	> 1.1 MPa	<= 1.1 MPa
Design Temperature (Hot Water)	> 120°C	<= 120°C
Design Code	ASME I	ASME IV

Boilers are most commonly used to produce steam, which is a highly effective heat transfer fluid. Steam energy can be used to power turbines to generate electricity, drive pumps, supply process heat, or for building heat.

Boilers can also produce hot fluids such as hot water, hot glycol, and hot oil. These are also very effective heat transfer fluids. They are used in processes not suited for steam. Hot fluids can be used for building heat, tank heating, wood kilns, and other process applications. An advantage of using hot oil is that very high temperatures can be achieved without high operating pressure.

From their beginnings, different types of boilers have evolved to meet specific industrial requirements. High pressure, high temperature, and high capacity boilers are used to produce electrical power. Thermo-flooding boilers are used to inject large amounts of heat into the ground for the purpose of oil production. Compact boilers have been developed for small industries such as dry cleaning and safety valve repair shops. The ASME BPVC covers all sorts of design and construction applications. Boilers designed to the ASME BPVC are recognized worldwide for their sound design and construction.

There are many different boiler designs, materials of construction, and firing methods. They may be firetube, watertube, shell type, or sectional designs. They may derive heat from coal, wood, natural gas, fuel oil, black liquor, electric, nuclear, or solar energy sources. There are boilers through which water continuously recirculates, permitting only steam to leave. There are boilers with no internal recirculation, where water enters at one end and transforms entirely to steam by the time it exits (**once-through boilers**). Some boilers must be built on the site where they will be placed in operation (**field-erected boilers**). Others are entirely factory-built and tested, and then transported to the plant site (**packaged boilers**). Boilers can be constructed of copper, cast iron, or steel. All these boilers fall under the auspices of the ASME BPVC.

Ideal Boiler Design

The chief aim in modern boiler design is to produce a boiler that will be safe and efficient in operation, and economical in fuel consumption.

In 1875, George Babcock and Stephen Wilcox wrote what they believed to be the key considerations in developing a “perfect” boiler. Their principles were carefully considered and expressed, and are still relevant today. Though the following is not their exact wording, most of their original principles are reflected in the following list:

a) A boiler must have a large heating surface so that the maximum amount of heat can be absorbed from the burning fuel. This increases the efficiency of the design by maximizing heat absorption.

b) All parts of the boiler-heating surface exposed to fire or hot gases must be covered by water. This is essential to prevent overheating of the boiler metal, which could result in catastrophic failure.

c) A boiler must have a thorough circulation of water through all of its parts, to prevent overheating of any part of the heating surface. The circulating water in the boiler cools the metal by removing heat from the boiler tubes. If circulation was impeded by tube blockage or poor design, affected tubes would be unable to shed the heat of combustion. Then, they would overheat or fail.

d) A boiler must be properly insulated to minimize heat loss to its surroundings.

e) The steam space of a boiler must be large enough for the steam to rise freely from the surface of the water, without carrying water droplets into the steam line. Steam that contains water can damage machinery, such as turbines, and can cause deposits in superheater tubes.

f) All parts of a boiler must be easily accessible for inspection, cleaning, and repairs.

g) A boiler must be simple in construction, built with high standards of workmanship, the best available materials, and to the best possible design standards.

h) A boiler should be inexpensive and easy to maintain.

i) A boiler must be strong enough to withstand the pressures and temperatures it will encounter in service.

j) A boiler must have proper allowance for expansion and contraction of all parts. As metal changes in temperature, it expands or contracts. The boiler components must be unrestrained in order to prevent damaging stresses.

k) A boiler must be furnished with the approved fittings such as gauges and pressure relief valves.

In general, a boiler should be designed to absorb the maximum amount of heat available from the furnace and, at the same time, provide maximum safety and reliability in operation. The design should also be compact to keep down building costs but provide adequate access to the parts for maintenance and inspection.

Objective 2

Describe packaged boilers.

Packaged Boilers

A packaged boiler is completely factory-built, and sold as an entire package. The package includes a properly sized burner, fittings, and accessories suitable for the boiler temperature and pressure, and all the necessary controls to be functional.

The boiler is constructed, outfitted, and tested in the manufacturing facility. Then, the completed unit is transported for installation. Packaged steam boilers only require field connections to fuel, feedwater, steam, electrical power, control systems, and a chimney. Packaged boilers are also available for hot water systems. In this case, they must be connected to the hot water supply and return lines.

Packaged boilers are mass-produced to existing specifications and design. They are usually limited in overall dimensions by railway or roadway height and width restrictions.

The largest packaged boilers are made to specific customer requirements. These are referred to as "shop assembled" boilers.

Packaged boilers have several advantages, including:

a) Lower construction costs, since the entire boiler can be mass-produced in the factory.

b) Lower purchase price, because it is mass-produced.

c) Lower shipping costs. This is because the boiler is transported as a single unit, rather than as several shipments of individual components.

d) The boiler is tested and inspected prior to site delivery to ensure the quality of the unit.

e) On-site installation is reduced, with only positioning of the boiler and connection of external auxiliary systems and piping required.

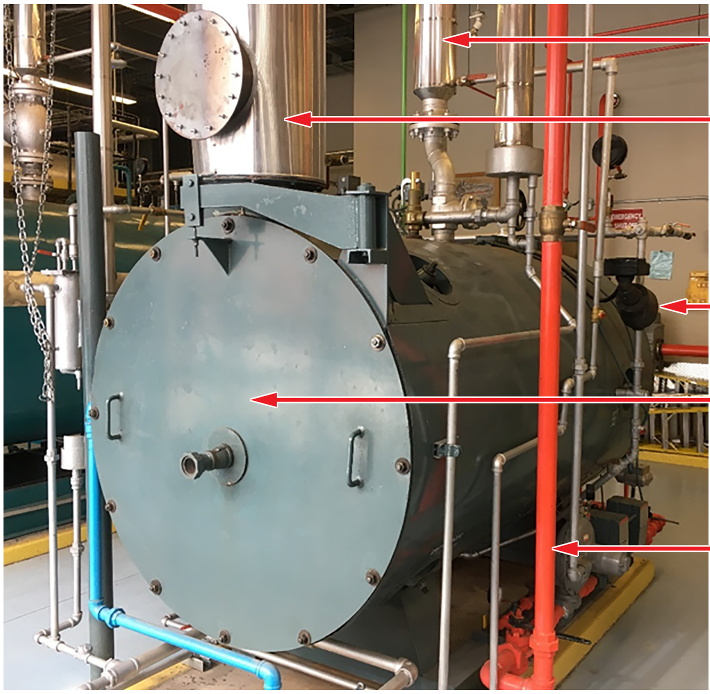
f) Compactness and versatility in design. Packaged boilers can be designed with a very small footprint.

Packaged Firetube Boilers

Early firetube boilers were manufactured at the factory and shipped to the site, where they underwent further assembly. Refractory, insulation, boiler fittings, controls, and firing equipment were installed locally by various trades. Today, practically every firetube boiler sold is a packaged boiler.

Packaged firetube boilers may be power boilers or heating boilers. For power boilers, the tubesheets, drum, tubes, and all boiler fittings are of stronger design and construction. This makes power boilers suitable for high pressure or high temperature service.

Figure 8 – Packaged Firetube Boiler



Packaged firetube boilers can be purchased in sizes ranging from just a few kW up to 25 000 kW (2500 horsepower). Models are available for low-pressure steam, high-pressure steam, or hot water service. Some are designed to operate at pressures greater than 2000 kPa. Various models are available to burn natural gas, propane, light fuel oil, heavy fuel oil, or coal.

Packaged Watertube Boilers

The bent tube watertube boiler is often produced as a packaged unit. Like their firetube counterparts, these units have water-cooled furnaces and mechanical draft systems. A steel casing covers the outside of the boiler and furnace to prevent combustion gas leakage into the boiler room.

A skid-type steel foundation is included. Like the packaged firetube boiler, the packaged watertube boiler is bottom-supported. This means the mud drum is supported by a steel structure, and the weight of the steam drum is carried by the tubes. This support requires special concrete footings to support the weight of the boiler and its water content.

Packaged watertube boilers are available for high and low-pressure applications, in both steam and hot water service. The largest packaged boilers are around 73 000 kW (7300 boiler horsepower), and deliver superheated steam at pressures of over 15 000 kPa. Fuel choices include natural gas, wood products, light fuel oil, heavy fuel oil, coal, and waste heat.

Figure 9 shows a small packaged watertube boiler, fired with natural gas. Boilers around this size produce about 850 kg of saturated steam per hour, at pressures up to 1035 kPa.

Figure 9 – Packaged Watertube Boiler

Figure 10 shows a larger packaged watertube boiler. Boilers of this size may produce around 5000 kg of saturated steam per hour, at pressures near 1725 kPa.

Figure 10 – Large Packaged Watertube Boiler

Objective 3

Describe the construction of shop-assembled and field-erected boilers.

As watertube boilers increase in capacity, they become too large to build entirely in the fabrication shop, and too large to ship as complete boilers. These boilers are categorized as **shop-assembled** (or modular) boilers, and field-erected boilers. Of these two, the field-erected boilers are the largest. In fact, the largest boilers in the world are field erected.

Shop-assembled and field-erected boilers are shipped in pieces. Final assembly takes place at a construction site.

Shop-Assembled Boilers

Shop-assembled boilers usually require site assembly of only a few major components, such as the burner, controls, and a few other large modules. Most of the boiler components that require field assembly are built and tested in the factory shop, prior to delivery to the job site.

Packaged and shop-assembled boilers are typically bottom supported on steel skids or supporting framework. The boiler must be placed on a suitably reinforced, level concrete base that has adequate strength to support the weight of the boiler, its contents, and any attached auxiliary equipment. Larger types may need to be placed on concrete pilings.

The packaged watertube boiler shown in Figure 10 has dedicated supports for the lower drum. These supports hold the entire weight of the boiler, and transfer the load to a level concrete base. The supports must be able to accommodate linear expansion of the boiler vessel, as it warms to operating temperature. For this reason, bottom-supported boilers are affixed to their foundations at only one end, and left free to expand lengthwise. Though Figure 10 is a packaged boiler, shop-assembled boilers are similarly supported.

Field-Erected Boilers

Field-erected boilers are assembled piece-by-piece on-site, with shop-fabricated components. Most field-erected boilers are extremely large, though some small packaged boilers can be purchased as field-erected types. These small, bottom-supported boilers are convenient for retrofits, where access to an existing boiler room may be difficult.

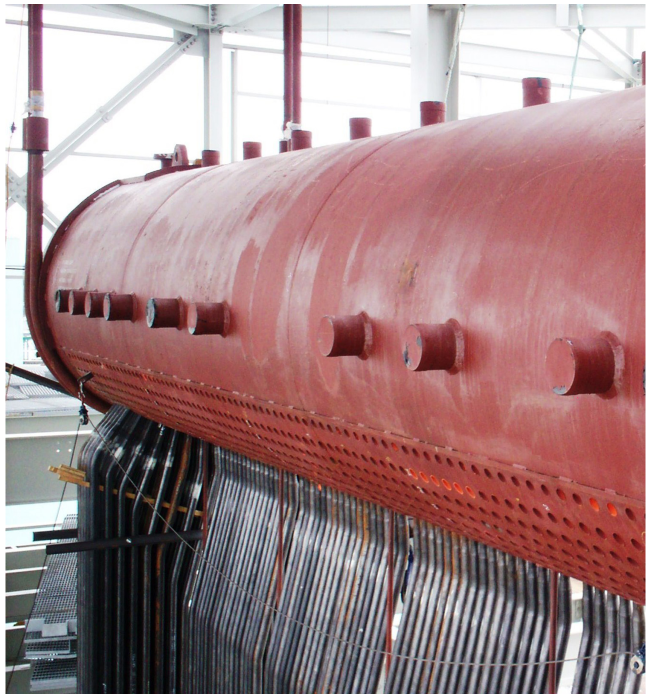
Large field-erected boilers are found in heavy industry and utility use. They include electrical utility boilers and black liquor recovery boilers. These boilers are all top-supported. This means that the steam drum and upper headers are hung from overhead structural steel framework. The mud drum, tubes, waterwalls, and lower headers are all supported from above by the overhead structural steel, or by their connections to upper headers or the steam drum. Because they are top supported, these boilers are free to expand in length as they warm up.

Before field-erection, a structural steel framework must be erected at the boiler's final destination. Individual components, such as drums and headers, are welded, drilled, and stress-relieved in the shop. Tubes and waterwalls are bent to precise dimensions in the shop prior to shipping. Then, several shipments of boiler components are made to the construction site.

At the construction site, boilermakers use cranes to lift components into position. The boiler is carefully assembled using detailed plans. After the boiler's pressure vessel is constructed, inspectors test its integrity. When all piping, ductwork, burners, heat exchangers, and auxiliary equipment are installed, refractory and insulation are applied to the boiler exterior.

Figure 5 shows a top-supported field-erected boiler. Figure 11 shows how a boiler like the one in Figure 5 would be supported and site-fabricated. Enormous U-bolt hangers, connected to overhead steel work, support each end of the steam drum. The mud drum (not shown) hangs from the steam drum, supported by the watertubes.

Figure 11 – Field Erection of a Watertube Boiler



Objective 4

Describe components and design aspects common to all boiler vessels.

All boilers, whether firetube, watertube, power, heating, packaged, or field erected are pressure vessels: closed containers designed to withstand internal pressure. Most pressure vessels designs are cylindrical containers, enclosed at each end. Boilers are no exception.

Boilers have additional features:

- Holes that permit the installation of tubes and furnaces
- Nozzles for attaching piping and pipe fittings
- Openings for inspection, repair, and maintenance

The parts that make up the pressure vessel are named a little differently, based on whether a boiler is a watertube or firetube design.

Shells, Drums, and Headers

The main cylindrical pressure vessel of a firetube boiler is called the **shell**. The main cylindrical vessel of a watertube boilers is called a **drum**. Shells and drums are both constructed in much the same way. Flat plate is rolled and then welded into cylindrical shapes called **courses**. Multiple courses can be welded together to make longer shells and drums.

Figure 12 shows a flat plate being rolled into a cylindrical shell. Shells and drums are formed in the same way. The plate material and thickness are dictated by the boiler design pressure and temperature. Thicker plate may require heating in order to roll it into a cylinder. Very thick material may be rolled as two semi-cylinders, and then joined by welding.

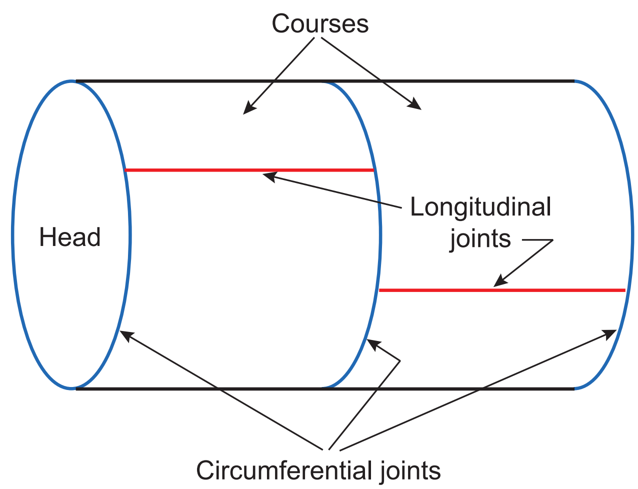
Figure 12 – Rolling a Boiler Shell

(Courtesy of Johnston Boiler Company, Ferrysburg MI)

After rolling, the edges of the plate are welded together where they meet, using a butt joint called the **longitudinal joint**. The completed cylinder is called a course. Several courses can be welded together with butt joints to form longer shells or drums. The joints used to join courses are called **circumferential joints**, because they traverse the circumference of the shell. Smaller diameter shells and drums may be made from lengths of seamless steel pipe.

Figure 13 labels the parts of a completed boiler shell or drum.

Figure 13 – Parts of a Boiler Shell or Drum



Whereas firetube boilers have only a single shell, most watertube boilers have two drums. Some varieties (especially older designs) have three or more drums. Some newer utility boiler designs (as in Figure 5) use only a single drum. Many once-through watertube boilers have no drum at all.

If boilers have two or more drums, the highest drum is the **steam drum**. This is where steam and water are separated. The lowest drum is called the **mud drum**. This is where sediment and debris accumulate, to be discharged from the boiler.

Watertubes are arranged so they directly connect to the steam and mud drums. In many instances, water tubes are connected to large collector pipes called **headers**, instead of directly to a drum. Headers are like small diameter drums. They are mostly cylindrical in cross-section, but may also be square or rectangular. Some headers distribute water to riser tubes. Others collect steam and water from headers, and direct the mixture to the steam drum.

Drums and headers have holes drilled in them for the installation of boiler tubes.

Heads

Shells, drums, and headers are enclosed at each end with **heads**. The heads are usually of the same material as the shell or drum to which they attach. Heads must be designed for the pressure and temperature of the boiler. After the courses are fabricated, the heads are welded into place with groove butt-welds, or occasionally fillet welds, around the circumference of the vessel.

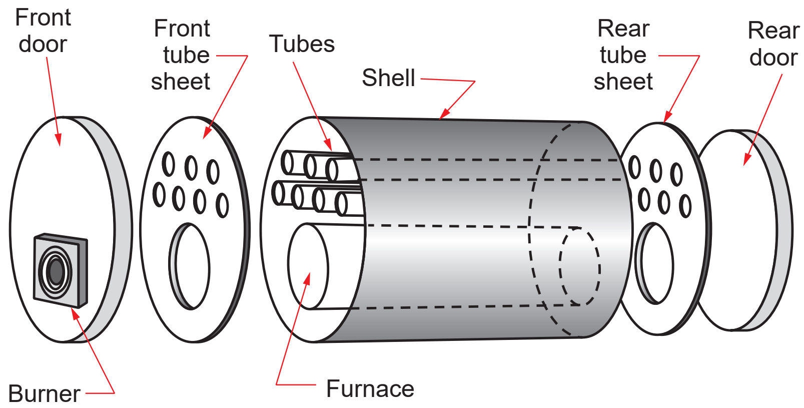
Firetube Heads (Tubesheets)

Firetube boiler heads are flat sheets, drilled to accept tubes. The heads are flat in order to accept the attachment of firetubes. Because tubes attach to these heads, they are commonly called **tubesheets**.

Flat heads do not restrain pressure very efficiently. They tend to bulge under pressure. To prevent this, and to make flat heads strong enough for the pressure they must support, they must be made extremely thick. This is costly. Flat heads made from thinner material must be supported to keep them from bulging. In a firetube boiler, the flat heads are mostly supported by the furnace tube and the firetubes. For this reason, firetubes are often called **stay tubes**. For the tubesheet areas that are not supported by tubes, **stays** are used for support. Stays are pieces of metal attached at one end to an unsupported tubesheet surface, and at the other end to the tubesheet or the shell.

Figure 14 shows an exploded view of a firetube boiler pressure vessel, and the relationship between the tubes, tubesheets, and shell (the doors are not pressure-retaining parts of the boiler). Note how little unsupported flat surface remains after the tubes and furnace tube are attached to the heads.

Figure 14 – Firetube Boiler Shell - Exploded View

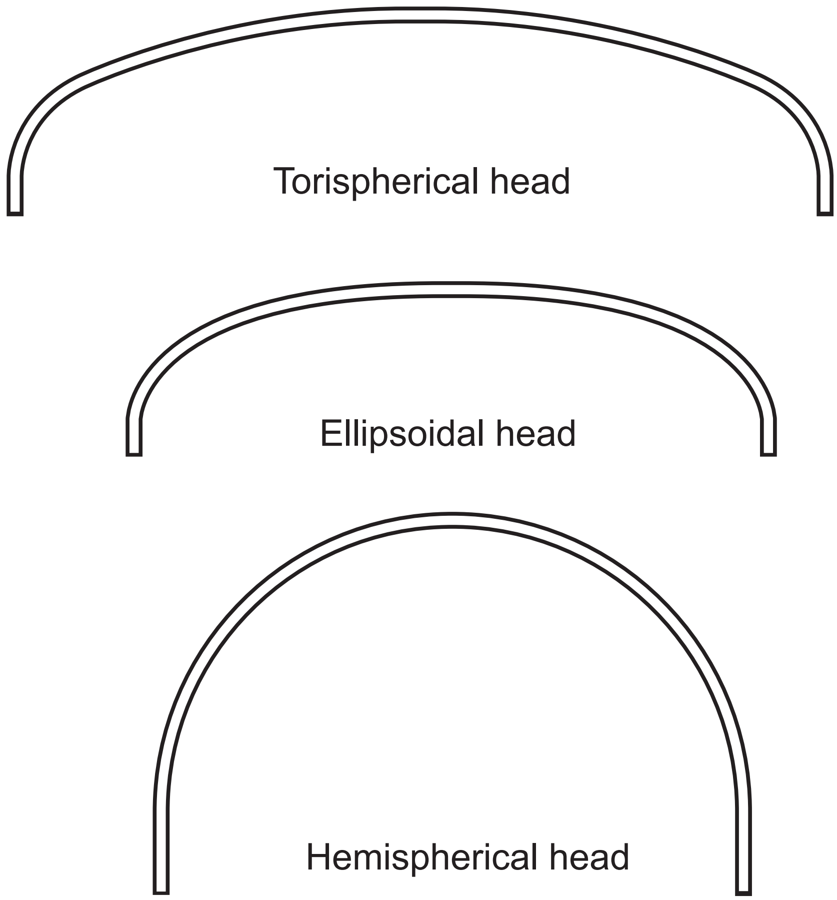


Watertube Boiler Heads

The drums of watertube boilers are enclosed with heads that are flat, or formed into a convex shape (**torispherical**, **hemispherical**, or **ellipsoidal**). The convex portion generally is exposed to the vessel pressure. Flat heads are not very common in watertube boilers. The most common head shape for a drum is ellipsoidal. Watertube boilers do not have stays because the heads and drum of watertube boilers are not flat, and because they do not have large flat surfaces to support.

Figure 15 shows torispherical, hemispherical, and ellipsoidal head shapes used on watertube boilers.

Figure 15 – Watertube Boiler Heads



Watertube boiler heads are often equipped with openings for inspection, maintenance, and repair, called **handholes** and **manholes**. Figure 16 shows a steam drum with a manhole opening.

Nozzles

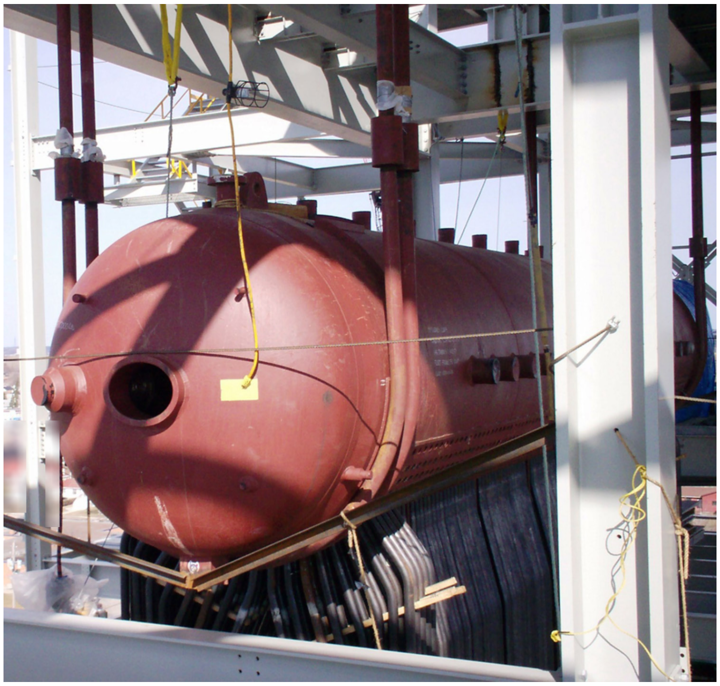
Shells, drums, and headers usually have nozzles welded to them. These are short tube stubs for the installation of:

- Pipe fittings, including steam outlet valves and safety valves.
- Feedwater, chemical feed, blowoff, blowdown and instrumentation piping.

As well, watertube boilers may have nozzles for the installation of downcomers and risers.

Nozzles may accommodate socket-welded, butt-welded, flanged, or threaded attachments. Figure 16 shows a watertube boiler steam drum during construction. The nozzles on the top of the drum are for attaching the pipes that carry saturated steam to the superheaters. The nozzles on the side of the drum are for piping that connects waterwall headers to the steam drum. When nozzles are welded to the drum, the entire drum is heat-treated for stress relief. When tubes or fittings are welded to the nozzles, only those points of attachment are heat-treated for stress relief.

Figure 16 – Watertube Boiler Steam Drum



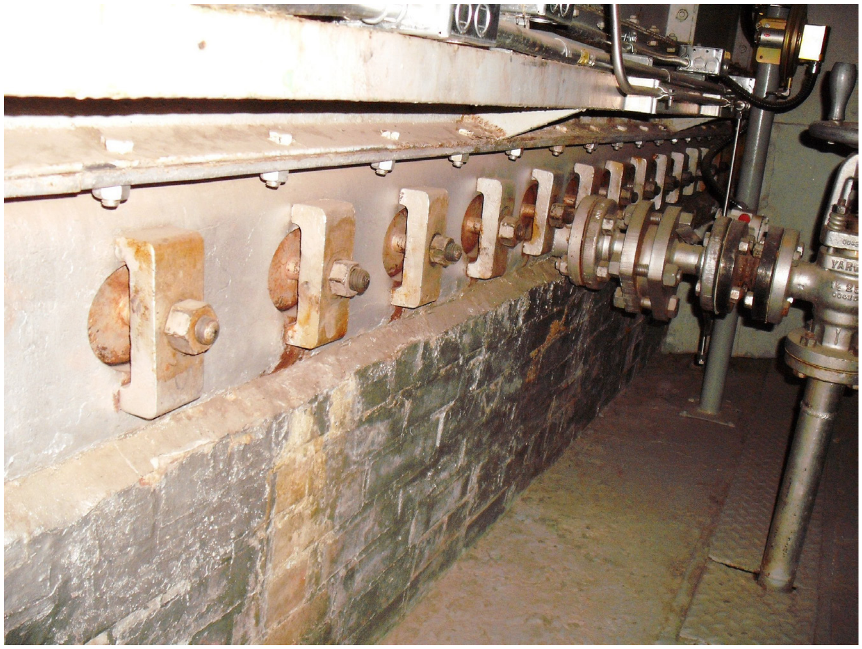
Access Openings

The ASME BPVC requires boilers to have adequate provision for inspecting, maintaining, and repairing internal parts of both firetube and watertube boilers. This means there must be openings in the shells, drums, and headers. These openings must be sealed tight when the boiler is in operation.

Larger firetube boilers have at least one manhole located at the top of the shell. In other shell locations, handholes are placed to assist inspection and cleaning. Some firetube boilers also have handholes and manholes located in the tubesheets.

Watertube boilers usually have manhole openings at the end of each drum. Occasionally, manhole openings are made in the top of the drum. Handholes are often located in headers at tube attachment locations. These handhole openings permit the expanded attachment of tubes, waterside cleaning, and inspection. Figure 17 shows a series of handholes located in the bottom header of an A-type watertube boiler.

Figure 17 – Handholes in a Watertube Boiler Header



Manhole and handhole openings are closed up with circular or elliptical plates. The left hand image in Figure 18 shows an uninstalled manhole plate, one of its two yokes, and with its gasket in place. The right hand image shows the same manhole plate installed on a boiler.

Manhole and handhole plates are held in place with one or two yokes, and one or two bolts, depending on the size of the plate. Internal boiler pressure helps hold the plates in place when the boiler is under pressure. Gaskets are used to seal the plates to the shell, drum, or head. Gaskets may be rubber, fabric, Teflon, or spiral-wound metallic.

Figure 18 – Manhole Plates, Yokes, and Attachment Bolts

In very high pressure boilers, access openings may be welded in place. The minimum size of handhole and manhole openings is mandated by CSA and ASME code.

Tubes and Tube Attachments

Both watertube and firetube boilers have tubes that must withstand pressure. Therefore, the tubes must be attached securely to the other boiler pressure vessel components.

Firetubes and watertubes are designed to withstand pressure differently. Watertubes are cylindrical components under *internal* pressure. Firetubes are cylindrical components under *external* pressure. Different sections of the BPVC are therefore used, due to the different nature of the loads they carry.

For moderate pressure service, boiler tubes are made from strips of steel that are formed into tubular shape. The edges are then welded using an electrical resistance-welding machine.

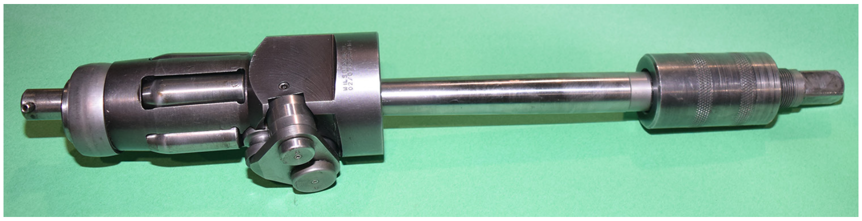
Tubes used for high-pressure service are usually seamless. These tubes are made by piercing a solid round billet of heated steel to form a rough tube. The rough tube then goes through a finishing process to produce the desired dimensions and smoothness. Boiler tubes are similar to pipe, but are made of thinner, higher quality materials for better heat transfer.

The most common method used to fasten tubes to drums or tubesheets is to expand the tube ends into the tube holes in the drum or sheet. This expanding (or rolling) is done by means of an expander. This tool consists of three rollers mounted in a cage that fits inside the tube end. A tapered mandrel fits between the rollers. When the mandrel turns, the rollers rotate. As they rotate, the mandrel forces the rollers against the tube wall, thus expanding the tube against the tube hole.

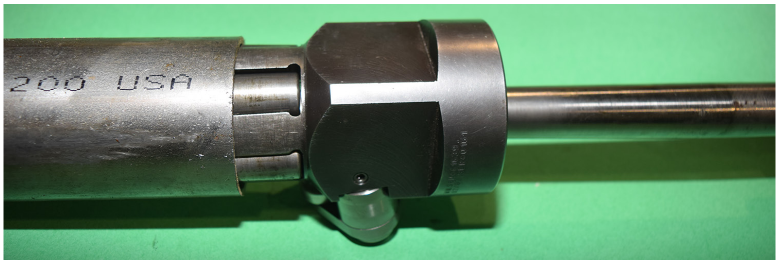
Firetube Attachment

Figure 19(a) shows an expander used for firetubes. It has an extra set of rollers turned at an angle, in order to flare or bell the tube end. Figure 19(b) shows the expander inserted into a tube, as it would be during the expansion process.

Figure 19 – Tube Expanders



(a)



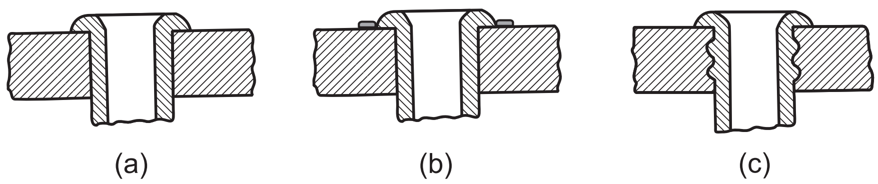
(b)

Figure 20 illustrates ASME BPVC approved methods of attaching firetubes by expanding. Figure 20(a) shows an expanded firetube with its ends beaded over. Beading involves bending the end of the tube so it makes physical contact with the tubesheet. The tube end is beaded because:

1. The contact between the tube end and the tubesheet keeps the ends of the firetubes cool when the boiler is in operation. Otherwise, the exposed ends would overheat and crack from exposure to hot flue gas.
2. Beading helps the tubes grab on to the tubesheet, keeping it from bulging.

The tube in Figure 20(b) has been expanded, flared, and then seal welded. The tube in 20(c) has been expanded into a grooved tube hole and then beaded over. Grooved tube seats are used for very high-pressure service in firetube and watertube boilers.

Figure 20 – Tube Attachments for Firetube Boilers

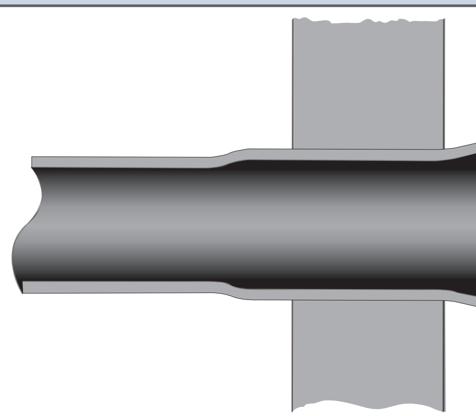


Watertube Attachment

In a watertube boiler, the tubes are expanded and flared as shown in Figure 21. Since the ends of these tubes are covered in water, there is no danger of overheating. Therefore, watertubes are not beaded over.

The flare at the end of the tube helps keep the tube from being pushed out of the drum by boiler pressure.

Figure 21 – Expanded and Flared Watertube

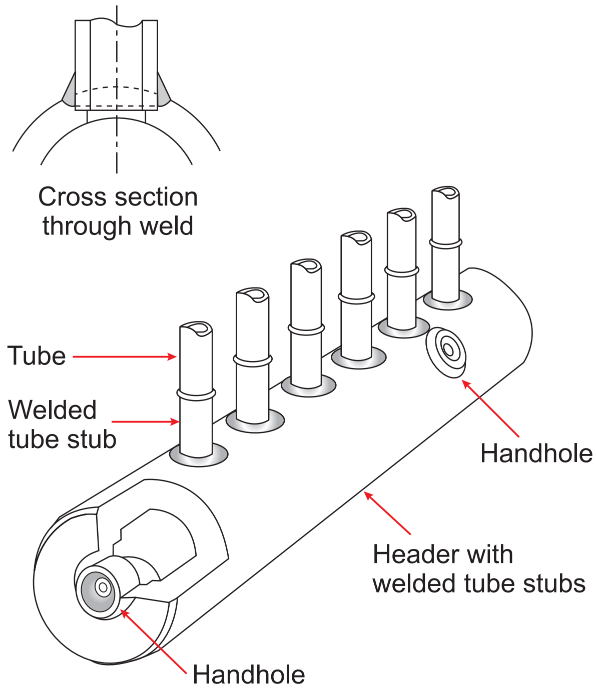


Instead of expanding, many high-pressure boiler tubes are welded into place. Welded attachments are permitted by the **ASME BPVC Sections I and IV.**

Firetubes can be welded directly to a tubesheet, without prior expanding.

Watertubes can be butt-welded directly to nozzles installed on headers or drums. The boiler drums and headers have stubs welded to them in the factory. The tubes are welded to these stubs during field erection. Tubes attached by welding are generally more suitable for higher-pressure service.

Figure 22 – Header with Welded Tube Stubs



Insulation and Refractory

Insulation and refractory materials are designed to:

a) Prevent heat loss, thereby increasing boiler efficiency.

b) Prevent metal failure by creating a barrier between the hot combustion gases and parts that are susceptible to heat damage.

c) Protect workers from exposure to high temperature surfaces.

Insulation is commonly fiberglass or mineral wool. Insulation is applied to the outside of the boiler pressure vessel, and is used to prevent heat loss. Often, protective metal sheets cover the insulation. The combination of insulation and the protective metal jacket is called **lagging**. Insulation must not be substituted for refractory, because insulation products are not designed to withstand high temperatures.

Refractory is highly temperature-resistant ceramic material. It can take the form of solid brick, boards, castable refractory (like cement or mortar), plastic refractory (like putty), or ceramic blankets. Refractory is found in the higher temperature zones of boilers, where it is used to protect metal surfaces. One common application of refractory blanket is for the protection of the front and rear doors of packaged firetube boilers. Castable refractory is commonly used around burner throats, to protect adjacent metal surfaces from intense radiant heat.

Modern boilers try to maximize the exposure of heat transfer surface to the radiant heat of the fire and to hot flue gas. They do this by surrounding the furnace with water-containing vessel components, such as submerged firetubes, submerged furnaces, and waterwalls. Surrounding the furnace with water-bearing parts has considerably reduced the need for refractory in modern boilers. Despite this, refractory still plays an important part in both firetube and watertube boilers.

Chapter Summary

The development of boilers to meet the needs of the modern day plant can be traced back hundreds of years. The advancements and innovative thinking of Savery, Newcomen, Watt, Trevithick, Babcock, Wilcox, and others are still evident in the boilers of today.

Modern boilers are designed to capture as much heat as possible from the fuel being burned, and to generate steam or other hot fluid safely. Boiler designs have improved – and continue to develop – for the sake of boiler safety and efficiency.

Industry demanded higher-pressure steam, which required these advances. Safety and efficiency improvements came about with the gradual introduction of firetube designs, watertube designs, water-cooled furnaces, welded construction methods, uniform design codes, and higher-pressure designs.

Power Engineers that understand the history of boiler development understand the design weaknesses inherent in particular boiler designs. This knowledge can be applied to the boilers they operate and maintain.

Though it isn't necessary to dwell on it, good Power Engineers understand that history informs the present day. As Winston Churchill said, "Those that fail to learn from history are doomed to repeat it."

CHAPTER 2

Firetube Boilers

Learning Outcome

When you complete this chapter you should be able to:

Describe the design, components, and characteristics of firetube boilers.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Differentiate the Scotch Boiler from the other firetube boilers, and describe its development history.*
2. *Describe circulation patterns in firetube boilers.*
3. *Discuss construction details of firetube boilers.*

Chapter Introduction

The **American Boiler Manufacturing Association** identifies a "*boiler with straight tubes, which are surrounded by water and steam, and through which the products of combustion pass*" as a firetube boiler.

Early firetube boilers were very inefficient. Much heat was passed to brickwork rather than boiler water. One of the early improvements was to direct combustion gases through firetubes submerged in boiler water. Subsequent improvements included submerged furnace tubes and multiple flue gas passes.

In comparison to modern boilers, early firetube boilers were also unsafe. Design codes were developed to standardize design calculations and construction methods. Welding methods also progressed, and eventually replaced riveted construction, leading to stronger boilers. Burners and control systems advancements made the modern firetube boiler safe to an extent unimaginable 150 years ago.

This chapter provides detailed coverage of the advancements in firetube boiler technology. Also, this chapter examines design and construction details specific to firetube boilers.

Objective 1

Differentiate the Scotch Boiler from the other firetube boilers, and describe its development history.

Firetube Boiler

Firetube boilers are extremely common and popular designs. Their popularity can be attributed to their numerous advantages:

a) Firetube boilers have simple, rugged construction.
b) Firetube boilers contain more water than watertube boilers of a comparable rating. This large water volume stores a lot of heat energy, making these boilers quick to respond to load change without suffering great loss in pressure.
c) Since there are no small water passages to block, firetube boilers can tolerate lower quality feedwater, without the worry of deposits disrupting water circulation.
d) Firetube boilers are less expensive to purchase than watertube boilers.
e) Firetube boilers cost less to maintain.
f) Firetube boilers are much simpler than watertube boilers to maintain and repair.

However, firetube boilers also have disadvantages, including:

a) They are limited in operating pressure to about 2.4 MPa. Higher pressures would require much thicker shells. This would greatly increase construction costs for both the boiler and its foundation.
b) The large water volume makes firetube boilers slow to heat up and bring to operating pressure and temperature. As well, firetube boilers take longer to recover from load increases, due to the greater volume of water to heat.

Firetube Boiler Development

The boilers shown in Figures 1 through 4 demonstrate the various advances in firetube boiler technology. Similar designs are still produced today. Though many of these boilers may be 100 years old, some are still in service today.

Figure 1 shows a single-pass, externally fired **locomotive boiler**. The locomotive boiler is so named because it was the type of boiler used in steam locomotives and steam traction engines.

The largest locomotive boilers could produce up to 45 000 kg/h of superheated steam at 2400 kPa. Most locomotive boilers however were much smaller. Locomotive boilers were either internally fired (with the furnace surrounded by waterlegs), or externally fired, as in Figure 1.

Most locomotive boilers were riveted designs. The few newly constructed locomotive boilers in existence are of all-welded construction. Locomotive boilers are extensively stayed to support the numerous flat surfaces, such as the crown sheet and wrapper sheet. Diagonal stays support the upper sections of the end plates from the shell. Radial stays support the crown sheet. Staybolts support the waterlegs.

Many locomotive boilers were taken out of service and placed in oil field, light industrial, and residential stationary service. Some have been well maintained and rebuilt for historical displays.

A locomotive boiler, with a waterleg that extends only down the sides, is called a dry bottom. A locomotive boiler with a waterleg that surrounds the furnace is called a wet bottom.

Locomotive type boilers are expensive to construct because of the tremendous amount of staying required. They also have poor water circulation, are difficult to maintain, and provide poor cleaning and inspection access. Though the ASME BPVC still publishes rules for their design and construction, they are of purely historical interest to today's Power Engineer.

Figure 1 – Dry Bottom Locomotive Boiler

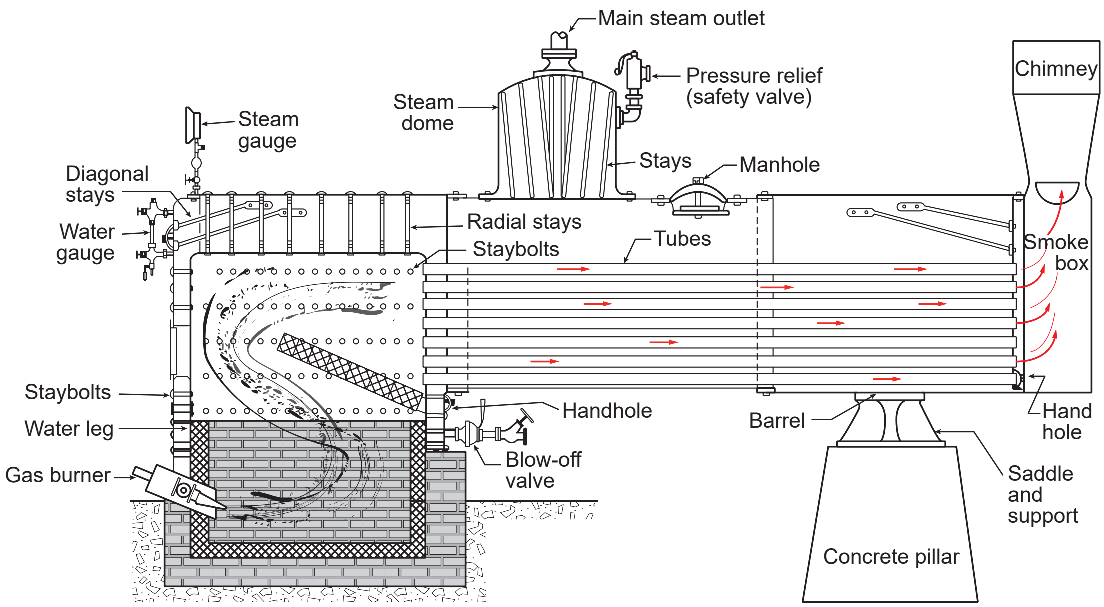
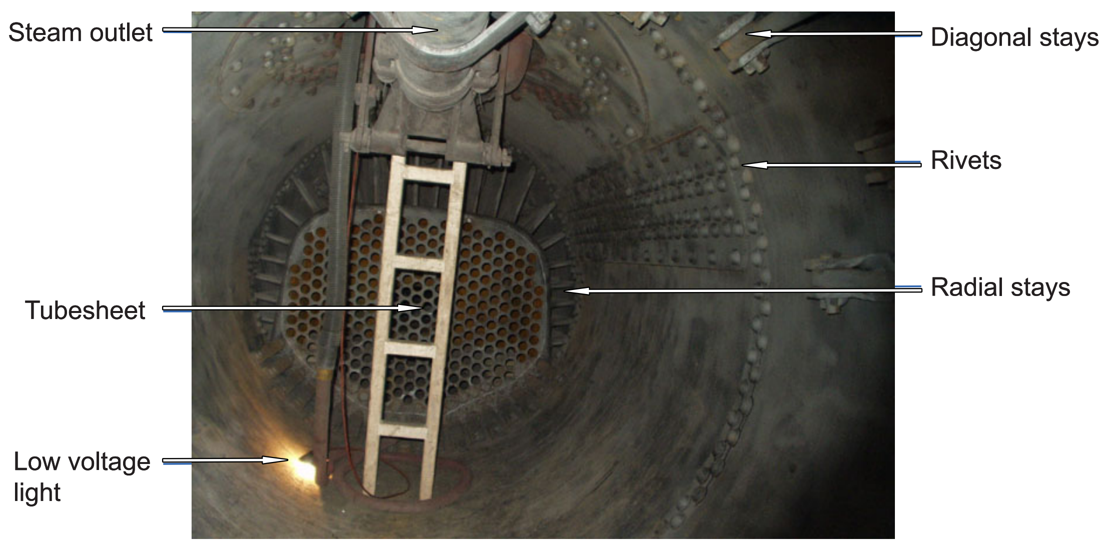


Figure 2 shows a locomotive boiler is out of service for maintenance and inspection. The boiler has the tubes removed. The view is from the stack towards the firebox, which is the other side of the tube sheet.

Figure 2 – Locomotive Boiler Maintenance



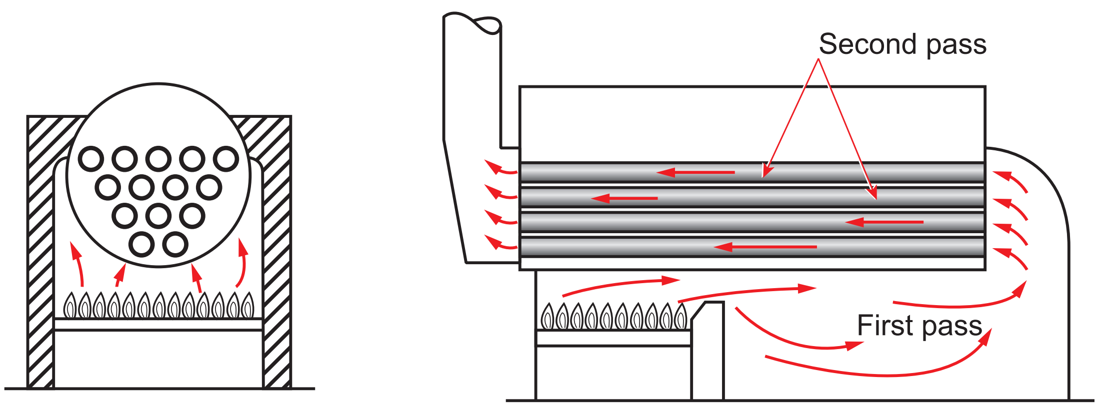
The **horizontal return tubular (HRT)** boiler was developed around the same time as the locomotive boiler. However, the HRT was not designed for portability. Figure 3 shows a two-pass, externally fired HRT boiler. Note that it is not internally fired.

Early HRTs were of riveted construction. Later models had welded shells. These boilers ranged in steaming capacity from about 500 to 7000 kg/h, at pressures up to around 1700 kPa.

HRTs were either top or bottom supported. The bottom half of the shell is part of the heat transfer surface. The combustion gases make two passes on their way to the chimney. By today's standards, HRT boilers are expensive to construct and quite inefficient, due to their extensive field-erected brickwork. For HRTs currently in service, the brickwork requires a lot of maintenance and frequent repair, especially for bottom-supported types.

Although these boilers are no longer constructed, there are still some in operation in small industrial and heating plants. These have been retrofitted for gas or oil firing.

Figure 3 – Two-Pass Horizontal Return Tubular (HRT) Boiler

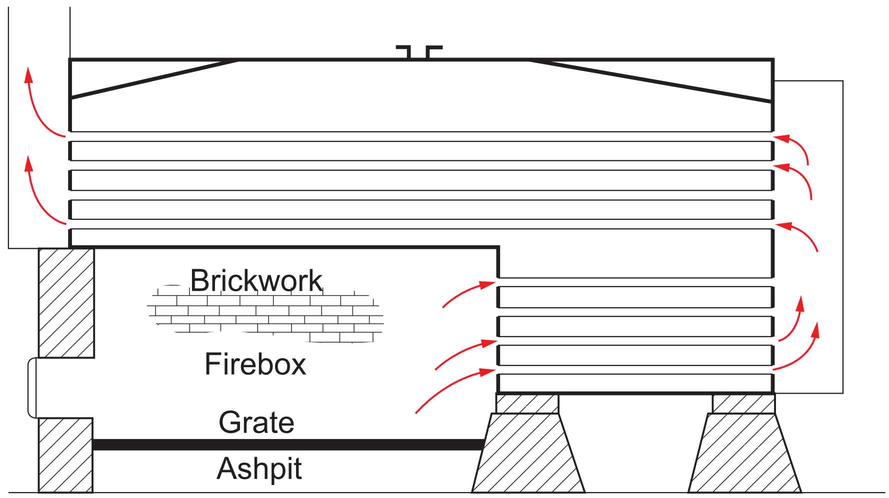


The **firebox boiler** is an externally fired, two- or three-pass, horizontal firetube boiler, similar to the HRT. Most firebox boilers were (and still are) designed for low-pressure heating service.

Figure 4 shows an older firebox design. The shell is made in two sections. There are two groups of firetubes. The combustion gases travel from the firebox, through the tubes in the lower shell section to the rear of the boiler. Then, they reverse through the tubes in the upper shell section to the chimney.

Modern firebox boilers do not have brick settings, and have minimal refractory. They have water-cooled furnaces and are usually 3-pass designs. Like the locomotive boiler, firebox boilers are heavily stayed, difficult to clean, and hard to inspect.

Figure 4 – Firebox Boiler Showing Gas Passes



In a boiler, the heat of combustion must transfer to the boiler water. External firing creates heat losses through the brick setting of the boiler, and through the base of the furnace. Moving the furnace to within the shell eliminates much of these losses. By having the furnace entirely surrounded by water, the heat of combustion has a much better opportunity to transfer to the water in the shell.

The **Scotch boiler** was designed to maximize heat transfer, and therefore increase efficiency, by utilizing the heat that would be otherwise lost through brickwork. The Scotch boiler is suitable for high-pressure and low-pressure service. This is the predominant style of firetube boiler manufactured today.

Side Track

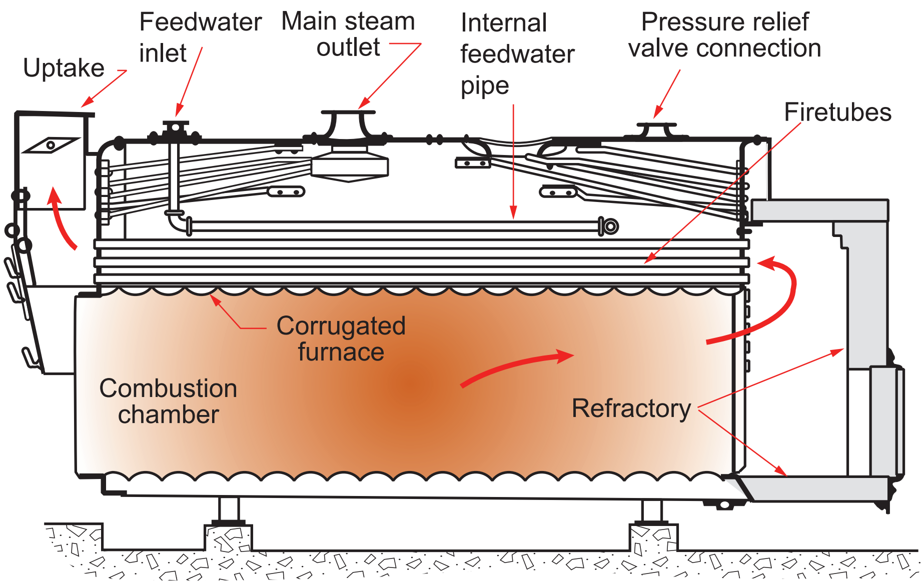
Packaged firetube boilers are also called "Scotch" boilers, "horizontal return tubular" boilers, and "return tubular" boilers. The term used depends on the preference of the manufacturer. ASME refers to all types generically as "firetube" boilers.

The Scotch boiler was originally designed for use onboard ships. For this reason, it is often called a Scotch Marine boiler.

Figure 5 shows an internally fired two-pass Scotch marine boiler. The area below the corrugated furnace contains water. An insulated door at the rear of the boiler (the right side of Figure 5) directs the **flue gas** to a second pass of tubes. Because the rear door is lined with refractory, this variety of Scotch boiler is called a **dry-back boiler**.

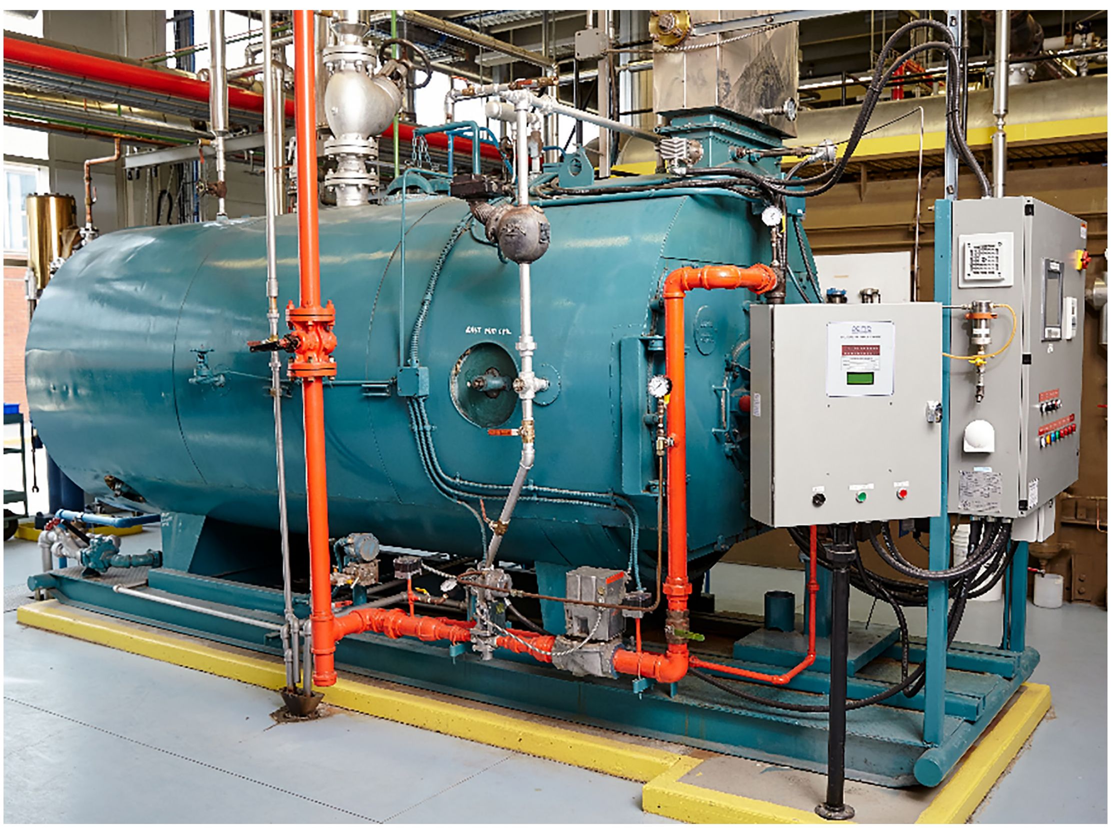
In some Scotch boilers, this rear door is replaced with a water-cooled surface to increase the heating surface. This is called a **wet-back boiler**.

Figure 5 – Two-Pass Dry-Back Scotch Boiler



Today's packaged firetube boiler incorporates multiple tubes, multiple passes, and internal firing. This leads to a very efficient boiler that is suitable for low-pressure or high-pressure steam, hot water, or thermal oil production.

Figure 6 – Four-Pass Dry-Back Packaged Firetube Scotch Boiler



Objective 2

Describe circulation patterns in firetube boilers.

Gas Passes

One of the advances in boiler technology was to add tubes within the shell of the boiler. This increased the length of the combustion gas path, which provided more time for heat transfer to occur.

The word "pass" refers to a passageway through which products of combustion flow, in essentially one direction. In the locomotive boiler, the flue gas made one "pass" through the shell from burner to stack. Designers understood that to allow flue gas to transfer as much heat as possible, single-pass boilers and their tubes would have to be excessively long.

Multi-pass boilers were developed so the flue gas path could be lengthened without the need for a longer boiler. Multi-pass boilers, like all multi-pass shell and tube heat exchangers, have reversing chambers at one or both ends. Each reversing chamber has one or more partition plates that redirect the flow of flue gas. With this technology, the flue gas path could be lengthened in multiples of the length of the tubes. This technology resulted in two- three- and four-pass designs.

Each time the flue gas passes through the shell, heat is transferred to the water. However, the rate of heat transfer diminishes as the flue gas temperature approaches the boiler water temperature. If the boiler is in hot water heating service, the flue gas temperature may drop below its condensation temperature, causing fireside corrosion.

The efficiency gain from each additional pass must be balanced against the cost required to add extra passes. Door complexity and refractory requirements increase with each additional pass. Also, the boiler becomes more restrictive to flue gas flow, and requires more powerful draft fans, which are more costly to operate.

Modern firetube boilers come in one-, two-, three-, and four-pass designs. Figures 7 through 13 show firetube boilers of one- to four-pass designs. Compare the flue gas paths in each figure. The keen observer will note that the relative location between the burner and the chimney tells whether the boiler has an even or odd number of passes. Also, note that the two-pass design is a dry-back, and the three- and four-pass designs are wet-back. The one-pass boiler has no need for refractory.

Figure 7 – One-Pass Firetube Boiler

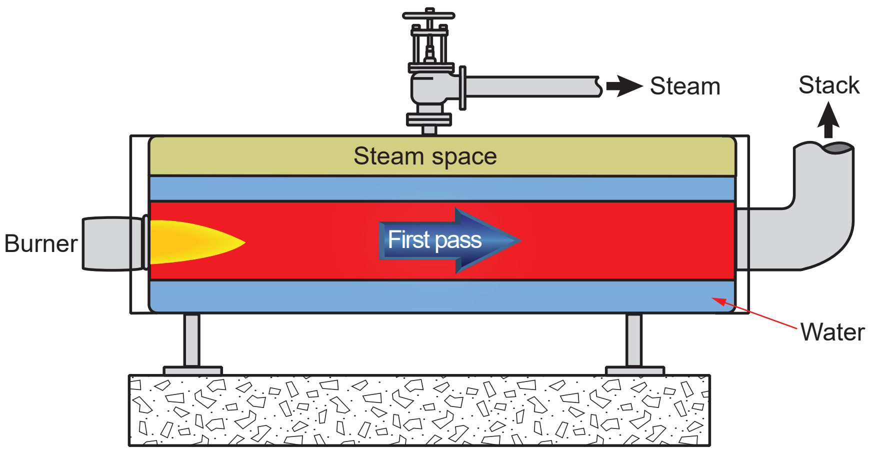


Figure 8 shows a modern single-pass firetube boiler, manufactured by Sellers. This boiler has no central furnace tube. Instead, each of the firetubes is a small-volume furnace. This configuration creates more radiant heat transfer surface, and less convective heat transfer surface. The resulting boiler transfers heat very effectively. As well, all tubes operate at the same temperature. This results in less tubesheet stress from differential tube expansion, as occurs in multi-pass designs.

Single pass boilers have no internal baffles and no refractory. This makes them more economical to maintain. Draft fans can be smaller, because single-pass designs have short flue gas travel paths, and little furnace pressure drop caused by changes in flue gas direction.

Figure 8 – Modern Single-Pass Firetube Boiler

(Courtesy of Sellers Manufacturing Company)

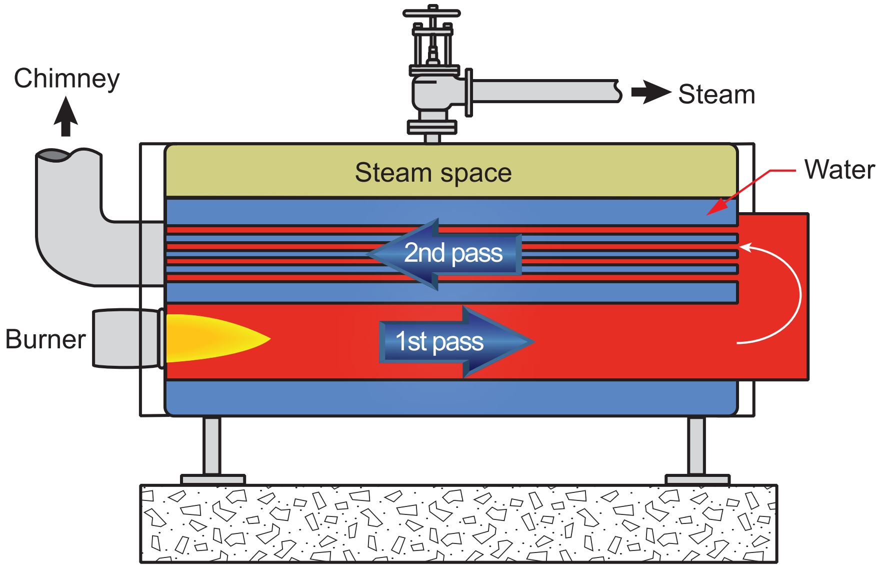
Figure 9 shows the burner assembly for a single pass firetube boiler. Note each tube has its own dedicated burner.

Figure 9 – Single-Pass Firetube Boiler Burner Assembly

(Courtesy of Sellers Manufacturing Company)

The two-pass firetube boiler shown in Figure 10 has a reversing chamber at the back of the boiler. The heat transfer is primarily radiant in the furnace tube, and due to convection in the firetubes. These boilers are economical to purchase, simple to maintain, and commonly installed. Outwardly, a two-pass boiler resembles a four-pass boiler.

Figure 10 – Two-Pass Firetube Boiler



The three-pass design provides greater economy than the two-pass design. This is because the flue gas travels a greater distance, and has more opportunity to transfer heat to the water. Figure 11 shows a wetback design. Dryback designs are just as common. Dryback pressure vessel designs are simpler than wetback designs, but have more refractory to maintain.

Figure 11 – Three-Pass Firetube Boiler

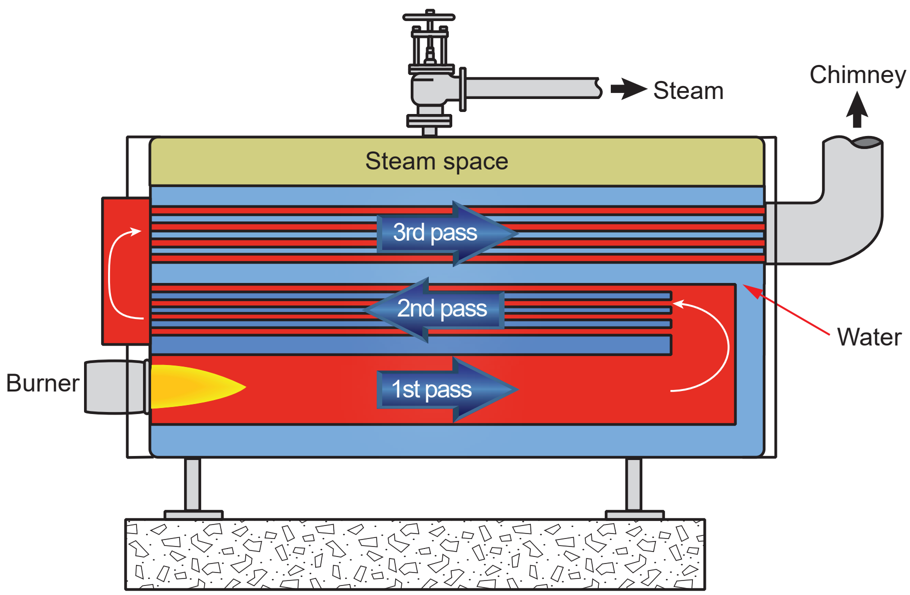
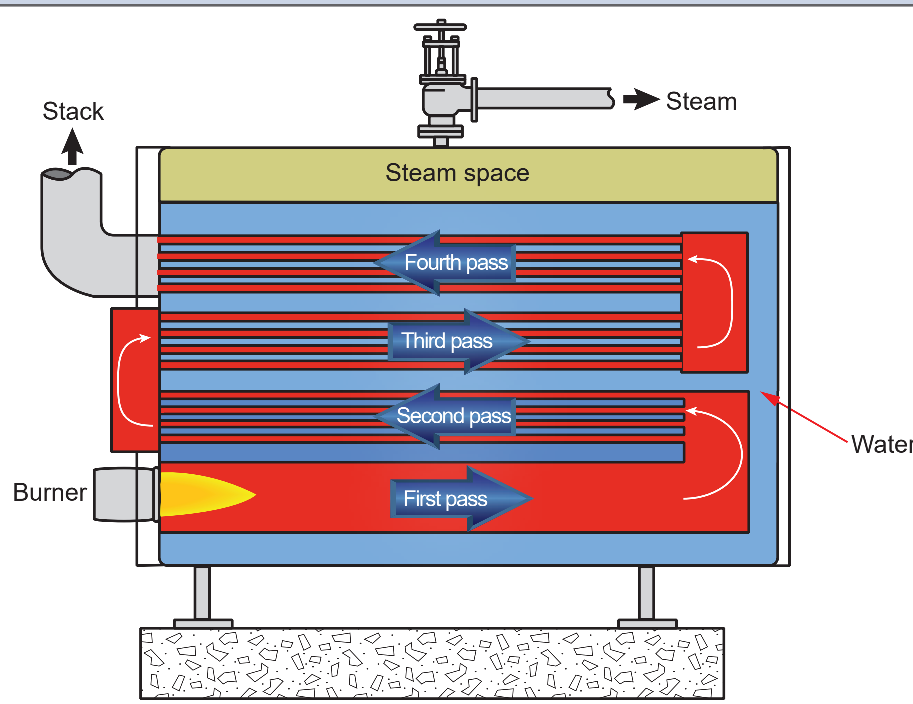


Figure 12 shows a three-pass firetube boiler, made by Saskatoon Boiler Manufacturing Company.

Figure 12 – Three-Pass Firetube Boiler

Many consider the four-pass firetube boiler to be the most economical design. Like the three-pass boiler, the four-pass is available as dryback or wetback designs. A dryback four-pass boiler is shown in Figure 6.

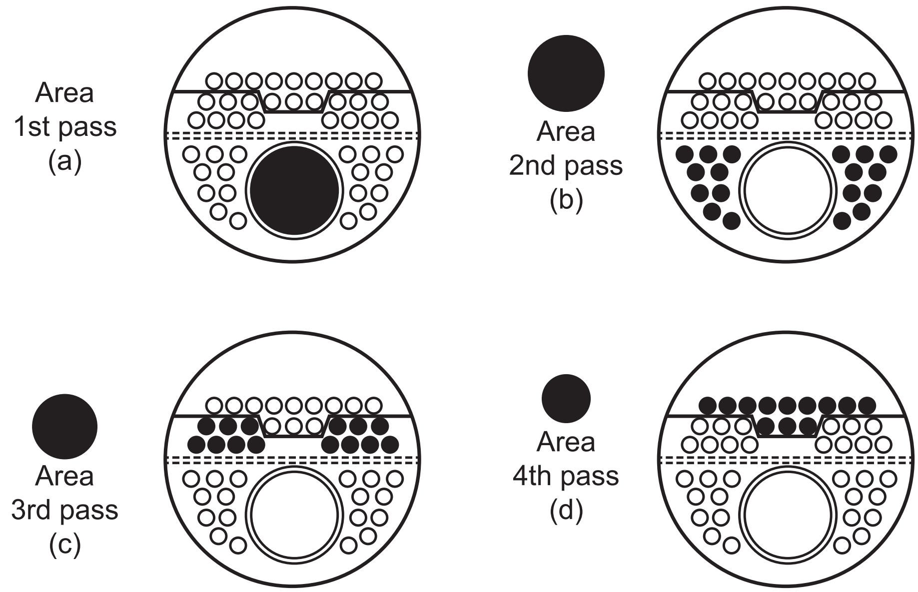
Figure 13 – Four-Pass Firetube Boiler



As flue gas transfers heat, it decreases in specific volume. As a result, the flue gas velocity decreases. To maintain proper conditions for combustion, the flue gas velocity must be kept above a minimum. Therefore, additional passes must have fewer tubes. Reducing the number of tubes in each pass effectively reduces the total cross-sectional area of each pass.

Figure 14 demonstrates this concept.

Figure 14 – Flue Gas Flow in a Four-Pass Boiler



Vertical Tubeless Boiler

A vertical tubeless boiler is a special two-pass firetube design. It is called "tubeless" because it does not have firetubes. However, it does have a central furnace tube, qualifying it as a firetube design.

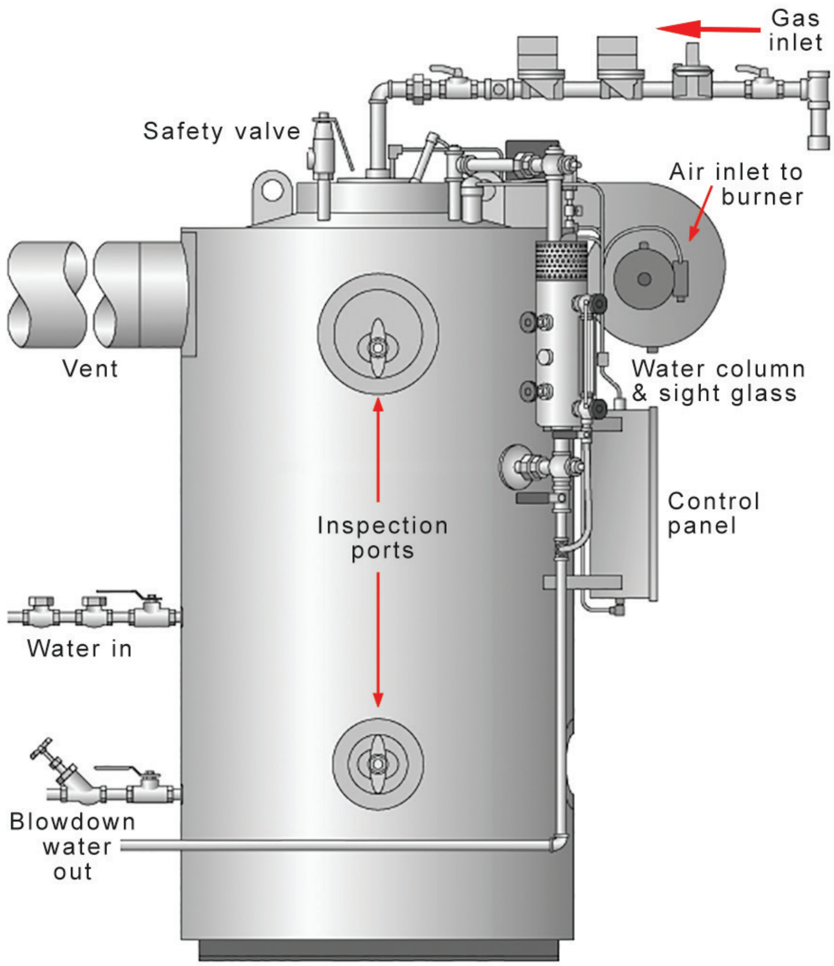
The vertical tubeless boiler is a high-pressure steam boiler widely used in dry-cleaning, laundry, and small industrial applications. The vertical tubeless boiler has many advantages. It is a simple, packaged design, ready for hook-up with automatic controls, and occupies very little floor space. Figures 15 and 16 show examples of this type of boiler made by Fulton Boiler Works.

This simple design is comprised of a vertical cylindrical boiler shell, closed at the top and bottom with flat heads. Inside the shell is a centrally located pipe which serves as the furnace tube. A forced draft fan and power burner are located at the top of the boiler, and fire downward through this central furnace tube. A larger diameter pipe surrounds the inner furnace tube. The space between the inner and outer pipes serves as both water and steam space.

Figure 15 – Vertical Tubeless Boiler

(Courtesy of Fulton Boiler Works)

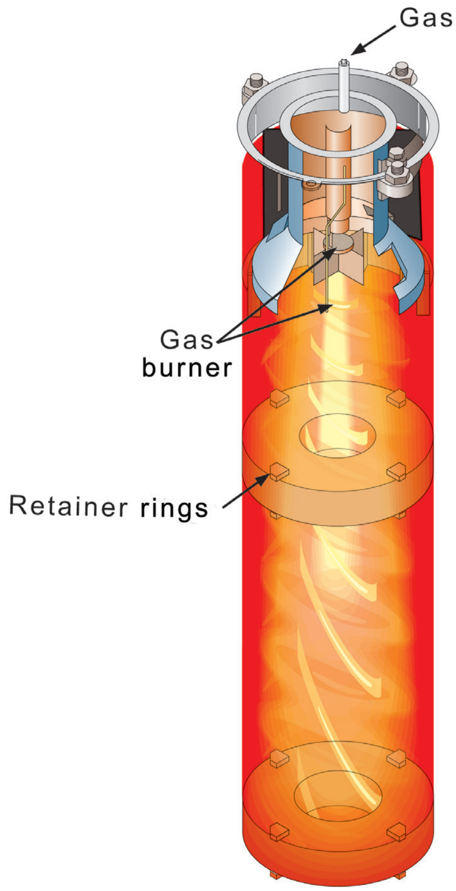
Figure 16 – Vertical Tubeless Boiler



(Courtesy of Fulton Boiler Works)

Figure 17 shows the downward firing direction of the burner in the central furnace tube. The outer pipe is not shown. Hot combustion gases swirl vigorously as they pass through the flame retainer rings. The flame retainer rings are made of castable refractory. They slow the progress of the combustion gases, to maximize contact time between the water and the hot gases. This is the first pass of the boiler.

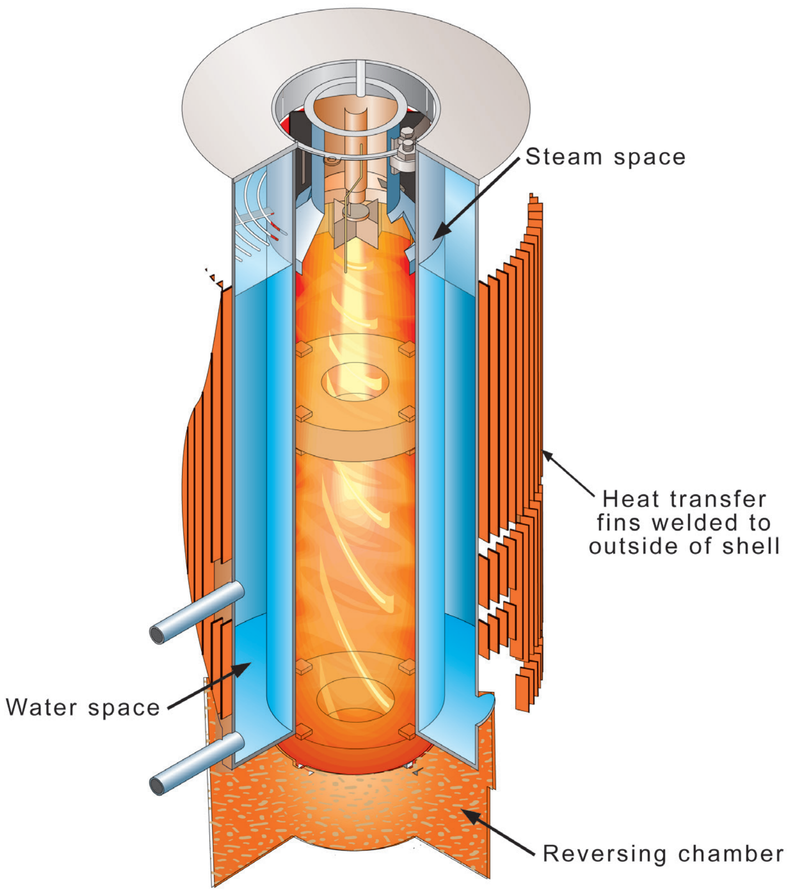
Figure 17 – Furnace Tube of Vertical Tubeless Boiler



(Courtesy of Fulton Boiler Works)

Figure 18 shows the second pass. A reversing chamber at the base of the boiler directs flue gas around the outside of the boiler shell, beneath the exterior insulation and lagging. Fins welded to the outside of the shell increase the convection heat transfer to the water inside the shell. Therefore, this boiler heats water from the inside of the furnace tube and the outside of the shell.

Figure 18 – Gas Flow from Furnace to Outer Chamber in Fulton Vertical Tubeless Boiler

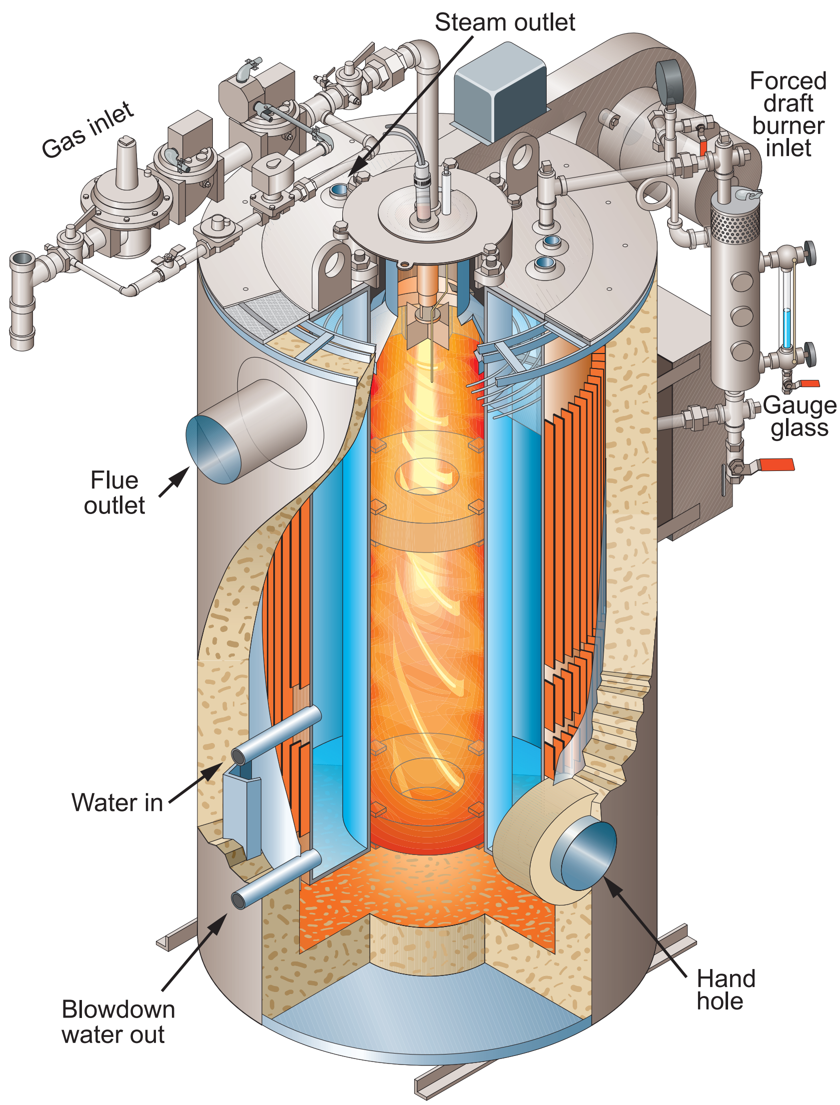


(Courtesy of Fulton Boiler Works)

Figure 19 is a complete cutaway of the boiler. The flue gases exit from the side of the boiler to a chimney. Feedwater enters the bottom side of the boiler, and steam exits from the top.

Vertical tubeless boilers can fire natural gas, propane, or fuel oil. They are available in ratings from 40 to 600 kW (4 to 60 BoHP). They can produce nearly 100% dry and saturated steam at up to 1035 kPa. Special designs can be manufactured with maximum allowable working pressures up to 3450 kPa. Individually, the largest of these designs can produce up to 940 kg/h of steam. When combined on a common header system, plants with boilers of this size could be easily rated Third or Second Class plants, depending on the jurisdiction.

Figure 19 – Complete Cutaway of a Vertical Tubeless Boiler



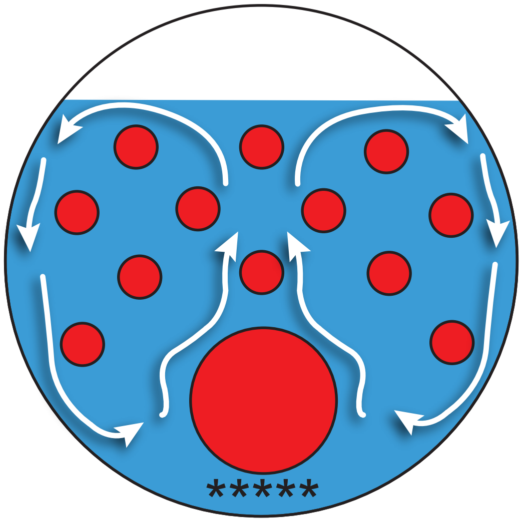
(Courtesy of Fulton Boiler Works)

Water Circulation

All boilers must be designed to provide adequate water circulation. This keeps all boiler heat transfer surfaces cool, and prevents uneven expansion. Firetube boilers in steam service rely on circulation caused by natural convection. Firetube boilers in hot water service use forced circulation. The following is a discussion of natural convection in firetube boilers.

The greatest heat transfer is from radiant furnace heat. Therefore, more steam is produced adjacent to the furnace tube. This causes a rise in fluid above the furnace tube, and a general settling of fluid adjacent to the shell. This is shown in Figure 20. The circulation is poorer directly below the furnace tube. Here, **sludge** may accumulate (shown with "*****"). In extreme cases, the sludge may interfere with the cooling of the furnace tube, causing it to overheat.

Figure 20 – Natural Water Circulation in a Firetube Boiler



Lowest Permissible Water Level

All boiler heat transfer surfaces require cooling. Boiler tubes are cooled with water. Superheater tubes are cooled with steam. It is imperative that surfaces designed to be cooled with water are submerged when the boiler is in operation.

The ASME BPVC requires boiler manufacturers to determine the **lowest permissible water level** for the boilers they construct. For locomotive and firebox boilers, the lowest permissible water level is usually taken as being 25 mm above the crown sheet. For HRT, Scotch marine, and packaged firetube boilers, this level is usually taken as 25 mm above the top surface of the top row of tubes. As a rule of thumb, the lowest permissible water level of a firetube boiler design is 25 mm above the uppermost heated surface.

Objective 3

Discuss construction details of firetube boilers.

Firetube Boiler Shell

A complete firetube boiler shell is constructed of courses, heads, furnace tubes, firetubes, stays, and access openings.

Tubesheets

The tubesheets are flat heads. These heads may have formed edges called flanges. The head fits inside the completed course. After forming, the head is drilled to accept firetubes and the furnace tube.

The finished tubesheets are welded to each end of the course, using weld joints permitted by **ASME BPVC Sections I and IV**.

Furnaces

Furnace tubes are cylindrical components made of steel. Both firetubes and furnace tubes are subject to external pressure. Because of this, furnaces are designed differently from the shell, which is subject to internal pressure.

Furnaces can be made from seamless large diameter steel pipe, or may be rolled into shape like a shell or drum, and welded with a longitudinal joint. They may be left as plain cylinders, or they may be reinforced with rings or corrugations.

Corrugations and reinforcing rings strengthen the furnace. Corrugated and ring-reinforced furnaces have several advantages:

a) Because of their increased strength, reinforced furnaces can be made thinner for the same working pressure. This allows for better heat transfer.

b) Corrugated furnaces have greater heat transfer surface area.

c) Corrugations cause greater furnace turbulence, which contributes to better combustion.

d) Corrugations help compensate for differential expansion between the shell and furnace, and reduce stress on the tube sheet attachments.

The **ASME BPVC Sections I and IV** show a number of acceptable ways of reinforcing furnace tubes.

Figure 21 shows an end view of a corrugated furnace tube.

Figure 21 – Corrugated Furnace Tube – End View

After the tubesheets are installed, the furnace tube is fit into the tubesheets. It is then welded in place.

Firetubes

Firetubes, like furnace tubes, are cylindrical steel components subject to external pressure. They are designed like furnace tubes, but are not reinforced. Firetubes can be made of welded or seamless tubing. Tubes can be joined to the tubesheets by expanding, welding, or both.

The tubes in a firetube boiler are subject to high temperatures. However, in boilers with three or more passes, temperatures are not constant across all tubes. As the flue gas flows through each boiler pass, it transfers heat to the boiler water. Therefore, the second pass tube inlets are hotter than the third pass tube inlets, which are hotter than the fourth pass tube inlets. As a result, tubes may be installed differently in each pass. Tubes in the hotter regions of the boiler may be expanded and welded. Tubes in other passes may be only expanded and beaded. Welds provide a stronger joint between the tubesheet and the tube.

Side Track

Firetubes are also called “flues.” If used to support the tubesheet, they are also called stay tubes.

Figure 22 shows the rear tubesheet of a three-pass firetube boiler. The furnace tube is on the left. The tubes adjacent to the furnace are part of the second pass. These tubes have been expanded and seal welded, because they are in a high temperature region of the fireside. The tubes on the right-hand side of the image are third-pass tubes. Note they are only expanded and beaded into place. This is because the flue gases are cooler in this region.

Figure 22 – Furnace Tubes, Three-Pass Scotch Boiler

The white residue on the tubesheet is developer left over from a visible liquid penetrant test. Liquid penetrant testing is commonly done on tubesheets to detect cracks.

Stays

Firetube boiler stays support the flat surfaces of the boiler. There are many different styles of stays.

Figures 23 to 25 show, in order, a **diagonal stay**, a **through stay**, and a **staybolt**. Diagonal stays are used where through stays would block manhole access to the waterside. Through stays are used where such interference is not a problem (such as in smaller boilers that do not require manhole openings). Staybolts are short through stays, usually attached by welding. These are commonly found supporting the flat furnace surfaces of locomotive and firebox boilers.

A | E

Figure 23 – Diagonal Stay

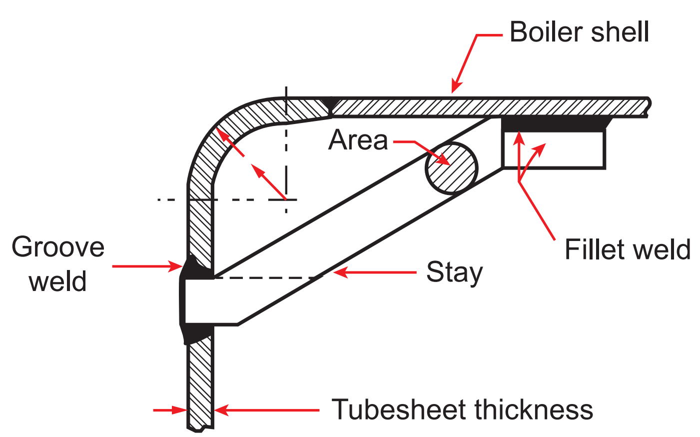


Figure 24 – Through Stay Attached with Nuts and Washers

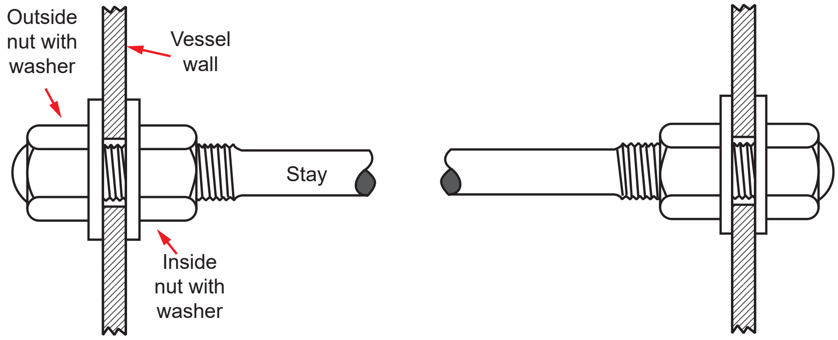
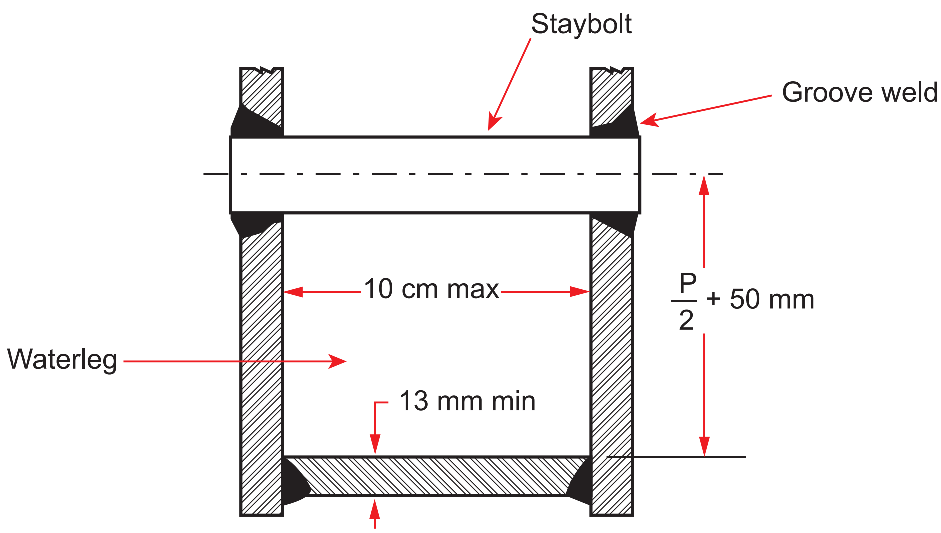


Figure 25 – Waterleg Staybolt



Tubes also act as stays.

Through stays and staybolts often have a small holes drilled into each end. The hole is deep enough to extend into the water space. This type of stay is most susceptible to corrosion and cracking where it meets the tubesheet. If a staybolt is damaged, water and steam leak out of the small hole to alert the operator that a problem exists. This small hole is known as a **telltale**.

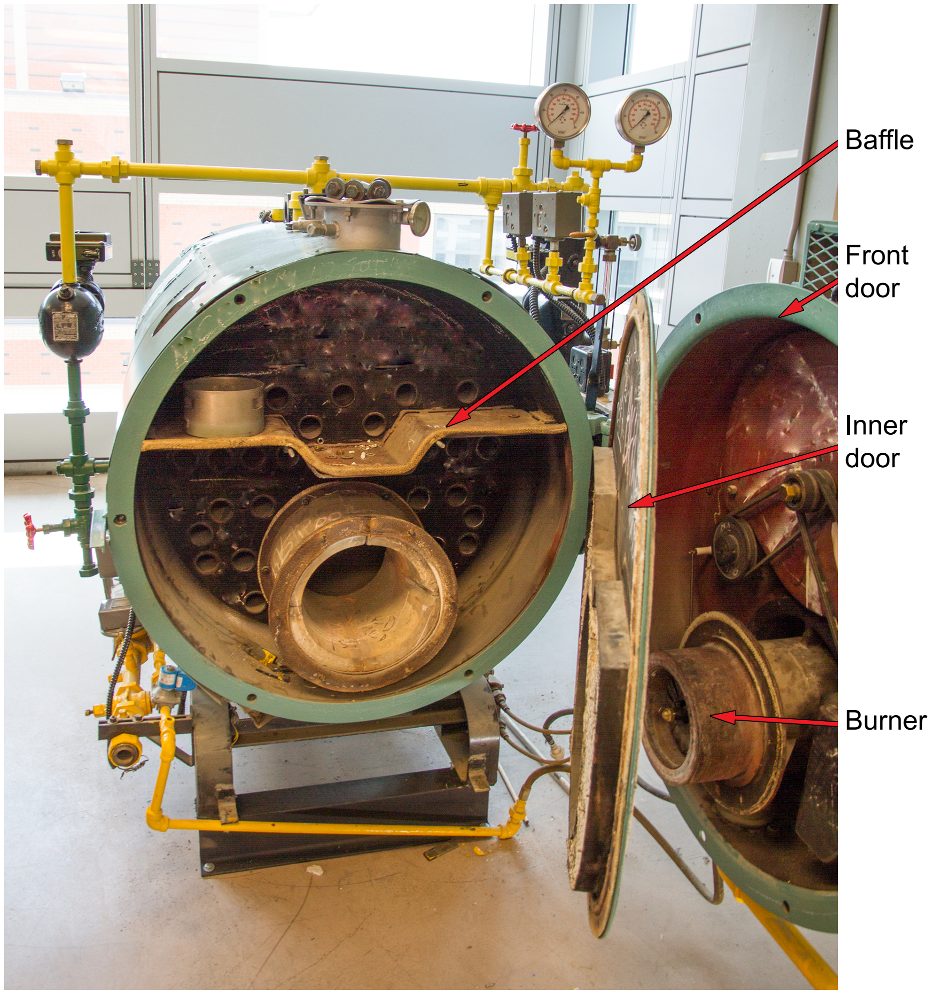
Front and Rear Doors

The tubesheets are covered by doors. These doors have serve several purposes. They:

- Contain the combustion gases.
- Direct the products of combustion through the flue gas passes.
- Provide a location to install the burner.
- Provide a place to install a viewport for observing the flame.
- Open to permit fireside inspection, maintenance, and repair.

A door encloses each end of a dry-back firetube boiler. On boilers with more than two passes, flue gases may be directed by an inner door combined with an outer door, combined with a baffle (see Figure 26). In this situation, the inner door redirects the flue gas. The outer door supports the burner assembly and the draft fan. Both doors swing on robust hinge assemblies.

Figure 26 – Inner and Outer Doors



When closed, the doors are held in place with threaded studs and nuts. The studs are made of steel, but the nuts are made of brass to permit easy removal of the nuts, and provide some relief in case of a furnace explosion.

Another type of door found on a firetube boiler is an “explosion” door. The primary purpose of an explosion door is to relieve pressure in the event of a combustion explosion. The shockwave that results from a fuel explosion can blow off doors and cause significant damage. Explosion doors can mitigate the damage by automatically relieving the pressure quickly and with relative safety.

Chapter Summary

Firetube boilers are popular designs, and enjoy many advantages over other types of boilers. They are simple in design, easy to maintain and repair, and economical to purchase and operate.

A major disadvantage of firetube boilers is that they are not designed to be used above approximately 2.4 MPa. This would require thicker shells, which would significantly increase construction costs. These boilers are also not produced in sizes larger than 25 000 kW.

Objective 1 traced the development of the modern packaged firetube (or Scotch) boiler. Early firetube boilers were very inefficient. Instead of being transferred to boiler water, a significant amount of heat was transferred to brickwork. One of the early improvements was to direct combustion gases through firetubes submerged in boiler water. Subsequent improvements included submerged furnace tubes and multiple flue gas passes. These design developments eventually led to the packaged firetube boiler, which is efficient, reliable, and capable of serving many industries.

Objective 2 covered the flue gas and water circulation in Scotch boilers. The desire to maximize heat transfer, by lengthening the travel of the flue gas, was discussed in detail. The addition of gas passes improves heat transfer and efficiency; however, the addition of gas passes requires more draft fan power. Therefore, firetube boiler designs are limited, practically, to four-passes.

Objective 3 looked at the specific vessel design details of firetube boilers, including stays, furnace tubes, tubesheets, and firetubes. Also, the purposes of the front and rear doors were discussed.

CHAPTER 3

Watertube Boilers

Learning Outcome

When you complete this chapter you should be able to:

Describe the design, components, and characteristics of watertube boilers.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Describe the design and operating principles of watertube boilers.*
2. *Describe watertube boiler components.*
3. *Explain the design and application of packaged watertube boilers.*
4. *Describe the design, construction, and components of large-scale steam generating units.*

Chapter Introduction

The **American Boiler Manufacturing Association (ABMA)** identifies a watertube boiler as "*a boiler in which the tubes contain water and steam, the heat being applied to the outside surface*." These boilers feature drums and headers connected by water-filled tubes. Combustion gases travel over the outside surfaces of these tubes, and transfer heat to the water within.

Early watertube boilers were less efficient than those of today. Like the early HRT boilers, much heat passed to brickwork rather than the boiler water. As well, the use of straight tubes restricted the location of heat transfer surface.

Advances in water treatment technology permitted boiler manufacturers to confidently install bent tubes. With bent tubes, boiler manufacturers could line furnace walls with watertubes, which reduced the amount of refractory brickwork. Bent tubes could be attached radially to boiler drums, allowing more heat transfer surface to be attached to smaller diameter drums. Ultimately, bent tube technology permitted boilers to increase to the massive sizes required by modern utilities.

As in the development of firetube boilers, codes standardized the design calculations and construction methods for watertube boilers. Welding methods developed and eventually replaced riveted construction, which lead to stronger boilers. Burners and control systems also developed, making modern watertube boilers increasingly safe to operate.

This chapter provides detailed coverage of the advancements in watertube boiler technology. As well, it examines design and construction details specific to watertube boilers.

Objective 1

Describe the design and operating principles of watertube boilers.

Watertube boilers have water or steam on the inside of their tubes, and have heat applied to the outer surfaces of the tubes. These tubes connect drums and headers, making paths for water and steam circulation between the drums. Water circulates from the one drum, through the tubes, and back to another drum. The heat from the fire and hot gases contacts the outside of the tubes.

Advantages and Disadvantages of Watertube Boilers

Watertube boilers have many advantages over firetube boilers. These include:

a) Less water content, compared to firetube boilers of the same steaming capacity. As a result, they can be brought to operating pressure and temperature quicker.

b) They have better water circulation.

c) They can be used for pressures higher than 2.4 MPa (up to and exceeding 22.09 MPa - the critical pressure of water).

d) They are more flexible in design.

e) They can be designed to create superheated steam.

Watertube boiler disadvantages include:

a) They have less heat energy reserve due to having less water. Therefore, they must be tuned to respond quickly to changes in steam pressure.

b) They require much higher quality water.

c) They are more complex to design and construct.

d) They are more expensive to purchase.

e) They cost more to maintain and repair.

Modern Watertube Boiler Designs

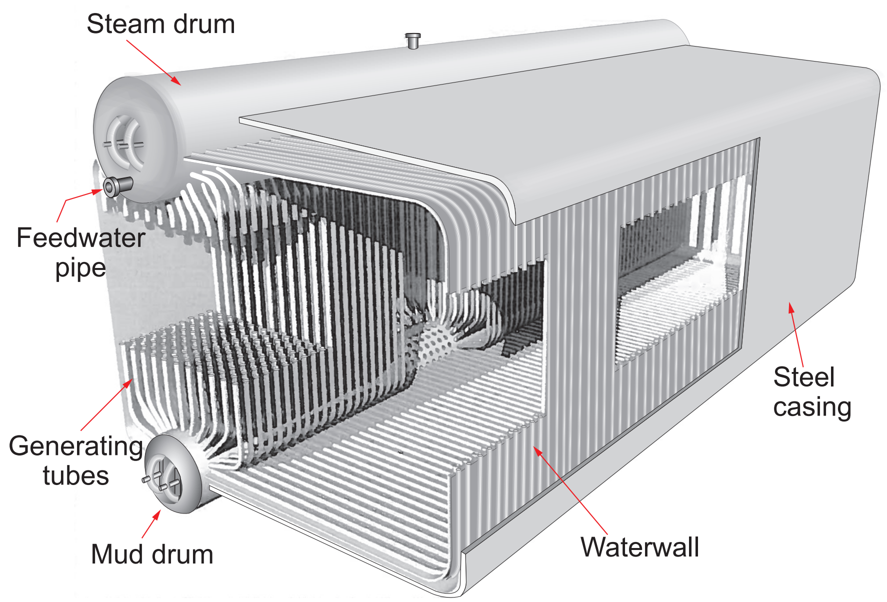
Watertube boilers can be very small, or taller than ten stories (thirty metres). Whereas most firetube boilers are basically all the same shape, there are endless watertube boiler designs. These versatile boilers are the only choice where extremely high pressures and temperatures are required. This is why watertube boilers are the only boilers used in the oil and gas industry, the pulp and paper industry, and the electric power industry.

Bent Tube Designs

Most watertube boilers manufactured today are of the bent tube design. Bent tube boilers are capable of large steaming capacities, high pressures, and high temperatures. As well, they allow optimal placement of superheaters, reheaters, and other heat transfer components, such as economizers and air preheaters. Watertube boiler furnaces are often lined with watertubes (a **water-cooled furnace**) to absorb more radiant heat from the fire.

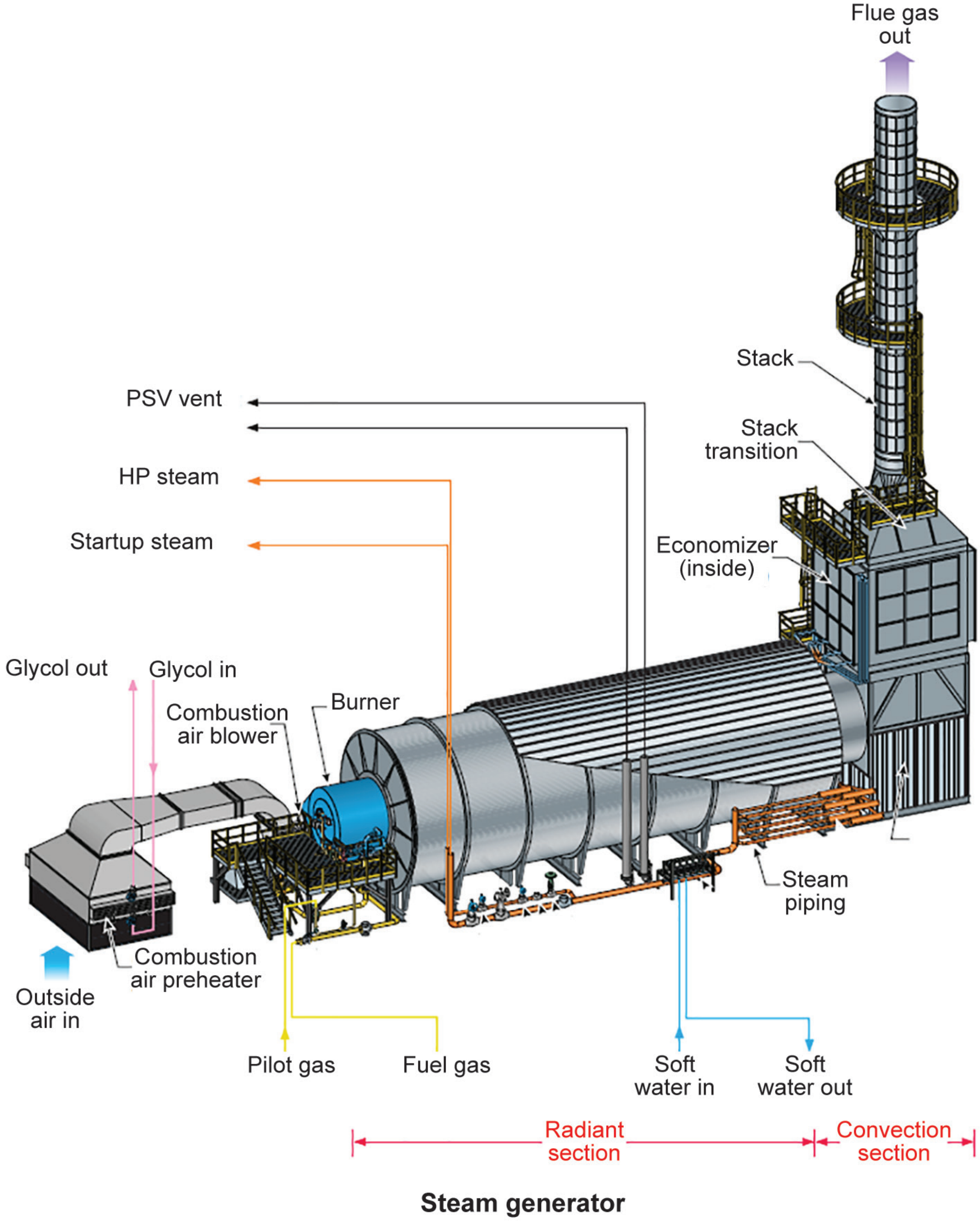
Figures 1 and 2 show two types of watertube boilers. Each one is a bent-tube design. The boiler in Figure 1 is a packaged two-drum watertube boiler, used for generating high-pressure steam. It has a large water-cooled furnace and numerous tubes. These designs produce saturated steam, or superheated steam if equipped with superheater tubes.

Figure 1 – Two Drum Packaged Boiler



The boiler in Figure 2 is another high-pressure watertube boiler. However, this is a once-through steam generator, which has no drums at all. This boiler produces very wet steam (approximately 85% dry and saturated) for bitumen extraction.

Figure 2 – Packaged Steam Flood Boiler



(Courtesy of Cenovus)

Natural and Forced Circulation Boilers

Figure 3 shows a simple cross-section of a bent-tube watertube boiler, and shows the circulation of water within it. The boiler has two drums: a steam drum and a mud drum. Watertubes transfer water or water/steam mixture between the two drums. Tubes containing water and steam are called **risers**. Tubes that contain only water are called **downcomers**. The large space on the right hand side of the figure is the location of the furnace. In Figure 3, the boiler has a water-cooled furnace, meaning that it is surrounded by water-filled tubes.

Water that contains steam is less dense than water without steam. In other words, two-phase fluids are less dense than single-phase liquids. In the watertube boiler, dense single-phase water flows from the steam drum, through downcomers.

The downcomers feed water to the numerous tubes located adjacent to the furnace area. The feedwater is heated to the saturation temperature as it flows through the downcomers. In the risers, steam bubbles begin to form and the density of the steam/water mixture continues to decrease as it returns to the steam drum. The difference in density between the downcomers and the risers provides the necessary driving force for natural circulation.

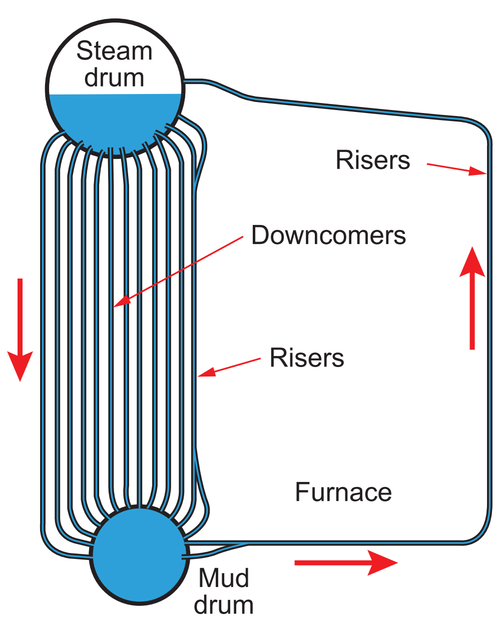
Most steam is produced in the tubes exposed to direct radiant heat of the furnace. This is because radiant heat transfer occurs at a greater rate than convective heat transfer. This is why the tubes surrounding the furnace (and those within the nest of tubes closest to the furnace) are called risers.

In the steam drum, the steam is separated from the water. Steam leaves through the boiler's steam outlet. The remaining dense water circulates back through the downcomers, repeating the process.

The difference in density between the fluid in the downcomers and the fluid in the risers drives the circulation in natural circulation watertube boilers. The greater the difference in density, the greater the rate of circulation in the boiler (refer to convection in the thermodynamics chapters). Steam tables show the difference in density between steam and water at various pressures. At critical pressure (22.09 MPa), one kilogram of steam occupies the same volume as one kilogram of water. Therefore, at such high pressures, natural circulation cannot occur. In reality, natural circulation becomes inadequate to properly cool boiler heat transfer surfaces when pressures of around 12.5 MPa are reached. So, for higher pressure designs, forced circulation (using pumps) is required.

The boiler shown in Figure 1 is a natural circulation boiler. Figure 2 shows a forced circulation boiler.

Figure 3 – Watertube Boiler



Objective 2

Describe watertube boiler components.

Drum Internals

Steam drums and mud drums are equipped with various internal mechanisms, appropriately called "internals." Steam drum internals may include feedwater, blowdown, blowoff, and chemical feed piping, as well as mechanisms for drying or purifying the steam.

Internal Feedwater Pipe

The internal feedwater pipe extends through most of the length of the steam drum. It is perforated along its length to evenly distribute the feedwater.

Feedwater, even if preheated by feedwater heaters and **economizers**, is usually quite a bit lower in temperature than the boiler saturation temperature. Internal feedwater pipes travel the length of the drum and raise the feedwater temperature to near the boiler water saturation temperature before discharging. This helps prevent thermal shock. Because feedwater is relatively cool, the feedwater pipe discharges close to the downcomers, thereby promoting proper water circulation. Internal feedwater pipes do not discharge against heat transfer surfaces.

Side Track

Though internal feedwater pipes are commonly associated with watertube boiler designs, many firetube boilers also use internal feedwater piping. In firetube boilers, internal feedwater piping serves the same purposes.

Continuous Blowdown Pipe

High concentrations of **dissolved solids** can lead to a condition called **foaming** in a boiler. This can cause water to leave the boiler with the steam. In a steam boiler, the highest concentration of dissolved solids can be found just below the water line. The continuous blowdown line is located near this point, and as far as possible from the discharge of the internal feedwater pipe.

The continuous blowdown pipe continuously removes a small stream of boiler water, in order to maintain proper dissolved solids levels to prevent foaming from occurring.

Chemical Feed Pipe

Chemical feed piping introduces chemicals to the boiler drum to help prevent scale formation and corrosion. The chemical feed pipe discharges near the internal feedwater piping, so that chemicals mix readily with the feedwater, and circulate throughout the boiler.

Side Track

Both firetube and watertube boiler designs may have continuous blowdown piping and chemical feed piping.

Steam Separating Equipment

Steam separating equipment is designed to separate the steam from the steam/water mixture entering the steam drum from the risers. The degree of dryness required determines the sophistication of the separating equipment installed.

A well-designed boiler can deliver steam of a high quality, which contains little moisture. In many cases, steam which has some moisture in it causes no problems, and basic steam separation is sufficient. Firetube boilers and smaller watertube boilers require only basic steam separation.

Baffles

In watertube boilers, the first stage of steam/water separation is done by baffles. Baffles separate the water in the steam drum from the two-phase steam/water mixture entering the steam drum from the risers. They also direct cooler inlet water to the downcomers. By keeping these fluid streams separate, natural circulation is encouraged.

Dry Pipes

A **dry pipe** is a basic steam separator attached to the steam outlet within the steam drum. The pipe has slots cut into its top surface, and has several holes drilled on its lower surface. The steam generated must make several sharp turns as it enters and exits the dry pipe on its way to the steam outlet. Water, being heavier than steam, cannot make sharp turns, and falls out of the flowing steam. The water collects on the bottom of the dry pipe, and drains back into the steam drum.

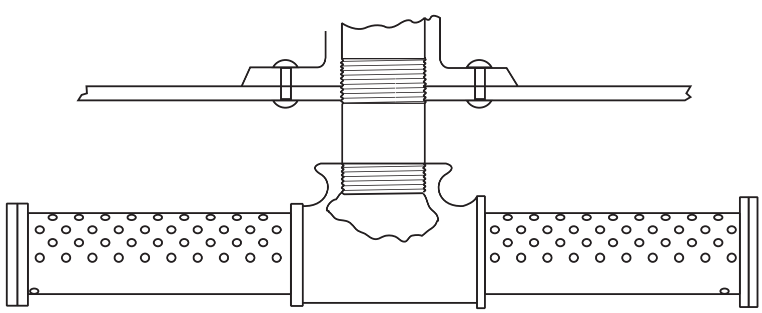
Side Track

Dry pipes are used in both firetube and watertube boiler designs.

Firetube boilers, though, have less need for steam separation equipment. Because of the size of their shells, firetube boilers have greater water surface area and more room in the steam space for water droplets to disengage from the steam.

Figure 4 shows a dry pipe installed at a boiler steam outlet. The installation shown is using rivets for attachment, which indicates this pipe is installed in a historical boiler.

Figure 4 – Dry Pipe



Centrifugal (Cyclone) Separators

Larger plants usually require steam that is almost completely dry when it leaves the steam drum. In these cases, more sophisticated means of steam separation is needed.

Cyclone separators are used together with baffles to further dry the steam. These devices impart a rapid spin to the steam/water mixture that enters the steam drum. Water and entrained water particles are flung to the outside of the separator with centrifugal force many times greater than the force of gravity. Dry steam leaves the top of the cyclone separator. From here, the steam either leaves the steam drum, or is scrubbed with other mechanisms. The separated water is reintroduced to the boiler water below the water line.

Figure 5 shows a cyclone separator that has been removed from the steam drum for maintenance. The separator has a diameter of about 30 cm and a height of about 60 cm. Water and steam from the risers enter the rectangular opening shown. Steam exits from one end of the separator and water from the other end. Boilers may have ten or more of these separators located over the length of the steam drum.

Figure 5 – Centrifugal Separator

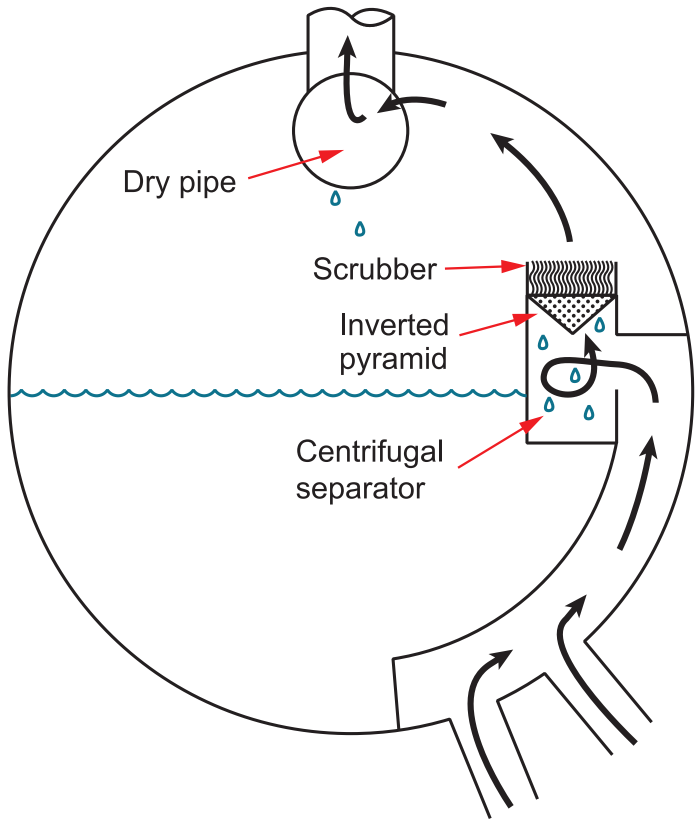
Chevron Dryers (Scrubbers)

Chevron dryers may be used with or without other steam separation devices. If used alone, they are often situated directly below the steam outlet. If used in combination with cyclone separators, they are often installed directly above the row of cyclones.

Chevron dryers are also known simply as **scrubbers**. They are comprised of multiple chevron-shaped plates, sandwiched together. Steam passing through the plates is forced to rapidly change direction several times. The result is that entrained water particles impinge on the surfaces of the plates, and drop back to the boiler water. Dry steam passes directly from one side of the chevron to the other.

Figure 6 shows a chevron dryer (scrubber) situated above a cyclone separator, to provide an additional stage of water removal.

Figure 6 – Steam Separation



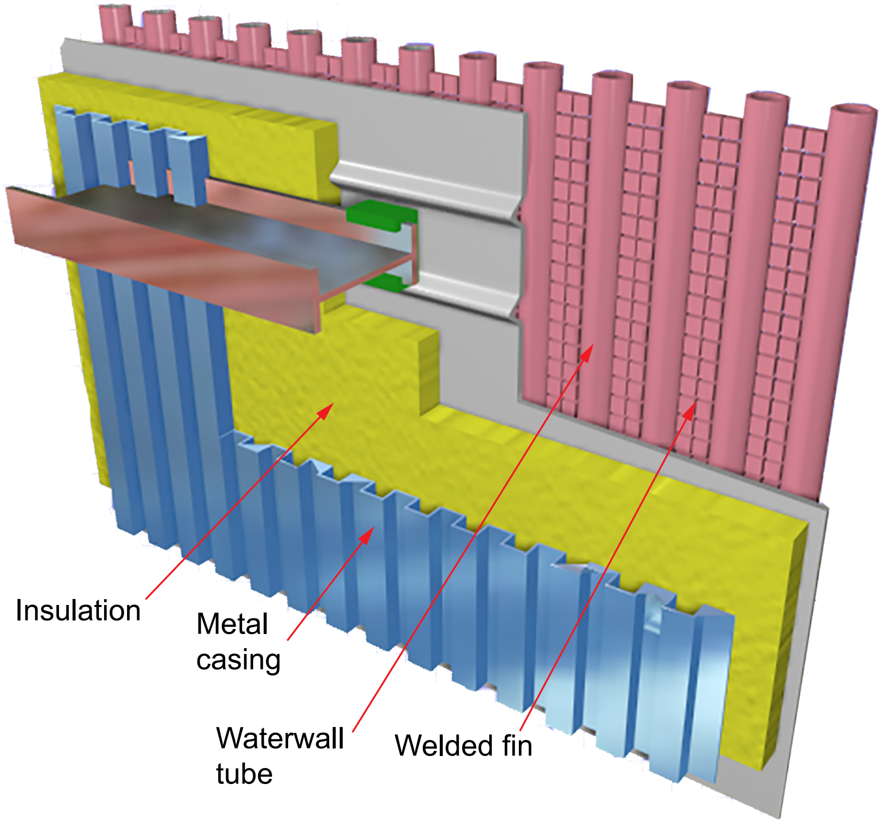
Setting

The word **setting** is an old boiler term that referred to the brickwork and refractory foundation that was erected to form the furnace region of firetube and watertube boilers. Images of early boiler designs, such as the HRT and straight-tube boilers, show this extensive brickwork. A lot of heat was transferred to this brick, rather than to the boiler water.

As the demand grew for larger capacity steam generating units, the brick walls gave way to water-cooled tube walls. The term "boiler setting" is now used to describe all the walls that form the boiler and furnace enclosure, including the insulation and lagging.

In the modern boiler, watertubes can be arranged to entirely surround a boiler furnace. These **waterwalls** improve heat transfer, decrease heat loss, and reduce the need for insulation and refractory. Figure 7 shows a section of a modern waterwall. Note that only insulation is used. No refractory is required, because of the waterwall construction. This type of wall is also airtight.

Figure 7 – Section of a Waterwall



FURNACES

The furnaces of watertube boilers differ greatly from those of firetube boilers. Watertube boiler furnaces are much larger and more complex.

Watertube boiler furnaces may need to accommodate single burners, multiple burners, **fluidized beds**, and **stokers**. This combustion equipment is designed to burn different fuels, such as biomass, municipal solid waste, pulverized coal, crushed coal, natural gas, light oil, and heavy oil. The boiler furnace must be configured to accommodate these various combustion setups. For example, fluidized bed boilers need very tall furnaces and refractory-lined tubes. Municipal solid waste boilers need special corrosion resistant tubes. Fluid-fired boilers (operating on gas, oil, or pulverized coal) need to have their tubes bent to accommodate the burners that penetrate the waterwall.

Boilers are designed to produce a certain maximum amount of steam. Their furnaces must have adequate volume to burn the amount of fuel needed to produce the steam. All combustion must take place within the furnace, rather than in later gas passes, in the **uptake**, or in the chimney. Therefore, boilers that burn more fuel need larger furnaces to accommodate the combustion air requirements, and to ensure the velocity of the combustion products is not so great that combustion continues outside of the furnace.

Regardless of the size, furnaces need to be cooled, and protected from the intense heat generated. There is much more design flexibility for this with watertube boiler furnaces.

Watertube boilers are either internally or externally fired. Old straight-tube models, with extensive brick settings, were externally fired. Bent tube models with water-cooled furnaces are internally fired, because their furnaces are surrounded with watertubes.

Figure 8 shows the furnace of a packaged watertube boiler. This furnace is about 1.5 m high, 1.5 m wide, and 2 metres long. The combustion gases travel to the back of the furnace and then pass behind the tubes on the left and right of the furnace. A second row of tubes is located between the tubes in the furnace and the outer casing. This is an older bent tube design. Refractory brick is visible behind the risers at the back of the furnace. Castable refractory can be seen lining the furnace floor, to help shield the mud drum from radiant heat. If the mud drum develops steam, it would disrupt water circulation.

Figure 8 – Interior View of Watertube Furnace

Objective 3

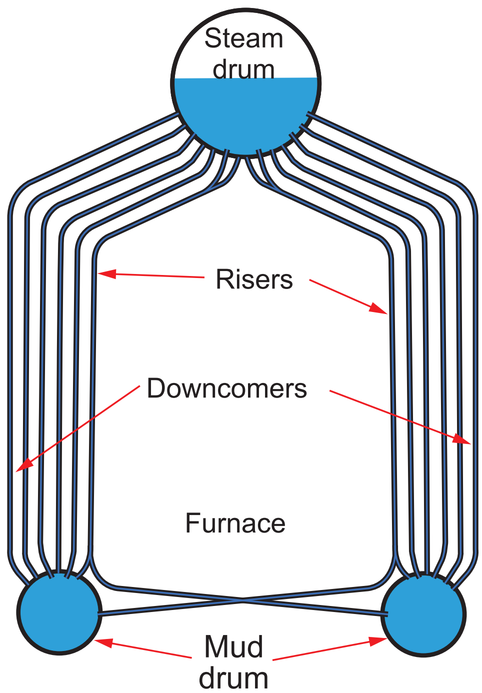
Explain the design and application of packaged watertube boilers.

Watertube boilers can be described by the shape that their tubes and drums form. Bent tube boilers are differentiated both by their type and number of drums. The most common type of boilers are A, D and O. These are the designs most often used for packaged watertube boilers.

A-Type Boiler

The A-type boiler shown in Figure 9 has two small mud drums. The steam drum is larger to permit separation of water and steam. Bent tubes running from the upper drum to the two mud drums form the furnace enclosure.

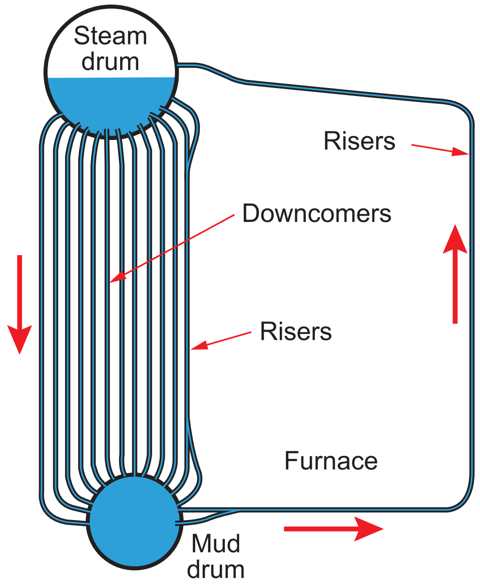
Figure 9 – A-Type Boiler

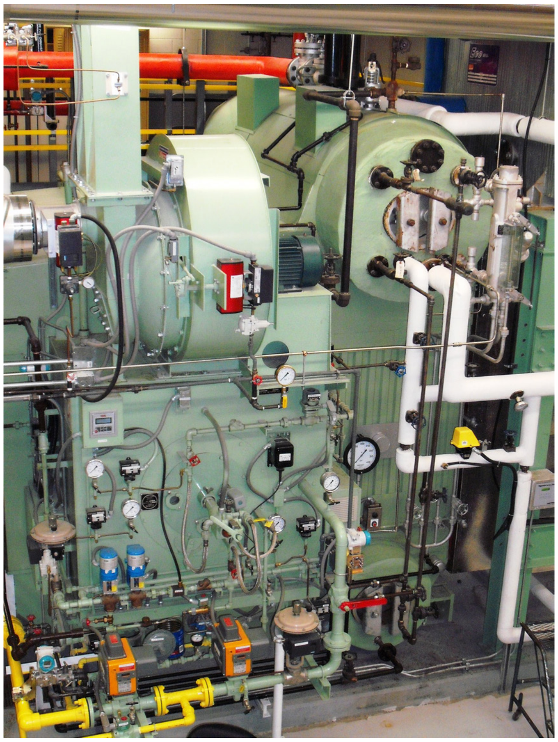


D-Type Boiler

The D-type boiler (Figure 10) has two drums. Bent tubes, on one side of the boiler, form a "D" shape, which creates a water-cooled furnace. The back wall, which receives radiant and convection heat, is usually protected by refractory. Some designs may have some wider spaced watertubes. The burner may be located in the front wall or in the side wall.

Figure 10 – D-Type Boiler

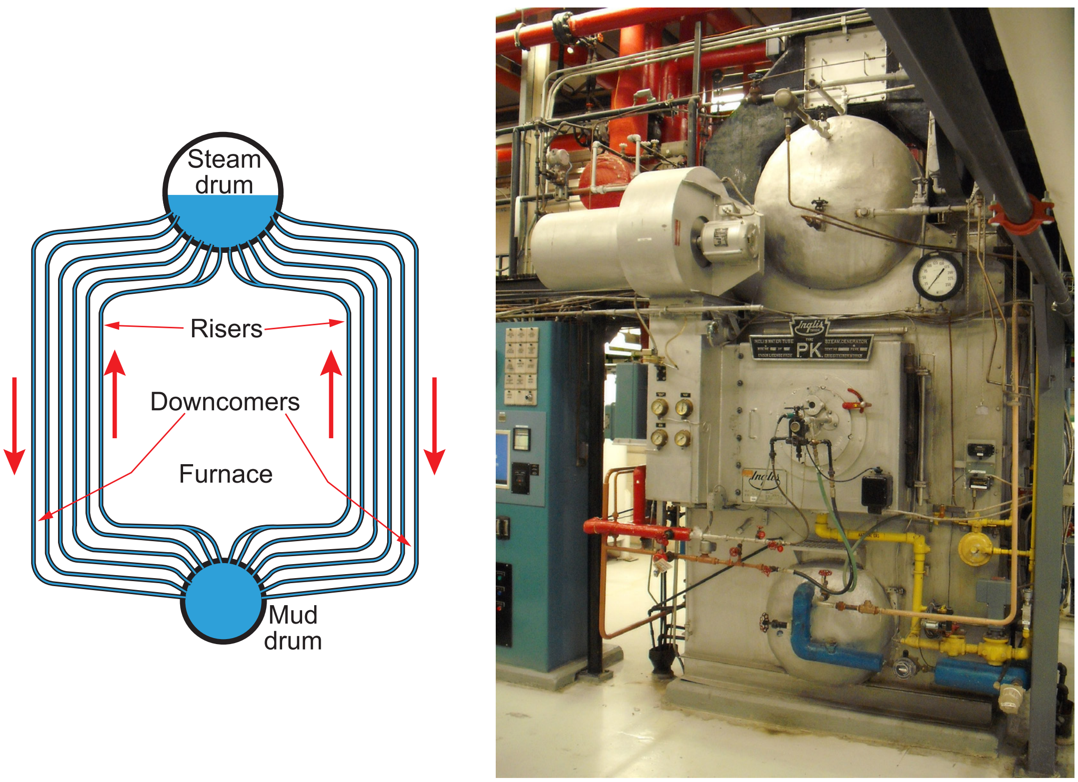




O-Type Boiler

The O-type boiler (Figure 11) is a two-drum design. The tubes connecting these two drums are arranged in an "O" shape to form a water-cooled furnace. While the O-type boiler exposes less tube surface to radiant heat than the A or D types, its compact design makes it a popular choice where space is limited.

Figure 11 – O-Type Boiler



In each of the three designs, steam forms in the fired tubes (the risers), and proceeds to the steam drum, where the steam is separated out of the water/steam mixture. Circulation is maintained by water returning to the mud drum through the unfired tubes (the downcomers).

Objective 4

Describe the design, construction, and components of large-scale steam generating units.

The term "boiler" is normally reserved for smaller units like packaged boilers. Extremely large boilers, used for producing tremendous amounts of high-pressure, high-temperature steam, are called **steam generating units**. The boiler is only one of the many heat exchangers found in a steam generating unit.

Steam Generating Unit

Steam generating units are extremely large field erected watertube boilers, with specialized heat transfer components to maximize unit efficiency. Heat leaving through a chimney represents a loss in efficiency. Efficiency losses are wasteful of fuel and money. Fuel costs are a significant expense to the plant; thus, efficient plant operation depends on extracting as much heat from the flue gases as possible.

A steam generating unit consists of all the heat transfer components and auxiliary equipment that contribute to the efficient production of steam. The heat transfer components of a steam generating unit consist of:

- A boiler
- One or more superheaters
- A reheater
- An economizer
- An air heater

Not all steam generating units have reheaters or economizers. Most have air heaters.

The auxiliary equipment includes:

- Fuel handling equipment
- Draft fans
- Ash removal equipment

Only steam generating units burning solid fuel have ash removal equipment.

Steam Generating Unit Heat Transfer Components

The purpose of each heat transfer component is the same: to extract heat from the flue gas and transfer it to another fluid, whether it be water, steam, or air. The heat transfer components of the steam generating unit shown in Figure 13 are:

1. The boiler (steam generating bank)
2. Superheaters (radiant and convection)
3. The reheater
4. The economizer
5. The air heater

1. Boiler (Steam Generating Bank)

The boiler section (also known as a **boiler bank** or **steam generating bank**), is where heat converts water to steam. This section includes the waterwalls, steam drum, and mud drum. Many steam generating units also have a nest of watertubes located after the reheater and superheater sections. The water walls receive a tremendous amount of radiant heat, and are the main producers of steam.

2. Superheater

Superheaters consist of a bank of tubes located at the furnace outlet. The convection superheaters are heated by flues gases in the gas path. The radiant area of the furnace contains the radiant superheaters.

Side Track

Often the words "primary" and "secondary" superheater are used. A **primary superheater** is the first superheater to receive steam from the steam drum. The **secondary superheater** receives steam from the primary superheater.

In superheaters, the heat of combustion first dries the moisture in the wet steam that is leaving the steam drum. Then, additional heat raises the temperature of the steam above its saturation temperature. This additional heat is called superheat.

Because superheater tubes are not water-cooled, they are designed from special heat resistant alloys.

Superheaters are used when the steam temperature required for power generation or a process must be higher than the saturation temperature. Superheaters minimize the chance of condensation of the steam in the latter stages of a steam turbine. Superheated steam also increases the overall plant efficiency by increasing the amount of energy that can be extracted from each kilogram of steam.

3. Reheater

The **reheater** bank is similar to a superheater bank, in that it adds superheat to steam. A reheater consists of a bank of tubes located near the furnace outlet, or radiant area of the furnace. It reheats exhaust steam from the high or medium-pressure turbine stages. The reheated steam then flows to the remaining turbine stages. Reheating the steam further reduces the chance of condensation in the low-pressure turbine, and increases the energy transferred to the medium or low-pressure turbines.

On Track

As steam passes through turbine stages, both its pressure and temperature drop as work is extracted from the steam. Reheaters operate at lower pressure than superheaters, but at approximately the same temperature.

4. Economizer

Economizers transfer waste heat from the flue gas to feedwater flowing to the steam drum. This process maximizes the fuel economy of the system by increasing the temperature of the feedwater entering the steam drum, and lowering the temperature of the flue gas. This also reduces the thermal shock of relatively cool water entering the hot steam drum.

5. Air Heater

The **air heater** (or **air preheater**) preheats the combustion air, which improves combustion efficiency, and assists in the burning of most fuels (especially solid fuels). Air heaters extract heat from flue gases that are leaving the economizer section of the steam generator.

One common type of air heater is comprised of a large wheel with multiple pie-shaped sections, each filled with corrugated metal plates. The wheel is situated in both the flue gas and the combustion air streams. Flue gas passes through and heats up one half of the wheel. The wheel turns continuously, bringing the hot sections into contact with the combustion air. This heats the combustion air, and cools the sections. Then, the cool sections re-enter the hot flue gas stream, and the process continues.

The air heater just described is a **regenerative air heater** (Figure 12). Figure 13 shows the location of the air heater.

Other air heaters are simple shell-and-tube heat exchangers. These tubular heat exchangers are called **recuperative air heaters**. The boiler shown in Figure 14 uses a recuperative air heater.

Figure 12 – Regenerative Air Pre-Heater

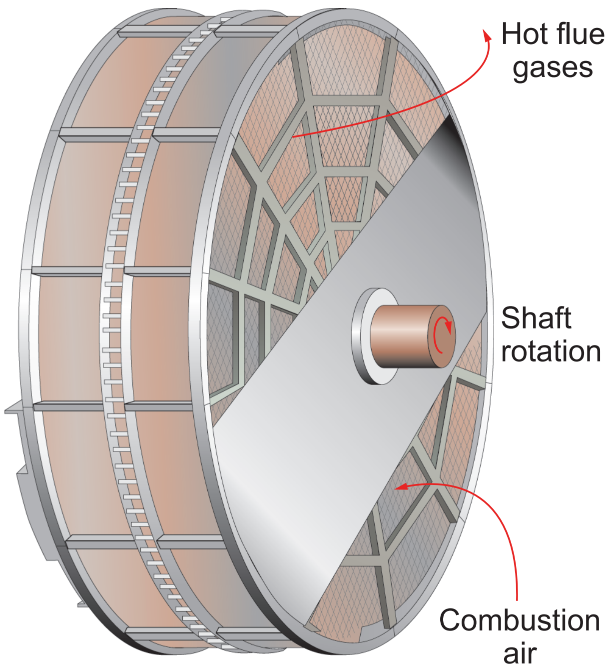
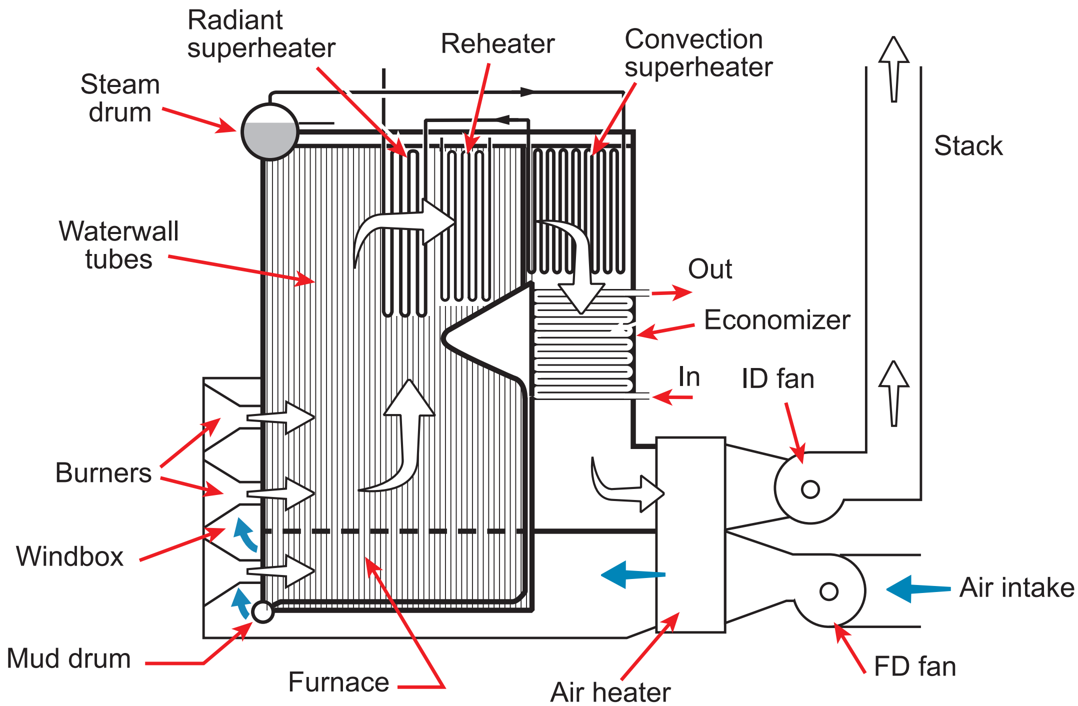


Figure 13 – Simplified Sketch of a Steam Generating Unit



Water, Steam, Air, and Flue Gas Flows

The heat transfer surfaces in steam generating units are primarily cross-counter flow heat exchangers. This can be determined by examining the direction of fluid flow in the steam generating unit.

Referring to Figure 13, the boiler water from the feedwater pumps enters the economizer, and then leaves the economizer, before entering the main boiler and waterwall section. The economizer inlet is located where the flue gas is the coolest. The economizer outlet is located where the flue gas is hotter.

The steam leaves the steam drum and then enters the primary superheater (a convection superheater). From the primary superheater, the steam enters the secondary superheater (a radiant superheater). Note that, like the economizer, the superheaters are cross-counter flow designs. Steam that leaves the radiant superheater flows to a steam turbine (not shown).

After the steam performs work in the steam turbine, it flows to the reheater, and then returns to the lower pressure steam turbine.

Generally speaking, the water or steam in each component flows opposite to the direction to the flue gases. In other words, the inlet to each component is at the downstream side of the flue gas.

Figure 13 is a very simplified representation of a steam generating unit. There are many different component arrangements, some much more complex than what is shown in Figure 13. There are also many different designs and configurations for each of the major heat transfer components. The purpose of Figure 13 is to show the general positions of the major heat transfer components in relation to each other and to the flue gas flow.

The flow of air and flue gases, from inlet to outlet, is as follows:

1. Combustion air is drawn in from the atmosphere by a **forced draft (FD) fan**.
2. The air is preheated in the air heater, where it receives heat by conductive heat transfer from the flue gases before they enter the stack.
3. The preheated air proceeds through the **windbox** to the burners, where it mixes with fuel and supports combustion.
4. Radiant heat from the furnace heats the radiant superheater and the reheater.
5. The hot combustion gases leave the furnace. After exiting the furnace, the combustion gas is referred to as flue gas.
6. The flue gas cools progressively as it transfers heat to each of the major heat transfer components, in the following order:
   i. Radiant superheater
   ii. Reheater
   iii. Convection superheater
   iv. Economizer
   v. Air heater
7. The cooler flue gases are then drawn out of the air heater by the **induced draft (ID) fan**, which discharges them up the chimney to atmosphere.

Types of Steam Generating Units

There are many types of steam generating units used in Industry. A brief synopsis will be given here. Steam generating units are discussed in further detail in advanced levels of Power Engineering. Some of the terms used to describe steam generating units are:

1. Natural circulation
2. Sub-critical
3. Radiant
4. Forced circulation
5. Supercritical
6. Once-through steam generating unit (OTSG)
7. Fluidized bed

1. Natural Circulation Steam Generating Unit

Natural circulation steam generating units use only natural convection currents to circulate the boiler water. Natural circulation steam generating units usually have both steam and mud drums.

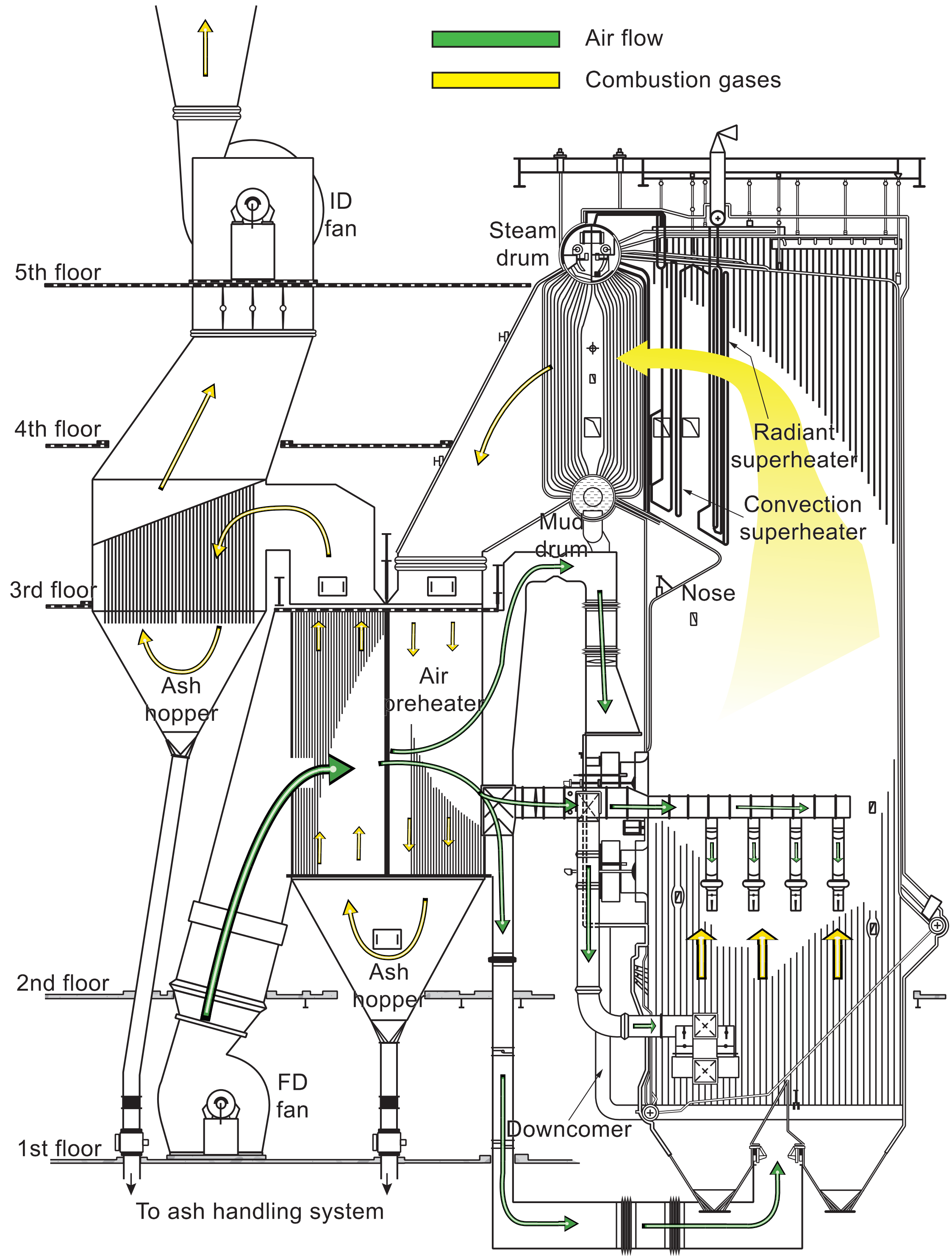
Recirculation rate, with regard to natural circulation boilers, refers to the kg of water recirculated through the boiler for every kg of steam leaving the boiler. Recirculation rates can vary up to 25:1. That is, for every 25 units of water circulating, one unit of steam is produced. Boilers with high recirculation rates have larger steam drums and complex steam separating equipment.

2. Sub-Critical Steam Generating Unit

Sub-critical steam generating units operate at pressures below the critical pressure of water and steam. At 22 090 kPa, there is no difference in density between steam and water. Steam generating units operating below 20 MPa may be natural circulation SGUs, using either a standard configuration or a radiant configuration. Sub-critical steam generating units operating above 12.5 MPa usually use forced circulation as noted later in this section.

Figure 14 shows a sub-critical, natural circulation power boiler, used in the pulp and paper industry. The ash hoppers are necessary when burning a solid fuel. The air heater is a recuperative design. Notice this steam generating unit does not have an economizer or a reheater. An interesting feature is the **external downcomer**. Positive water circulation is enhanced by completely shielding the downcomer from the heat of combustion. In this way, the downcomer cannot generate steam bubbles that would disrupt circulation.

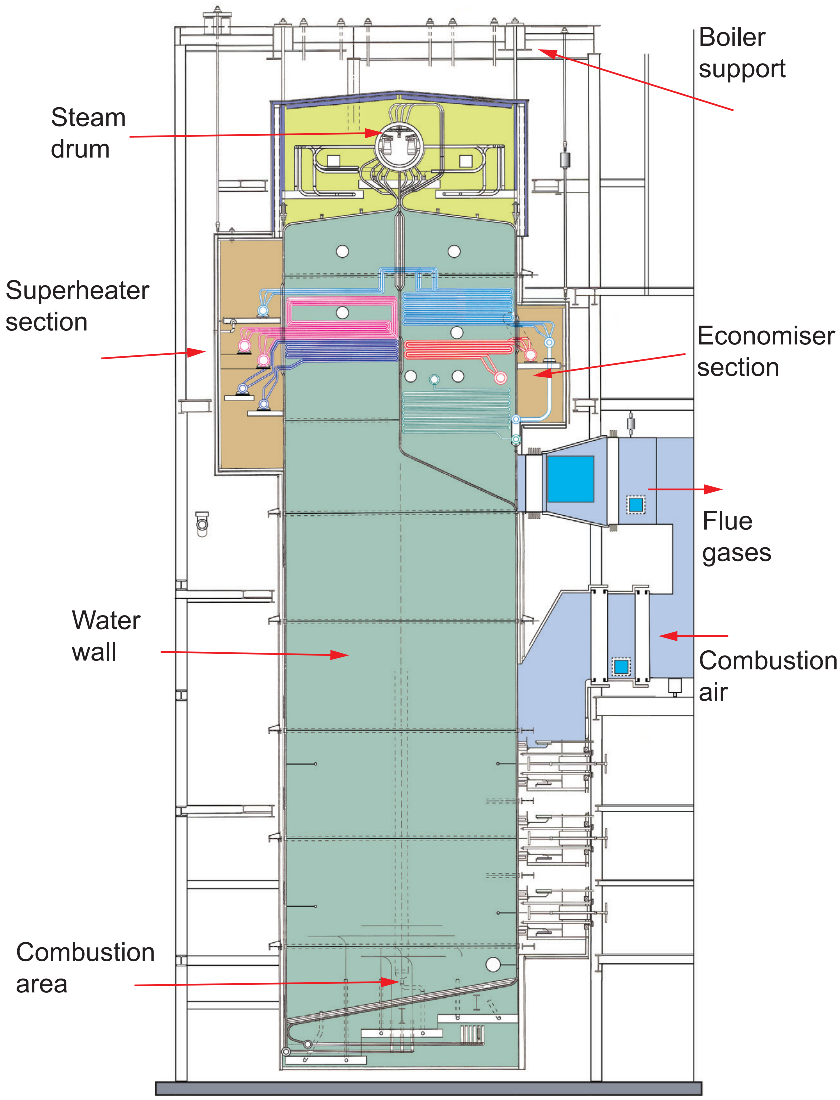
Figure 14 – Sub-Critical Natural Circulation Power Boiler



3. Radiant Steam Generating Unit

Figure 15 shows a radiant steam generating unit. This type does not have a boiler bank. It also lacks a mud drum. The water is heated to evaporation in the waterwall furnace tubes, and the steam is separated in the steam drum.

Figure 15 – Radiant Steam Generating Unit



4. Forced Circulation Steam Generating Unit

Forced circulation is required for boilers operating at about 20 MPa and above. Forced circulation increases the equipment, operating, and maintenance costs. It is advantageous to use forced circulation above 12.5 MPa, but is not required until about 20 MPa. Boilers operating under the supercritical threshold may use forced circulation for efficiency or for design reasons.

5. Supercritical Steam Generating Unit

At 22.09 MPa, the density of water and steam is equal. This is known as the "critical pressure." Boilers designed to work above this pressure are called **supercritical steam generating units**. Those operating below critical pressure are "sub-critical" steam generating units.

Supercritical steam generating units use forced circulation. They do not have steam or mud drums. There may be a steam separator vessel used for startup, but usually these units send steam directly into the superheaters. The feedwater is pumped into the economizer. From there, it flows through the waterwall section, the convection superheater, the radiant superheater, and out to the high-pressure steam turbine. The turbine exhaust steam returns to the reheater. There is no water level to maintain.

Supercritical boilers are a type of **once-through steam generator (OTSG)**.

6. Once-Through Steam Generators (OTSG)

OTSGs may be sub- or super-critical in design. In this type of boiler, water enters the unit, travels through in one pass, picks up heat, and is changed into steam.

An OTSG has no internal recirculation. OTSGs do not need steam drums because the entire mass of water entering is turned to steam.

In **steam-assisted gravity drainage (SAGD)** operations, forced circulation OTSGs are used to create steam for in-situ extraction of heavy oil (bitumen). They are typically operated in the sub-critical pressure region. OTSGs are designed to operate with lower quality feed water than conventional boilers. Because of this, the boiler is generally operated between 70% to 80% steam quality range to maintain enough liquid phase to keep a large majority of solids in solution. This reduces the formation of deposits in the boiler tubes that may require taking the system offline for maintenance. (Some SAGD operations run at higher steam quality but require a more rigorous boiler water pre-treatment regime.) Depending on feedwater quality, the solids that do accumulate in the tubes are removed by specialized cleaning operations, often called pigging. Steam generators typically operate for between 6 months and 2 years before being taken offline for 2-4 days for cleaning.

7. Fluidized Bed Combustion Steam Generators

A **fluidized bed combustion (FBC)** steam generator looks very similar to other steam generating units. However, the furnace is a specialized design. Instead of burning fuel with burners or stokers, fuel is burned suspended in mid-air, in a bed of an inert material (like sand or gravel). The bed is kept in suspension, with combustion air fed from below. The burning bed, though comprised of solid materials, behaves like a suspended fluid rather than a solid mass.

Fuel is introduced to the bed with a variety of stoker mechanisms.

Watertubes may be located directly within the bed. These tubes absorb radiant heat and heat conducted directly from the bed particles to the tubes. The in-bed tube is in addition to the watertubes located elsewhere throughout the steam generator.

The advantages of FBC steam generating units include:

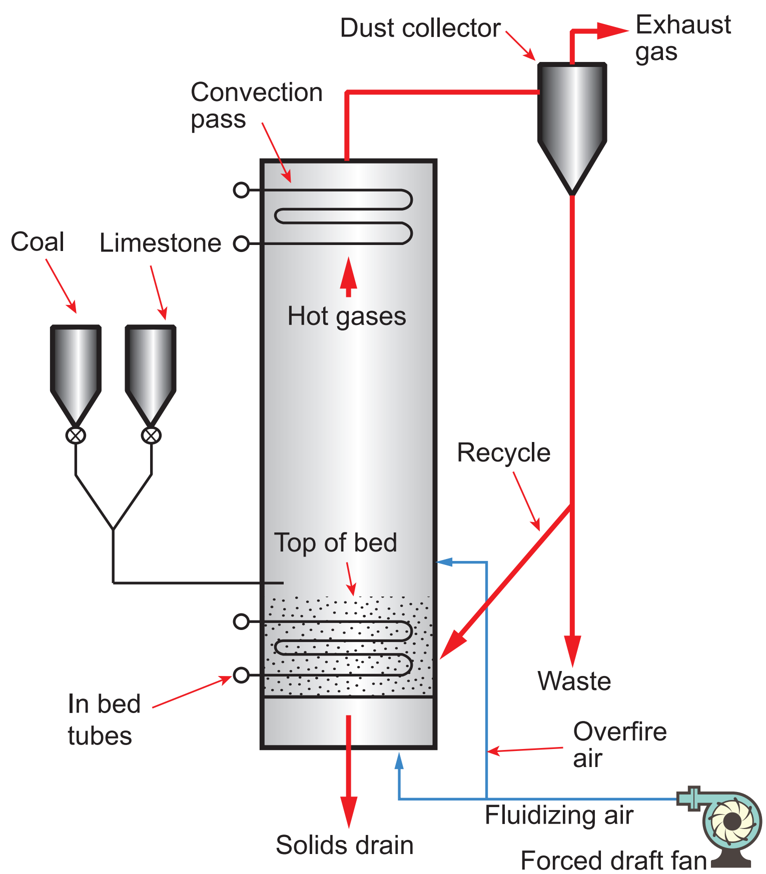
a) High efficiency operation.
b) Suitability for a wide range of fuels, such as crushed coal, wood, refuse, and shredded tires.
c) The plant may be smaller because of higher heat transfer rates in the furnace.
d) Lower furnace temperatures reduce NO_X production.
e) Limestone, if added directly to the bed, dramatically reduces SO_X emissions.

Fluidized bed steam generating units, however, do have higher power requirements for the combustion air fans. They require separators in the flue gas to return unburned fuel back to the bed. Also, it is difficult to control combustion at low firing rates.

Figure 16 shows an FBC boiler with in-bed tubes. This type of boiler is called a **bubbling bed** FBC, because the combustion air passes through the bed like large bubbles.

Other designs use more combustion air. In this type of FBC boiler, the flue gas carries burning fuel through the boiler to the dust collector, which is lined with steam generating tubes. This smouldering fuel is reintroduced to the furnace to increase the firing rate, or withheld to keep the firing rate low. This type of FBC is called a **circulating fluidized bed boiler**.

Figure 16 – Fluidized Bed Furnace

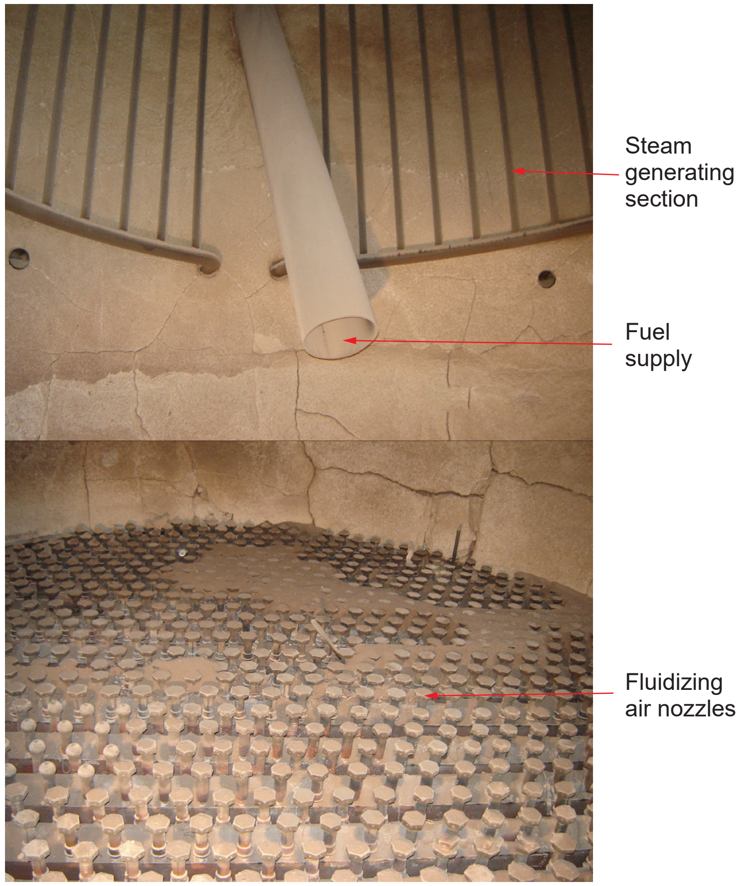


Fluidized bed boilers have auxiliary conventional burners to preheat the inert bed material, so that combustion of the solid fuel begins as soon as it contacts the bed.

Fluidized beds have been applied to forced circulation and natural circulation designs.

The FBC shown in Figure 17 uses sand in suspension to burn woodchips. Combustion air is delivered through the fluidizing air nozzles at the base of the furnace, and at other locations above the bed. Note the extensive use of refractory.

Figure 17 – Fluidized Bed Furnace



Chapter Summary

Watertube boilers are more complex in design, operation, and maintenance than firetube boilers. However, watertube boilers are more versatile and varied in design. Since firetube boilers are only available at pressure ratings up to about 2.4 MPa, watertube boilers are the only choice for higher-pressure service. As well, only watertube boilers meet current industrial needs for superheated and reheated steam.

Watertube boilers can be factory built packaged units, shop-assembled, or field-erected units. Steam generating units are field-erected. Packaged units are mostly A-, O-, or D-type in layout.

The addition of auxiliary heat transfer components, such as economizers and air heaters, make modern steam generating units quite efficient. The addition of other heat transfer components, such as superheaters and reheaters, greatly improve the plant efficiency of processes that use large turbines to generate power.

Chapter 4

Electric Boilers

Learning Outcome

When you complete this chapter you should be able to:

Explain the general design and application of electric boilers.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Discuss the advantages and disadvantages of electric boilers.*
2. *Describe the construction and operating principle of electric boilers.*

Chapter Introduction

The boilers described in other chapters, namely the firetube and the watertube types, obtained the heat necessary for converting water to steam from the burning of fuel within the boiler furnace. The electric boiler uses electricity to heat the water and convert it to high or low-pressure steam or hot water.

Electric boilers have traditionally been used in smaller plants for low-pressure heating, sterilizing, and in laundries and kitchens.

However, recently it has been realized that electric boilers can be used to increase the efficiency of traditional plants by using them in times of low electrical demand.

This chapter will describe the main types of electric boilers, and the applications they are best suited for.

Objective 1

Discuss the advantages and disadvantages of electric boilers.

Electric boilers, though not commonly used, are useful for certain power plant applications. As auxiliary boilers, electric boilers can be used to keep standby steam generators warm so they can be brought on-line quickly. Electric boilers can also be used during periods of low process steam demand.

Low capacity electric boilers are used for many purposes, even though electricity is more expensive than fossil fuel. Running large fossil fuel boilers at low output can cost as much, or even more, than running electric boilers. Carefully choosing when to run electric boilers can decrease overall energy costs.

Electric boilers are also used in facilities where large amounts of electricity are available at low cost. For example, aluminum smelters use large quantities of electricity for the smelting process. To facilitate this, smelters are located near hydroelectric facilities, and negotiate special energy rates from the local utility.

Electric boilers may be used for high-pressure or low-pressure applications, in both steam and hot water service.

Advantages and Disadvantages of Electric Boilers

The advantages of electric boilers over fuel-fired boilers are as follows:

a) Electric boilers are very compact. Unlike fuel-fired boilers, they do not require furnace space for combustion, vent connectors, combustion air equipment, or chimneys.

b) No fuel storage space is required, unlike oil or coal fired boilers.

c) Electric boilers are installed or replaced quickly and easily, since ductwork, chimneys and fuel lines are not required.

d) Electric boilers are highly efficient. A high percentage (99%) of the energy delivered by the electricity is absorbed as heat in the boiler.

e) Electric boilers produce no pollution, such as smoke, dust, or ashes. However, the electricity must be produced at another location using thermal, hydroelectric, or other systems where some environmental impact will occur.

f) Electric boilers are silent in operation.

g) Electric boilers pose no threat of furnace explosion; therefore, they are somewhat safer than fuel-fired boilers.

The disadvantages of the electric boiler are as follows:

a) Electricity is usually much more expensive than fossil fuels.

b) Most designs are limited in pressure to about 2100 kPa due to the effect of high temperature on the electrodes or heating elements.

c) Many electric boilers operate at high voltages. To avoid dangerous contact, operators must observe safe limits when approaching energized boiler electrical connections or high-voltage switchgear.

Objective 2

Describe the construction and operating principle of electric boilers.

Electric Boiler Types

There are two general types of electric boilers:

1. Electrode
2. Immersion (or resistance)

Electrode Boiler

Pure water does not conduct electricity. However, when the water contains dissolved mineral salts, it becomes an excellent conductor. In an electrode-style electric boiler, electrodes and the water become part of an electric circuit. Electric current travels through the conductive water, and passes from one electrode to another. Heat is produced, which turns the water into steam. The steam is then drawn off leaving water impurities (mineral salts) behind to keep the water conductive.

There are two types of electrode boilers. In the first type, the electrodes are submerged in the water. The level of the water can be controlled to change how deep the electrodes are immersed. The amount of electric current passing through the water, and therefore the steam production rate, is directly proportional to the depth of electrode immersion.

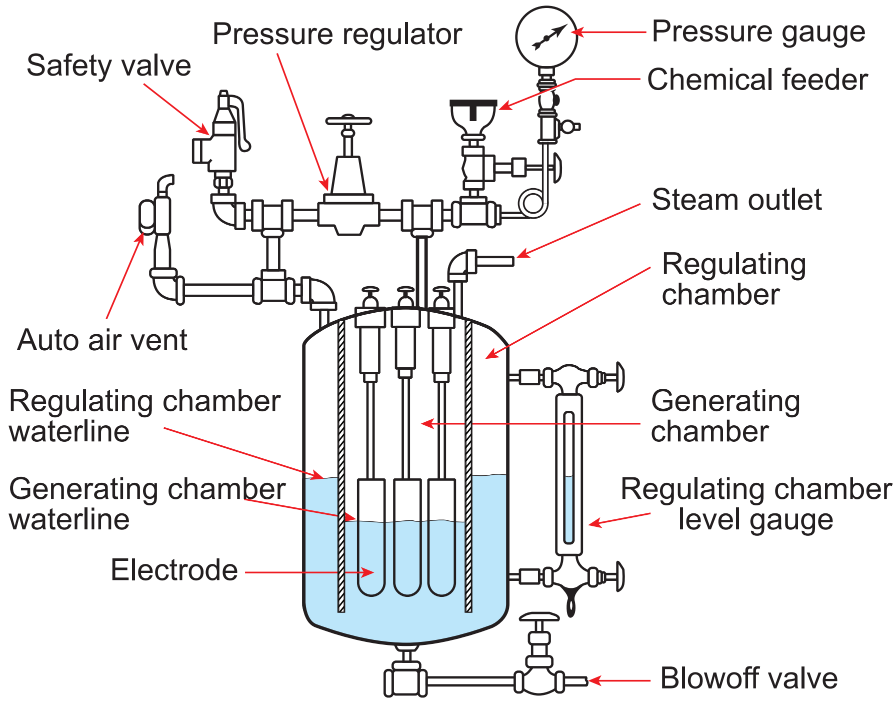
Figure 1 shows a submerged electrode design electric boiler. In it, water is supplied from the outside regulating chamber to the generating chamber. Steam is produced in the generating chamber in response to the load. When the steam load drops, the pressure in the generating chamber increases slightly. The pressure increase forces some water out of the bottom of the generating chamber, and lowers the generating chamber level. This reduces the immersion level of the electrodes, which reduces the current flow and the rate of steam production.

An increase in load does the opposite. The generating chamber pressure drops slightly, the water level rises, current increases, and steam production increases to meet the larger demand. The boiler is thus completely self-regulating.

At zero load, the pressure will increase enough to force the water out of the generating chamber and completely stop the current flow. For this reason, a high-pressure limit switch is not required on this boiler. This boiler does not need a low-water cutoff either, since the current flow stops when the level drops below the electrodes.

A float valve, which regulates the supply from the feedwater pump, controls the water supply to the regulating chamber.

Figure 1 – Submerged Electrode Type Boiler



In another electrode boiler design, water is sprayed onto electrodes that are mounted above the water level of the boiler. The amount of current produced depends on the amount of water sprayed. This boiler design is known as a "jet-type electrode" electric boiler.

Figure 2 shows a jet-type electrode boiler of Cleaver Brooks design. Models like this can be designed to operate at voltages from 4.16 to 25 kV. The largest produce up to 85 450 kg of steam per hour, at pressures up to 3100 kPa.

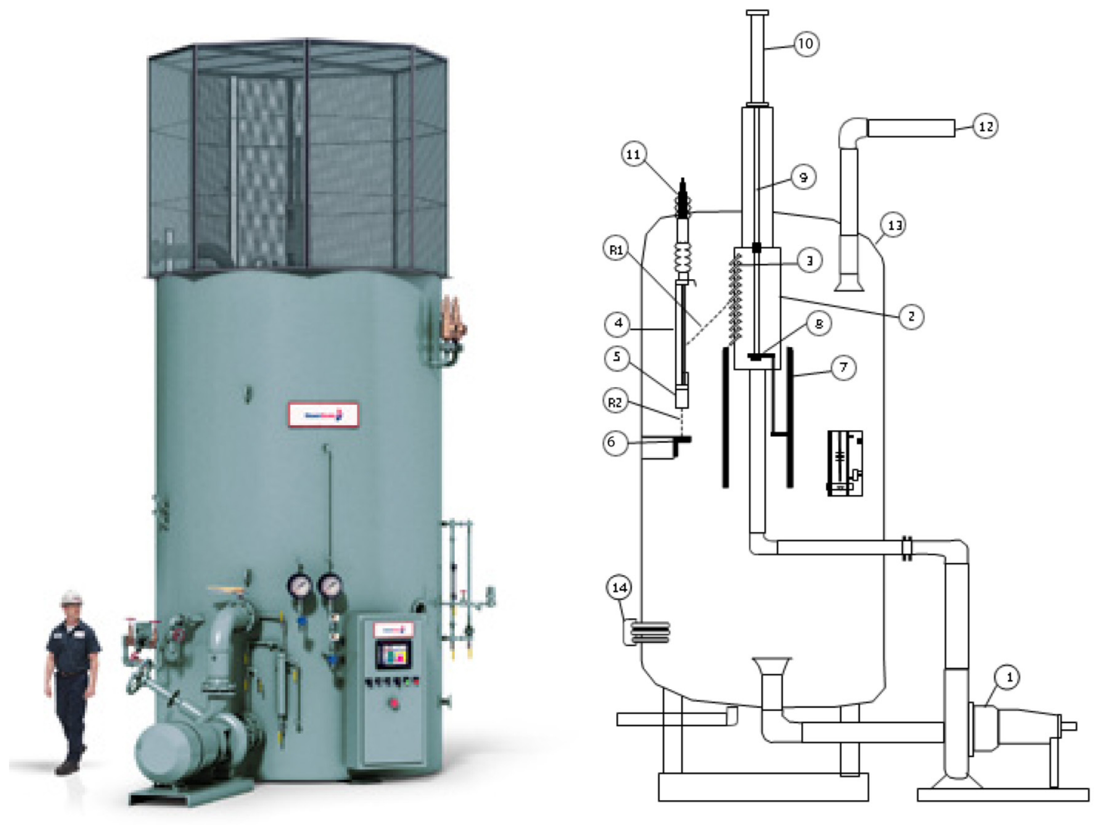
In Figure 2, water from the lower part of the boiler is pumped by the circulating pump (1) up a collection pipe (2) to the spray nozzles (3). The water is forced through the nozzles, and strikes the electrode plate (4), which creates an electrical current path (R1). The unevaporated water flows from the electrode through the nozzle plate (5) to strike the counter electrode (6), creating a second current path (R2).

Control of the boiler output is accomplished by raising or lowering the control sleeve (7). The control sleeve adjusts the amount of water that sprays on the boiler electrodes, thus controlling the amount of steam produced. The control sleeve diverts the water away from the electrodes, and directly back to the lower portion of the boiler. The control sleeve is moved hydraulically by the control cylinder (10) that is positioned by an electronic boiler pressure and load control system. This control system maintains the steam pressure at set point, and matches the boiler steam output to load requirements.

A stand-by heater (14) maintains pressure at a pre-set level in order to reduce startup time. A proportioning feed water regulator (not shown) maintains a constant water level in the boiler. A load monitoring system prevents the electric demand from exceeding boiler capacity, and enables the boiler to be manually set at levels lower than its full MW rating.

The boiler is shut off by turning off the circulating pump.

Figure 2 – Jet-type Electrode Electric Boiler



(Courtesy of Cleaver Brooks)

Immersion (or Resistance) Boiler

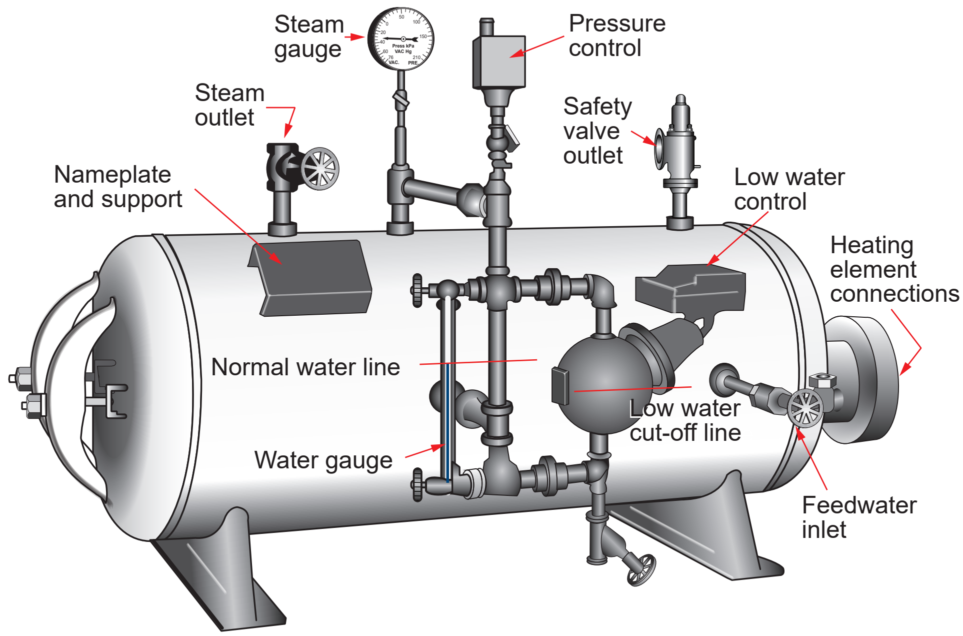
The immersion heater electric boiler differs from the electrode boiler, in that no electric current travels through the water. Instead, the electric current flows through a high-resistance heating element, which is entirely submerged beneath the boiler water level. This principle is the same as in an electric water heater. As the current flows through the heating element, it heats up. This in turn heats the water, causing it to turn into steam.

Immersion heater boilers are controlled by turning on and off the power supply to one, two, or more elements as required. This varies the firing rate and steam production of the boiler.

Figure 3 shows the external view of an immersion heater electric steam boiler. The boiler design shown is manufactured in sizes up to 1500 kilowatts, and for pressures up to 2100 kPa.

Immersion boilers like that in Figure 3 require low water cut-offs to protect the elements and the shell from overheating. The low water cut-off is situated to turn off electric power to the heating elements above the top surface of the upper-most heating element. Not shown in Figure 3 is the high-pressure cut-off, the water level control, the bottom blow-off valves, and the insulation that covers the boiler shell.

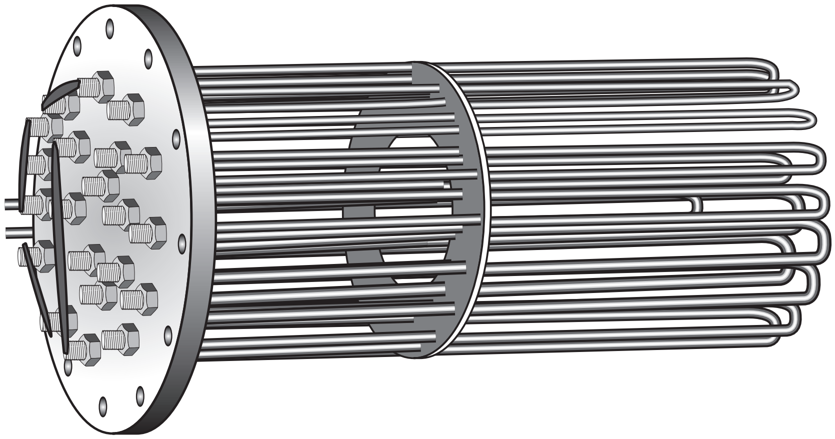
Figure 3 – Immersion Heater Boiler Parts



The immersion boiler elements are arranged so that they are easily accessible for maintenance or replacement. Figure 4 shows the arrangement of a number of elements, and also illustrates the general design of an element which has been removed from the boiler.

Connections to the heating elements can be rearranged to provide full load operation on various voltages (which may vary due to plant location).

Figure 4 – Immersion Heater Elements



The packaged boiler concept is also used for some electric boilers. These packaged units may include controls, feed pumps, and condensate tank all within one cabinet.

Chapter Summary

Electric boilers, although limited to lower capacities and pressures, can fill the needs of certain segments of industry. In certain situations, despite the relatively high costs of electricity, they can be economical to install and operate.

Electric boilers are considered safer than fuel-fired boilers because they have no furnaces, and cannot sustain furnace explosions. In addition, electrode boilers, by their very design, cannot fail due to low-water conditions. Both varieties are compact and relatively easy to install and replace, as long as the electrical service is adequate to provide the high voltages and high currents these boilers need.

CHAPTER 5

Special Boiler Designs for Heating Plants

LEARNING OUTCOME

When you complete this chapter you should be able to:

Describe the special design considerations of boilers used in heating plants.

LEARNING OBJECTIVES

Here is what you should be able to do when you complete each objective:

1. *Describe the design of watertube and coil tube heating boilers.*
2. *Describe cast iron boilers and vertical firetube boilers.*
3. *Describe the construction and application of firetube heating boiler designs.*

Chapter Introduction

Although Scotch boilers and larger A, O, and D type watertube boilers are very versatile and effective boilers, there are instances where they are simply too big to be considered for some heating applications. Smaller boilers, designed with firetube and watertube principles, meet the needs of these smaller heating plants.

Flexible tube watertube boilers, coil tube watertube boilers, and cast iron sectional boilers have their own advantages and disadvantages, distinct from the larger boilers.

Flexible tube and coil tube type watertube boilers:

a) Are compact. They are considerably smaller and lighter than firetube boilers of equal capacity.
b) Require no special foundation.
c) Warm up very quickly.
d) Develop little thermally induced stress.
e) Respond rapidly to fluctuating heating loads.
f) Come as packaged units, complete with firing equipment, automatic controls, and safety devices.
g) Are safer than firetube boilers with respect to tube failure, because watertube boilers contain very little potential energy stored in their water.
h) Have minimal maintenance costs.
i) Have minimal refractory.

These are significant advantages. However, these boilers need to be more closely monitored for proper water treatment as compared to firetube and cast iron sectional heating boilers.

Cast iron sectional boilers have their own advantages:

a) They are more corrosion resistant than steel boilers.
b) They are easy to assemble, without the need of highly skilled labour.
c) They can be shipped either fully assembled or in pieces. The individual pieces are small enough to be moved through doorways, so walls do not have to be demolished.
d) They may be increased in capacity by installing more sections. This may be more cost effective than installing more boilers.

However, cast iron sectional boilers are prone to leaks from the sealing elements in between their sections.

This chapter covers boilers made of steel, copper, and cast iron, used in heating service.

Objective 1

Describe the design of watertube and coil tube heating boilers.

Watertube Heating Boilers

Industrial type watertube boilers are seldom selected for low-pressure heating plants, except for large building complexes. The main reasons are the high cost of this type of boiler as compared to the cast iron or steel firetube boiler, and the need for closer supervision, especially with regard to water treatment.

Specially designed watertube boilers, usually supplied as packaged units, are used for low-pressure heating applications.

Bent Tube Watertube Boiler

Bent tube watertube boilers, like the one shown in Figure 1, have become increasingly popular for use as heating boilers. The boiler shown is actually a low pressure version of a common high-pressure "O" type packaged watertube boiler. This boiler design is used to generate either low-pressure steam or hot water.

In hot water service, the upper and lower drums are equipped with full-size nozzle attachments for hot water return and hot water supply. Cooler water returns to the mud drum, and hot water leaves the steam drum.

Figure 1 – Cut-Away of a Watertube Boiler with Membrane Waterwalls

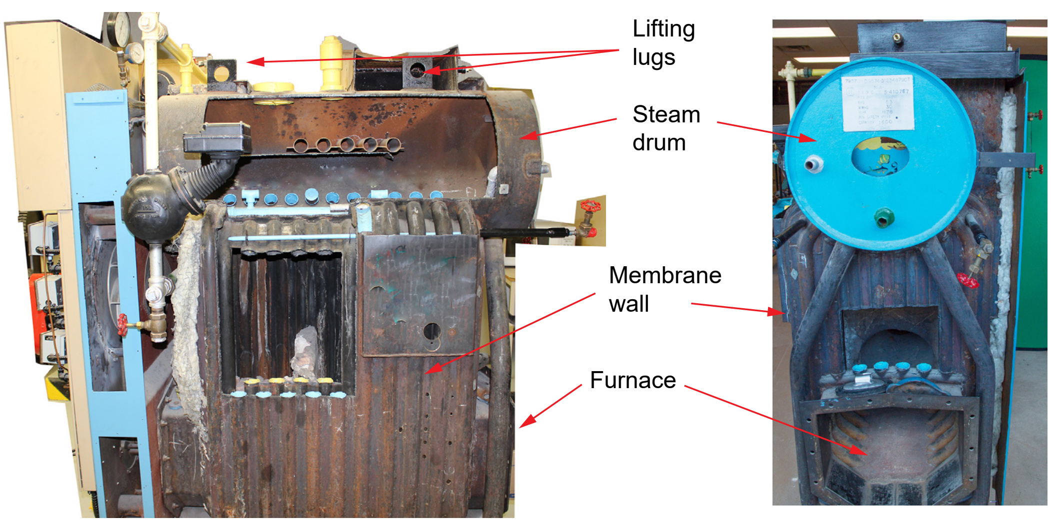


Figure 1 shows a cut-away view. This boiler has a large upper drum, a small lower drum, and several bent watertubes which connect the upper and lower drums.

The tubes are arranged in such a way as to form the furnace enclosure. The furnace walls are formed by water-filled tubes and form waterwalls. The tubes in these walls are spaced apart but connected to each other by steel plating welded to the tubes, so that gastight walls (membrane waterwalls) are formed. Two such walls are used in each side of the boiler. The inner walls form the furnace enclosure. The outer walls form a passageway for the flue gases. The front and rear of the boiler are closed by single waterwalls. As a note, this type of waterwall is very common in large watertube boilers. Figure 2 shows a sectional view of a **membrane tube** waterwall.

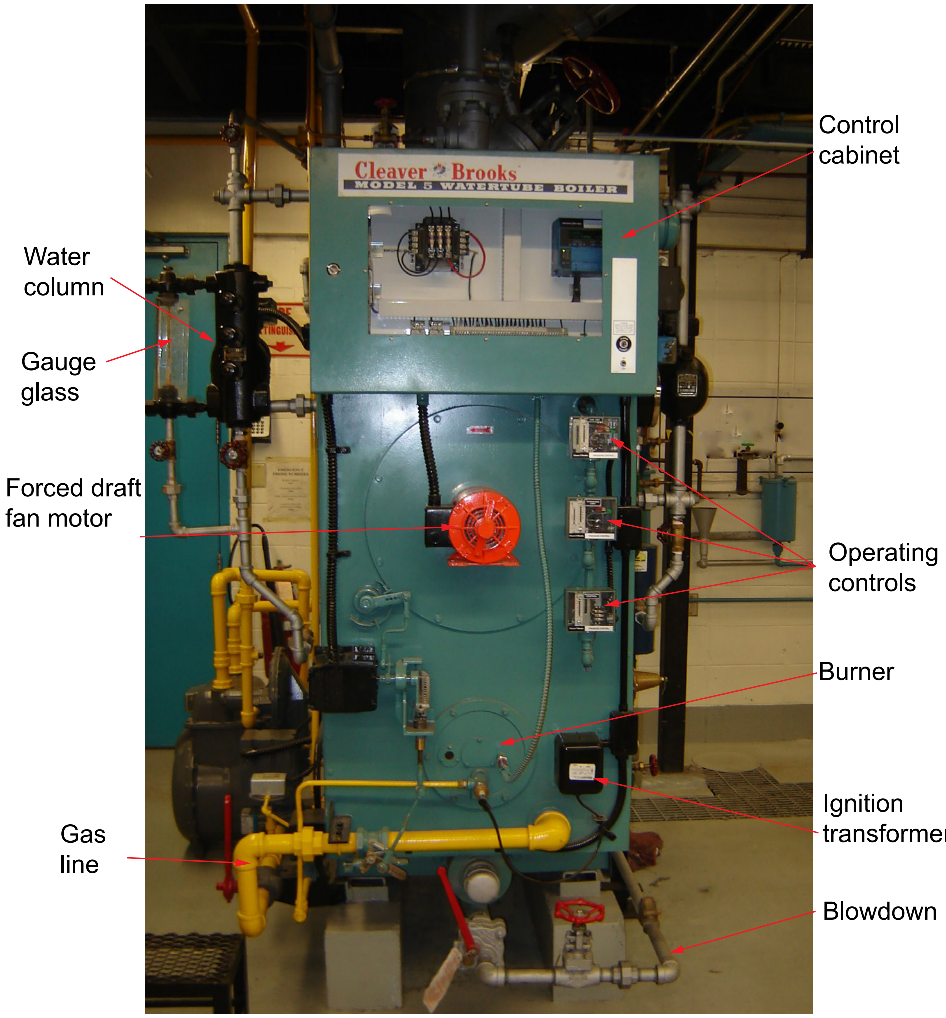
Figure 2 – Section of a Membrane Waterwall

The furnace walls absorb large amounts of radiant heat from the fire. The rapidly circulating water in the tubes carries off this heat. In hot water applications, water is forced through the boiler with a circulating pump.

After leaving the furnace, the combustion gases travel between the inner and outer membrane walls on their way to the chimney, transferring heat to the walls by convection.

An insulated steel casing encloses the boiler. This particular boiler design may be either oil or gas fired, and equipped with a forced draft fan. Figure 3 shows an illustration of the boiler complete with casing, firing equipment, fittings, and controls. Boilers of this type are approximately 2 m high, 1 m wide, and 3 m long. Because they are compact, they can fit through a standard doorway. This makes them easy to replace. They can also replace existing boilers, when the boiler room has limited access.

Figure 3 – Watertube Boiler



Flexible Watertube Heating Boiler

A popular type of watertube heating boiler is a variation of a bent tube boiler. The **flexible watertube** boiler has several exaggerated bends in the watertubes, which attach the steam drum to the water drum. This increases the heating surface, and allows the tube to expand and contract without creating excessive stress. These tubes may be attached either by threading or by using ferrules. They are designed for simple replacement.

The combustion chamber of this boiler is below the tubes. This exposes the lower part of the tubes to the radiant heat of the fire. The combustion gases travel between the tubes, upwards to the flue. Even though the gas travel is relatively short, heat transfer is efficient due to the arrangement of the tubes, which causes turbulent and intensive scrubbing of the gases around them.

Figure 4 – Flex Tube

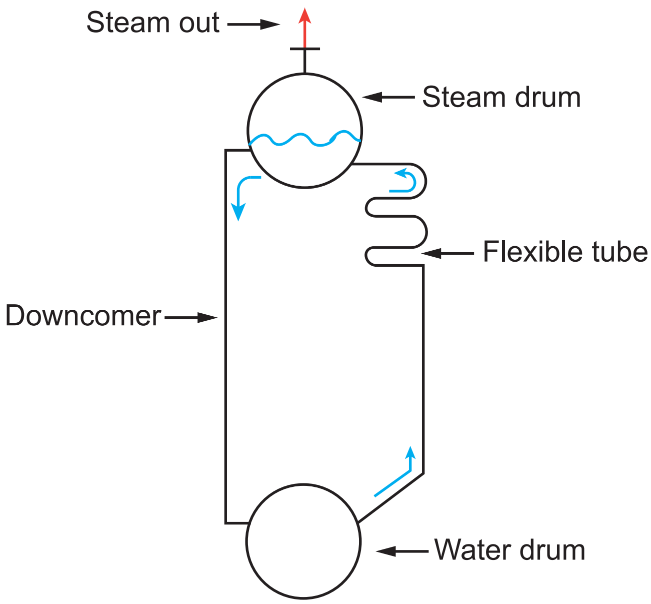
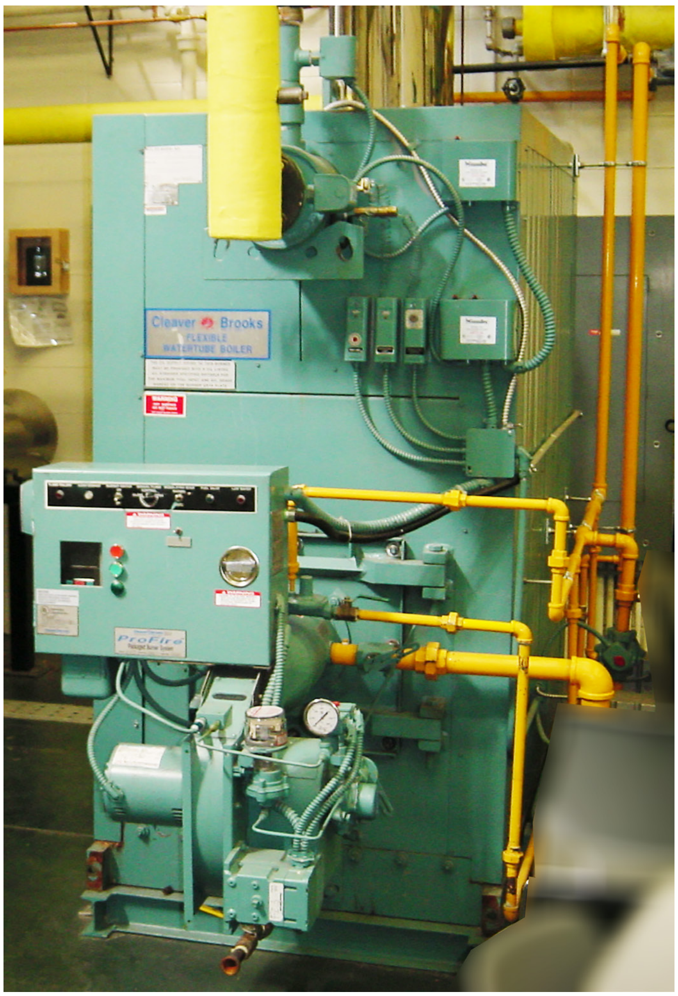


Figure 5 – Flexible Watertube Boiler in Heating Service



Coil Tube Heating Boiler

A **coil tube boiler** is actually a watertube boiler. In fact, it may be described as a forced circulation once-through boiler. This boiler has no drums or headers. Instead of having a large number of tubes, it has one or more continuous coils of copper or steel tubing. The number of tubes, and overall length of the tubing determines the capacity of the boiler. A pump forces water through the coil which is exposed to the hot products of combustion.

Steam boiler varieties use steel tubing. Because these boilers have small tube diameters, water treatment is important, to prevent scale deposition. If scale is present, water flow could become restricted, and tubes may overheat. These boilers may have atmospheric burners or power burners (forced draft).

Coil tube boilers are very common in hot water supply and hot water heating service. They are frequently used to directly heat domestic hot water. Many are installed banks of several boilers attached to common supply and return headers, and operate sequentially according to heating demand.

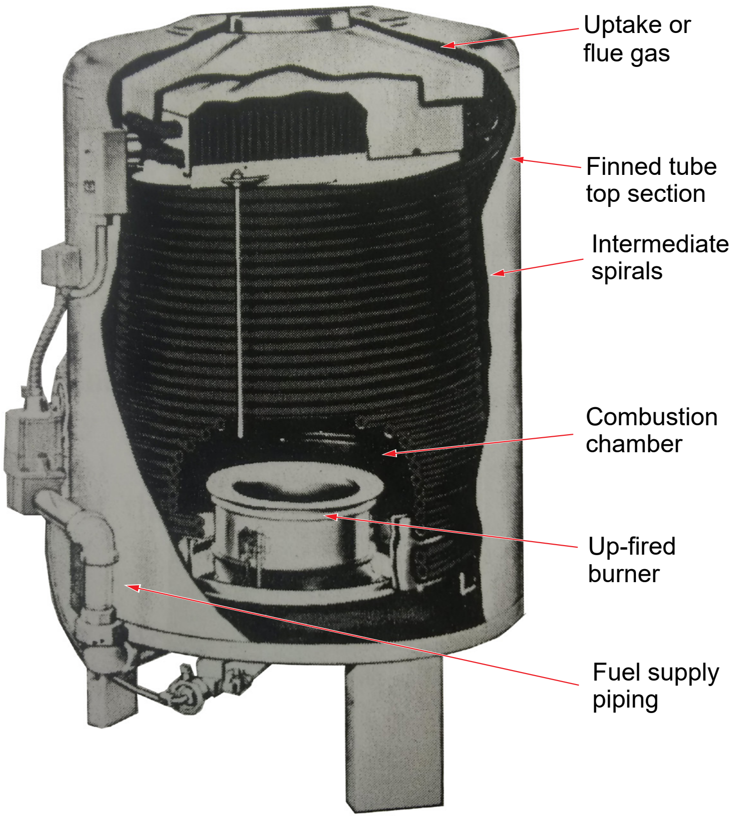
Most **copper tubular boilers** are natural draft designs, though many newer varieties have forced draft or fan assist burners. Almost all operate on natural gas or propane.

The copper tubular heating boiler, shown in Figure 13, is popular in residential and commercial hot water heating systems. These compact boilers are available in sizes up to about 150 kW. The heating surface consists of one continuous, small diameter copper tube. Copper is used because it resists corrosion, and it has a better heat transfer rate than cast iron or steel.

The heating surface is divided into three parts:

1. The lower section, consisting of a tightly wound coil that surrounds the combustion chamber.
2. An intermediate section, made of several layers of loosely wound spirals. Because the spirals are loosely wound, flue gases can flow freely around the tubing as they leave the furnace.
3. The upper section, which is a fin-and-tube type heat exchanger. Fins are crimped or bonded on the tubes, increasing the heating surface so more heat is absorbed from the hot gases before they head to the chimney.

Figure 6 – Copper-Tubular Boiler



(Courtesy of A. O. Smith)

Objective 2

Describe cast iron boilers and vertical firetube boilers.

Cast Iron Boiler Construction

The cast iron sectional boiler is generally used for steam and hot water heating systems in small and medium sized buildings. They range in capacity from about 30 kW to over 2000 kW, in both low-pressure steam and hot water service.

The boiler is built up from a number of hollow, cast iron sections. Each section has circular holes at the top and bottom, to permit the free movement of steam and water between sections. These passageways are sealed with **push nipples** or gaskets. Push nipples are short pieces of pipe, tapered on each end, and designed to wedge tightly between cast iron sections, creating a seal.

The sections are placed either side by side like slices in a loaf of bread (vertical sectional), or stacked one above the other like pancakes (horizontal sectional).

Vertical Sectional Cast Iron Boilers

A cutaway view of a typical gas-fired vertical sectional cast iron boiler is shown in Figure 7 (front view) and Figure 8 (side view). The cast iron sections are placed side by side, connected by gaskets, and held together with **tie rods**. The vertical sections, and the hood section on top, are sealed with high temperature rope or high temperature silicone sealant.

Figure 7 – Cutaway of a Cast iron Sectional Boiler, Showing Six Sections

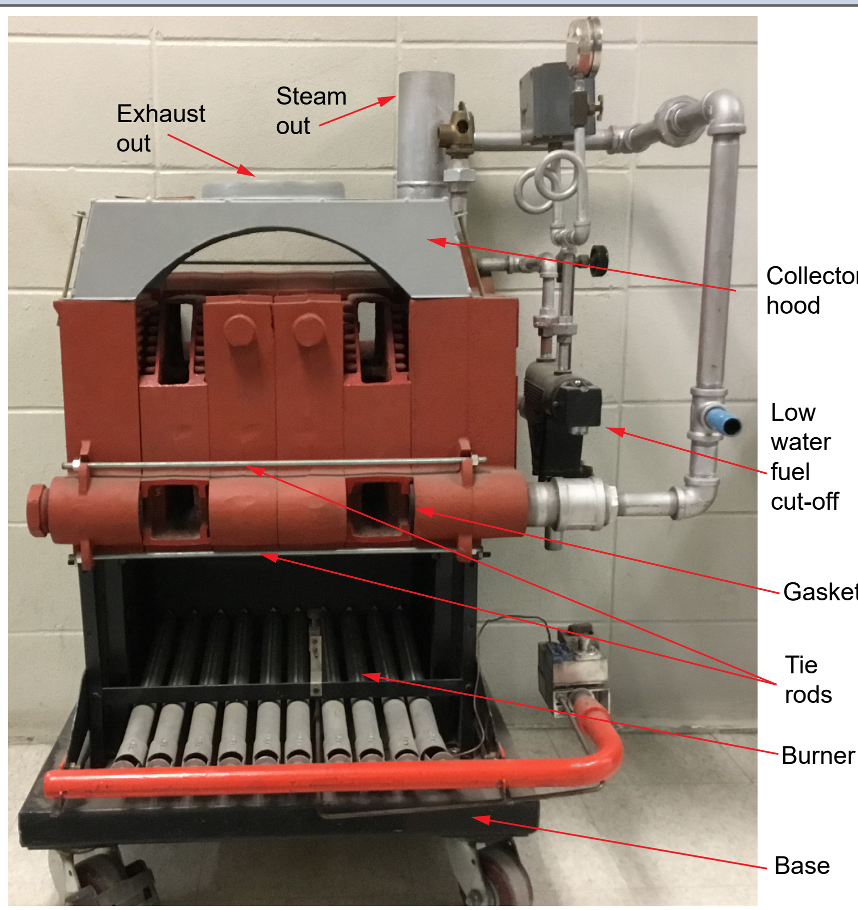


Figure 8 – Cast Iron Sectional Boiler

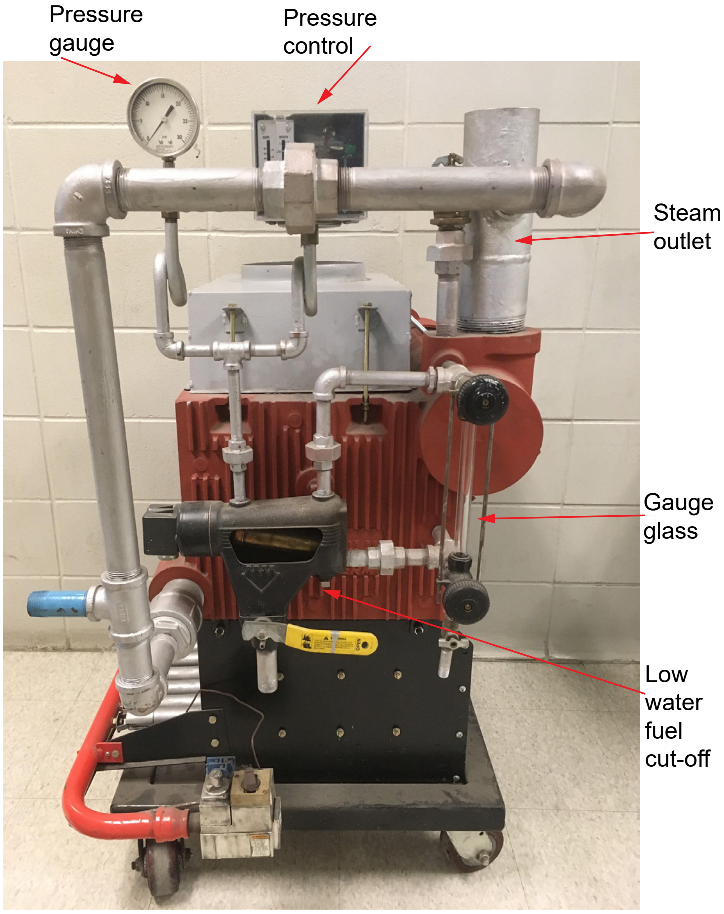


Figure 9 shows how the sections are connected by push nipples and short tie rods. Other boilers use long tie rods running from front to rear sections, as shown in Figure 10.

Figure 9 – Sections Connected by Push Nipples

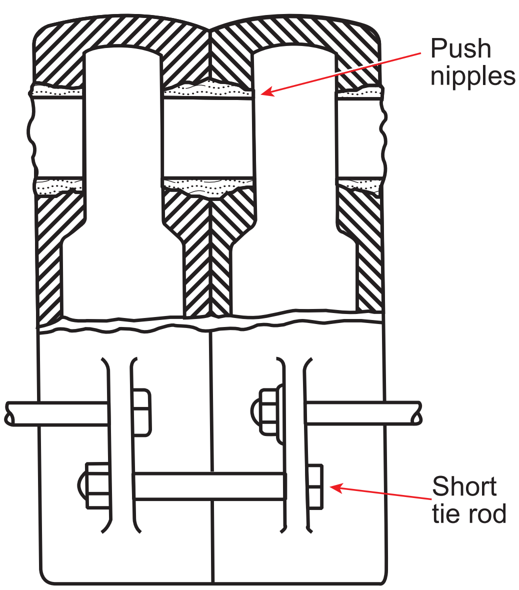
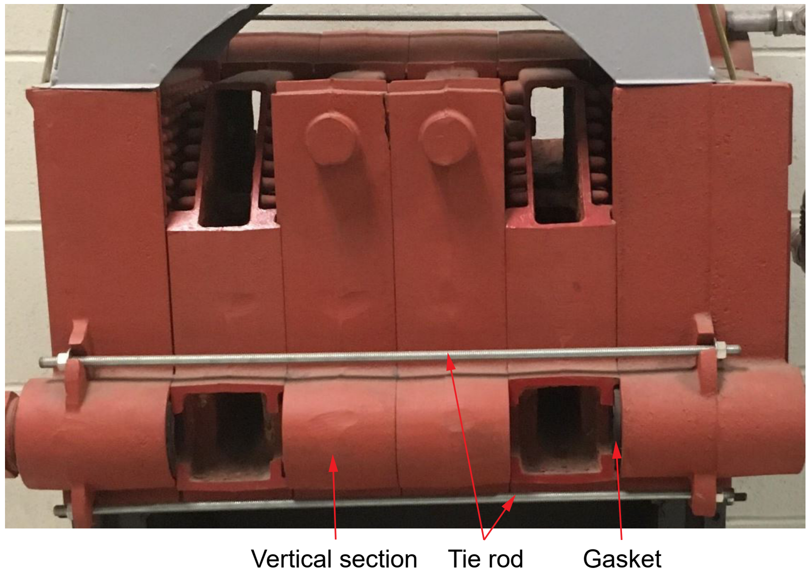


Figure 10 – Sectional Boiler with Long Tie Rods



The sections are placed on a rigid supporting base that also contains the gas burners. The hot combustion gases travel upwards, between the sections, to the collector hood which guides the gases to the draft hood from where they rise into the vent connector.

An insulated sheet metal casing encloses the boiler. The casing has removable panels to provide access to the boiler sections and flue gas passageways.

The sections of cast iron boilers come in a wide variety of shapes. However, all are designed to obtain maximum heat transfer from the hot gases to the heating surface. This transfer is accomplished by exposing as large a surface as possible to the hot gases, or by lengthening the time of contact between the gases and the heating surface. Extended surfaces on the section also increase the heating surface area.

The extended surface is visible in the cutaway shown in Figure 11.

Figure 11 – Cast Iron Sectional Boiler

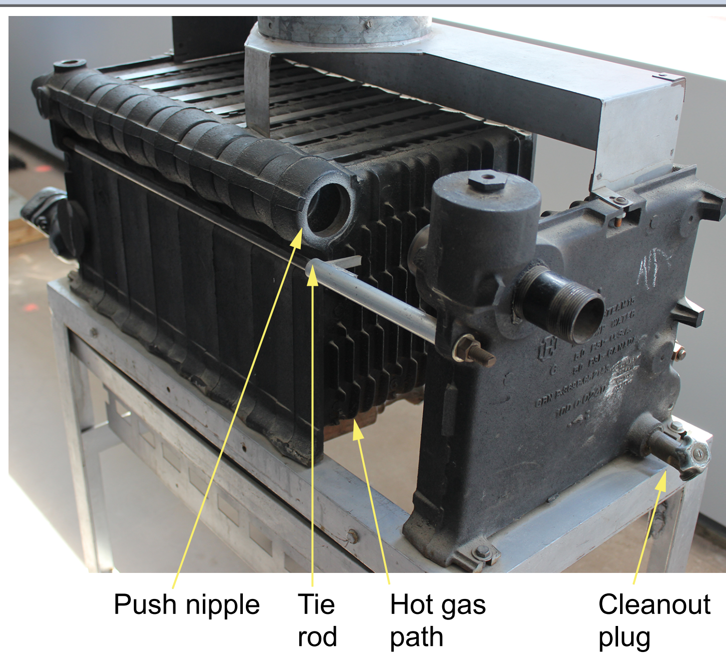
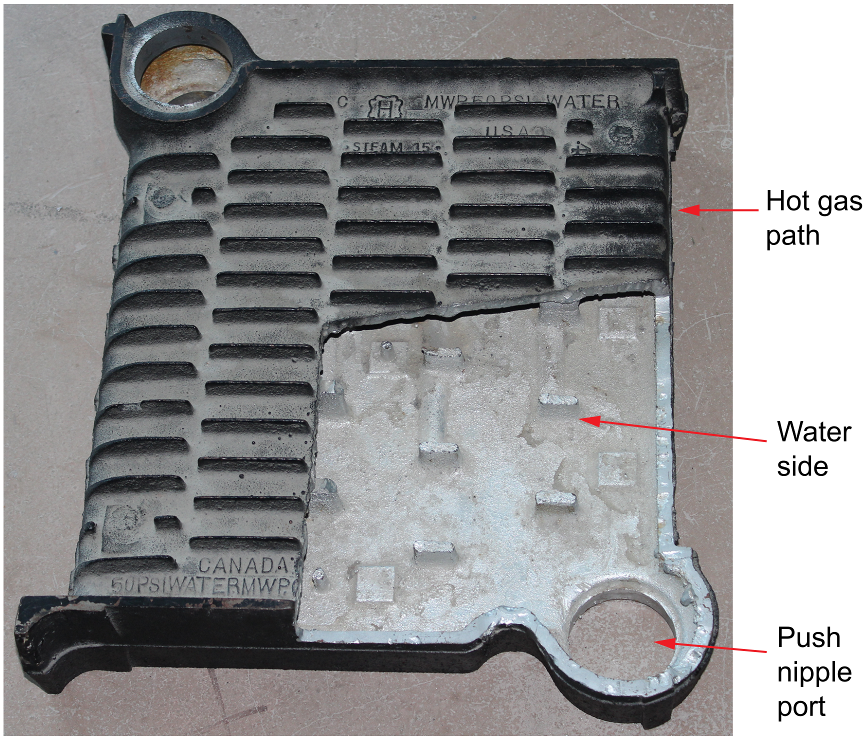


Figure 11 shows a single cast iron section. Note the push nipple connections at the top and bottom, and the extended heating surface area in the flue gas passages.

The section shown in Figure 12 is mounted above the furnace; the hot gases travel from the fire upwards, between the sections, toward the draft hood and chimney. Note the capital letter "H" cast into the section at the top of Figure 12. This symbol indicates that the section is designed, manufactured, and inspected according to **ASME BPVC Section IV**.

Figure 12 – Cast Iron Boiler Section



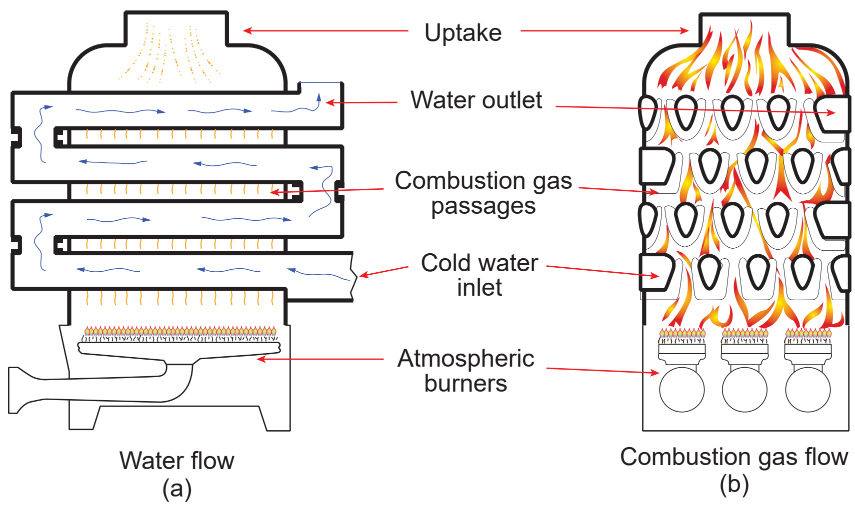
The front and rear sections of cast iron boilers differ in design from the intermediate sections. They are only fitted with push nipples on one side, and have cleanout plugs on the side facing the outside of the boiler, as can be seen in Figure 11.

Horizontal Sectional Cast iron Boilers

Smaller cast iron sectional boilers may be designed with horizontal sections. The sections are stacked on top of each other. With this design, only a single nipple connects two sections.

The nipples are placed at alternate ends so that the water is forced to travel back and forth through the boiler from the bottom up, as illustrated in Figure 13(a). The hot gases travel upwards in a zigzag pattern through the gas passages in the sections, Figure 13(b).

Figure 13 – Gas and Water Flows



(Courtesy of HydroTherm)

These boilers are used in both low-pressure steam and hot water service.

Heating Plant with Multiple Boilers

Large boiler capacities are required for the steam or hot water heating systems in large building complexes and high rises in colder climates. As far as boiler capacity is concerned, the mechanical designer has the following two choices:

1. To specify one or two large boilers, capable of carrying the full heating load during the coldest weather.
2. To specify several small boilers, installed in parallel, with a total capacity matching the heating load.

Boilers attain maximum efficiency when they operate continuously at full load. Experience has shown that during 90% of the heating season, only 60% or less of the heating plant capacity is required.

This means that a single, large capacity boiler will operate near full capacity only 10% of the time. During the remaining time, it will operate at reduced load either intermittently or continuously; maximum efficiency is hardly ever achieved. For example, a large firetube boiler operating at full capacity will have a thermal efficiency of approximately 80%. However, the same boiler operating at 20% capacity will have an efficiency of only 70%.

By selecting several small boilers to carry the full heating load instead of a single boiler, the thermal efficiency of the boiler plant can be improved considerably. During most of the heating season, when less than full boiler capacity is required, only those boilers needed to carry the load will be in operation. All the boilers, except one, will be operating at full capacity, thus at maximum efficiency. Only one boiler will cycle off and on, or operate at reduced capacity to maintain the temperature or pressure at the required level.

The capacity of the cycling boiler in a multiple boiler plant is only a fraction of that of a single boiler in a one-boiler plant. The decrease in efficiency due to cycling affects the overall efficiency of the multiple boiler plant much less. For example, if the plant has five small boilers instead of a single large boiler, and the efficiency of the cycling boiler drops by 10%, the overall efficiency of the plant drops by only 2%.

Multiple heating boiler plants also have the following additional advantages when compared to a single boiler plant of equal total capacity:

a) Should one boiler fail, the other boilers will be able to carry the full load except during extremely cold weather. A malfunction of the boiler in a single boiler plant shuts down the entire heating system.

b) Burners and controls for small capacity boilers are relatively simple and cheap.

c) The amount of water in a low capacity boiler is quite small, which substantially reduces the risk of damage or injury should a pressure part fail.

d) Less space may be required for several small capacity boilers than for a single large boiler of equal total capacity.

e) Small boilers are relatively light; no reinforced foundation is required.

f) Most low capacity boilers can pass through standard doorways, and can be installed or removed without the need for rigging.

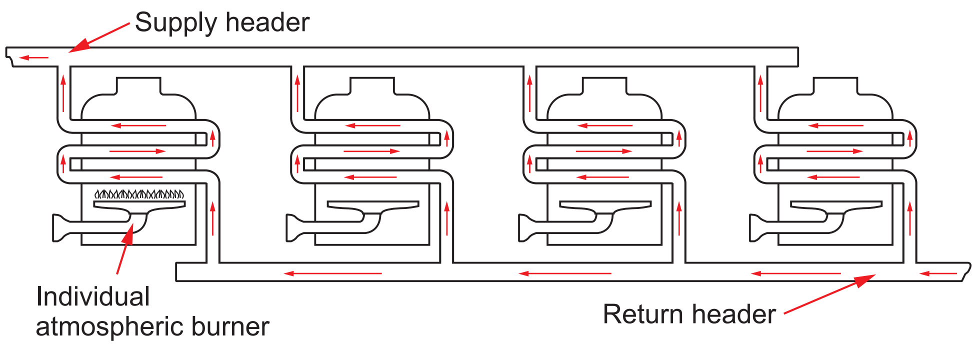
A plant consisting of three hot water boilers is illustrated in Figure 14.

Figure 14 – Hot Water Plant with Multiple Boilers

This modular heating boiler plant has several boilers integrated to form a unit, with a single inlet and a single outlet. The boilers, or "modules," are connected in parallel between the supply and return header of the hot water heating system. The water flow through all modules is continuous, as shown in Figure 15. Each individual module has its own burner system and controls.

The operation of the burner of each module is controlled by a step controller. Modules start or stop in sequence, as load demand increases or decreases.

Figure 15 – Hot Water Modular Boiler Setup Showing Parallel Flow



Another type of multiple boiler plant has boilers tied in with the primary (main) hot water circulating system. Each boiler is equipped with its own secondary circulating pump. When a boiler is not operating, its circulating pump stops.

A step controller senses outdoor air temperature and hot water supply temperature. Based on these conditions, the controller operates each boiler in sequence. As a result, the heat supplied by the boiler water balances the heat lost from the building.

Objective 3

Describe the construction and application of firetube heating boiler designs.

The same firetube boiler configurations used in high-pressure steam service are equally suitable for use in heating plants. Despite outwardly similar appearances, there are significant design differences between high-pressure and low-pressure boilers. High-pressure firetube boilers (designed to **ASME BPVC Section I**) can be used in low-pressure service, if equipped with low-pressure controls, and a low-pressure safety valve. Heating boilers are designed to a low-pressure code (**ASME BPVC Section IV**), and cannot be used in high-pressure service.

Firetube boilers are used in traditional hot water heating systems that are engineered to use water at around 80°C. If the return water becomes too cool, the moisture in the flue gas may condense and cause fireside corrosion.

Hot water firetube boilers have controls like those used on watertube, cast iron, and copper tubular hot water boilers. These controls include an aquastat, a water temperature regulating device that has a high water temperature cut-off, and a low water cut-off.

In low-pressure steam service, the controls of these firetube boilers are similar to those of watertube and cast iron low-pressure steam boilers. These controls include a pressuretrol, which is an on off device with a high-pressure cut-off, and a low-water cut-off.

Scotch Boilers

Scotch boilers are found in both low-pressure steam service (under 100 kPa) and hot water heating service. These boilers are available as small as 100 kW (10 BoHP), and are designed to burn light fuel oil, natural gas, and propane.

In hot water service, these boilers are equipped with full-size hot water return and hot water supply connections. Both the hot water return and supply connections will have isolation valves, to permit servicing or repairing the boiler without draining the entire heating system.

Firebox Boiler

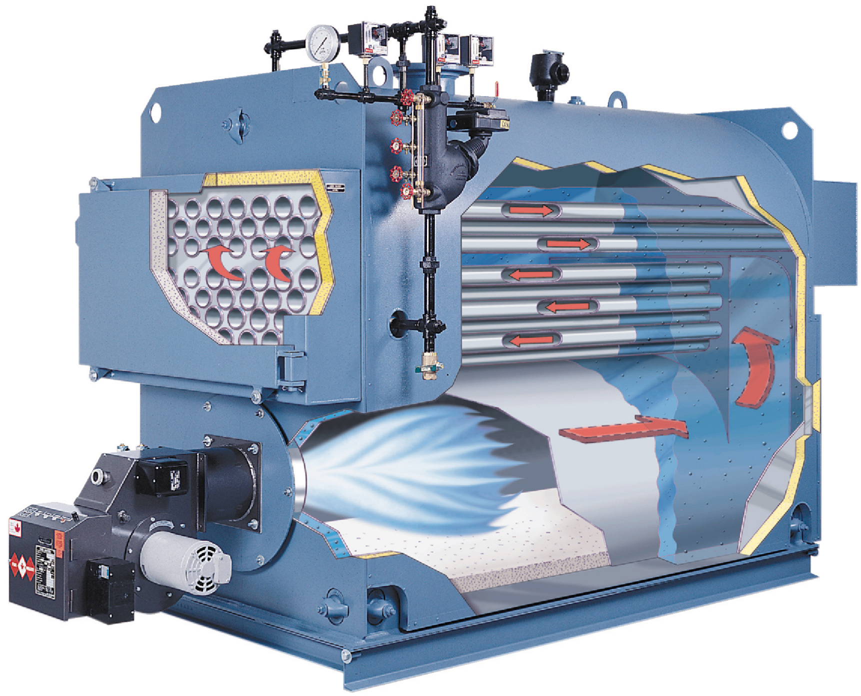
The modern firebox boiler is predominantly a low pressure heating boiler design, though some high-pressure steam models are available. These boilers come in capacities from 150 kW to 7000 kW (15 to 700 BoHP), in both low-pressure steam and hot water service.

Figure 16 shows a modern three-pass firebox design, constructed of steel, and manufactured by Boilersmith to ASME BPVC Section IV. It has a furnace cooled with waterlegs, so it has little of the refractory brickwork associated with early firebox designs. Figure 16 shows a cutaway of the reversing chamber, furnace, and shell. The gas passes are clearly identified. The fireside is accessed through the front reversing chamber door, the burner opening (after the burner is removed), and through removable panels at the rear of the boiler, near the flue collar outlet. These boilers are easy to maintain from the fireside.

At the front of the boiler, near the base of the shell, are handholes for cleaning and inspecting the waterside. A manhole is provided at the top of the shell for cleaning and inspection. Because of the flat waterlegs surrounding the firebox, numerous staybolts are used for support.

Firebox boilers are taller and narrower than comparable Scotch-type firetube boilers. For this reason, firebox boilers are more compact, and can be designed to fit through standard doorways. This makes firebox boilers ideal for replacement or retrofit purposes.

Figure 16 – Modern Three-Pass Firebox Heating Boiler



(Courtesy of Boilersmith Ltd.)

In hot water service, these boilers are equipped with full-size hot water return and hot water supply connections. Both hot water return and supply connections will have isolation valves.

Vertical Firetube Heating Boilers

The **vertical firetube boiler** was at one time quite popular as a supplier of small quantities of low-pressure steam and hot water. These steel-shell boilers are like HRT boilers, stood on end. In steam service, the upper head is cooled by steam. The flue gas acting on the upper tubesheet helps dry the steam (and may even provide a few degrees of superheat).

Vertical firetube boilers are still manufactured, but they are not as common in heating plants as they once were. Vertical firetube boilers have an advantage when floor space is limited, but require more headroom. In comparison, horizontal firetube boilers require more floor space, but less ceiling height.

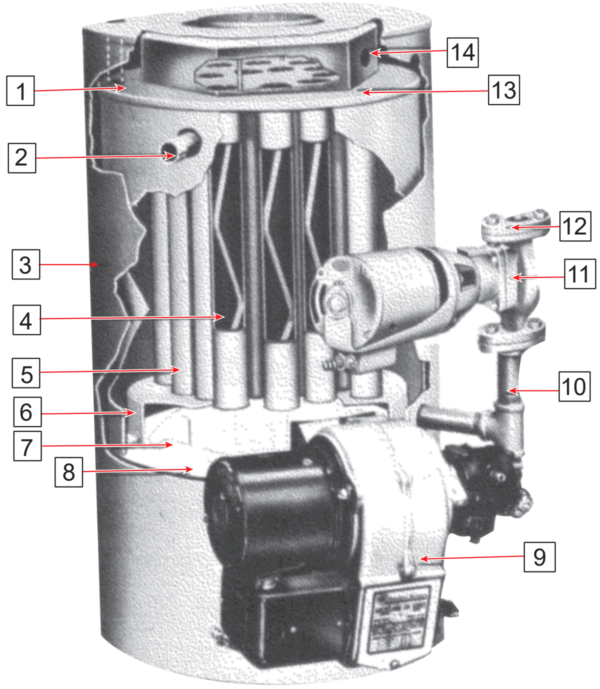
Vertical firetube boilers are one-pass designs, and are not very efficient. Figure 17 shows a cutaway view of this type of boiler, used in hot water service. Small capacity, low-pressure hot water boilers like this were once commonly used for hot water heating systems in residences and small apartment blocks. Part of the boiler jacket, boiler shell, lower tubesheet, and some firetubes are cut away in order to show the boiler internals.

The hot gases travel upwards through the firetubes, giving off heat to the tube walls. The hot gases are then collected by a flue gas collector box, which is connected to the chimney with a vent connector. In order to help the heat exchange from the gases to the tube walls, baffles made of thin steel strips are installed inside the tubes, to slow the flue gas and maximize contact time.

The cooler water returning from the heating system radiators is forced into the lower part of the boiler shell by a circulating pump. The water then flows upward around the tubes, picks up heat from the tube walls, and leaves the boiler through the top outlet at a higher temperature. This outlet is connected to the supply line which takes the water back to the heating system.

Figure 17 – Vertical Firetube Hot Water Boiler

1. Connection for expansion tank
2. Hot water outlet connected to system supply
3. Insulated boiler jacket
4. Tube baffle
5. Boiler tubes
6. Heat exchanger part of boiler
7. Combustion chamber
8. Boiler base
9. Oil burner
10. Cool water inlet piping
11. Circulating pump
12. Return line connection
13. Gasket to provide gas proof seal between boiler and flue gas
14. Flue gas collector box



(Courtesy of American Standard)

Figure 18 shows a modern vertical firetube, high-efficiency hot water boiler, made by Fulton Boiler Works. This is a **condensing boiler**, designed for use with low temperature, large surface area heat transfer surfaces (such as in-floor radiant heat systems).

In conventional hot water heating systems, heat exchange surfaces are compact and hot water temperatures are high (around 80°C). In-floor radiant heating systems can transfer the same kW of energy using large surfaces and lower water temperatures. In these systems, the hot water is so cool that the moisture in the boiler flue gas condenses, resulting in efficiencies of over 95%.

Figure 18 – Modern High-Efficiency Vertical Firetube Hot Water Boiler

(Courtesy of Fulton Boiler Works)

Chapter Summary

Heating boilers of steel construction appear very similar to their power boiler counterparts. They are available in watertube and firetube designs. However, these boilers are designed to operate only at the lower pressures and temperatures suitable for heating buildings.

Cast iron sectional boilers and copper tubular boilers are unique to heating plants. Smaller versions of these boilers may be installed in multiple boiler banks, and operated sequentially to maximize overall heating plant efficiency throughout the entire range of heating loads. Cast iron sectional boilers are available in a wider range of capacities.

All heating boilers are designed to **ASME BPVC Section IV (Heating Boilers)**. Therefore, they must never be operated above 100 kPa steam pressure, 1100 kPa water pressure, or with water temperatures exceeding 120°C.

Chapter 6

Differences between Power and Heating Boilers

Learning Outcome

When you complete this chapter you should be able to:

Differentiate between ASME Section I and ASME Section IV boilers.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Discuss the differences between power boiler and heating boiler design and installation.*
2. *Discuss the differences between power boiler and heating boiler operation.*

Chapter Introduction

Heating Boilers and Power Boilers are designed to different sections of the **ASME BPVC**. **ASME Section IV** is entitled **Rules for Construction of Heating Boilers**. **ASME Section I** is entitled **Rules for Construction of Power Boilers**. The basic difference between **ASME Sections I** and **IV** is revealed in paragraphs that describe the service limitations of these codes.

ASME I, under **PG-2 Service Limitations**, states:

PG-2.1 *The rules of this Section are applicable to the following services:*

(a) boilers in which steam or other vapor is generated at a pressure of more than 15 psig (100 kPa) for use external to itself

(b) high-temperature water boilers intended for operation at pressures exceeding 160 psig (1.1 MPa) and/or temperatures exceeding 250°F (120°C)

PG-2.2 *For services below those specified in PG-2.1, it is intended that rules of Section IV apply; however, boilers for such services may be constructed and stamped in accordance with this Section provided all applicable requirements are met.*

ASME IV, under **HG-101 Service Restrictions**, states:

HG-101 ***Service Restrictions****. The rules of this Section are restricted to the following services:*

(a) steam boilers for operation at pressures not exceeding 15 psi (100 kPa)

(b) hot water heating boilers and hot water supply boilers for operation at pressures not exceeding 160 psi (1 100 kPa)

(c) hot water heating boilers and hot water supply boilers for operation at temperatures not exceeding 250°F (120°C), at or near the boiler outlet

The higher temperatures and pressures of power boilers introduce higher stresses and greater risks, and require different considerations when building and operating them. This chapter explores some of the major design differences and operational considerations for Heating Boilers and Power Boilers.

On Track

This chapter makes numerous references to the **ASME BPVC,** and to the **CSA B-51 code**. It is important to read the relevant ASME code sections in the **ASME PanGlobal Academic Extracts.**

OBJECTIVE 1

Discuss the differences between power boiler and heating boiler design and installation.

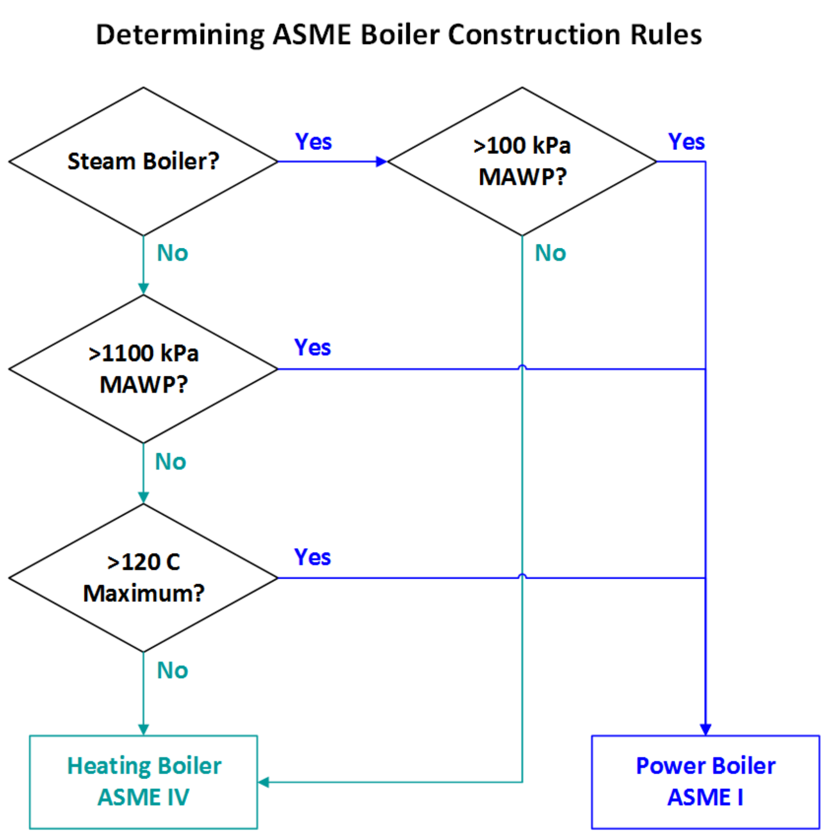
REASONS FOR DIFFERENCES BETWEEN ASME I AND ASME IV

The service restrictions identified in the introductory parts of **ASME I** and **ASME IV** can be illustrated with a simple decision-making flowchart (Figure 1). This flowchart summarizes the service limitations for heating and power boilers. These limitations are necessary, because they inform the engineering design decisions for building code-compliant boilers. Designers cannot "blend" sections of the BPVC together. If designing a **heating boiler**, all design decisions are based on **ASME IV**; if designing a **power boiler**, all design decisions are based on **ASME I**.

One of the main design concepts in both codes is the **maximum allowable working pressure (MAWP)**. The MAWP is the maximum pressure for which a boiler is designed. Even the weakest component of a boiler must be strong enough to operate at the MAWP. Operation of a boiler at or in excess of the MAWP is prohibited.

The boiler MAWP is determined at the design stage. It is used to calculate the thickness of the various boiler components (such as drums, shells, heads, watertubes, firetubes, and furnaces). The MAWP is based on the design pressure and the allowable stress of the material of construction. The allowable stress includes a factor of safety that allows for deterioration of the boiler shell over years of service. Both **ASME I** and **ASME IV** prohibit the installation of a safety valve with a pressure set point higher than the MAWP of the boiler.

Figure 1 – Flowchart for Determining Applicable ASME Design Code for Boilers



Consider a firetube boiler with dimensions of 1.85 m inside diameter and a length of 2.5 metres. If this boiler were operating as a low-pressure steam heating boiler at 70 kPag, the total force contained by the shell would be approximately 1400 kN. If that same boiler were operated as a power boiler at 1700 kPag, the force contained would be 34 000 kN.

To put 34 000 kN of force into perspective, a modern supercar can accelerate from zero to 100 km/h in less than three seconds. This represents an acceleration of 9.26 m/s^2. Assuming the car has a mass of 2000 kg, such acceleration requires only 18.5 kN.

This explains why **ASME I** boiler design calculations are different than those of **ASME IV**. As a rule, power boilers must be substantially stronger than heating boilers.

The saturation temperature of water at 1700 kPa it is 207°C. The higher the pressure of the water, the higher its saturation temperature will be. The operating temperature is important, because metals weaken at higher temperature. Consider high-pressure, high-temperature steam superheated to 500°C. Power boilers must be designed to withstand extremely high pressures while exposed to extremely high temperatures.

On Track

The strength of a pressure-retaining component is always dependent on temperature: the pressure rating decreases as temperature increases. The term **service rating** refers to the maximum safe temperature and pressure for a pressurized component.

By comparison, heating boilers do not require the same consideration of high pressure and high temperature exposure. Heating boilers do not produce superheated steam. At 70 kPa, the saturation temperature of water is only 117°C. **ASME IV** permits entire boilers to be made from cast iron. This is because temperatures below 120°C, at pressures of 100 kPa or less, are well within cast iron's service rating.

However, because it is a brittle metal, cast iron is restricted by **ASME I** to specific fittings, as long as they are not exposed to pressures exceeding 1.7 MPa, or temperatures exceeding 230°C. Pressures and temperatures beyond these figures exceed the service rating of cast iron.

Because heating boilers operate at lower pressure and temperature, they do not need exotic, high cost alloys. Inexpensive materials such as cast iron are completely suitable. This makes economic sense when building or buying boilers for heating plants. Power boilers, on the other hand, may require materials that retain their strength at very high pressures and temperatures.

Based on the above, it should be obvious why differences exist in how power and heating boilers are constructed and operated.

Identifying Heating and Power Boilers

Despite external appearances of the final boiler, the differences in **ASME IV** and **ASME I** designs run deep. From a distance, the differences between packaged heating boilers and power boilers may not be noticeable. On closer observation, the following differences are apparent.

Shell Stamping

Boilers designed to **ASME IV** are stamped with the letter "H." Boilers designed to **ASME I** are stamped with the letter "S." On some boiler designs, the shell stamping is exposed and easy to find. On others, lagging inspection plates may require removal.

Nameplate

Some boilers have their "S" or "H" stamps on highly visible nameplates, attached to the outside of the lagging.

Material of Construction

Cast Iron: All cast iron boilers are designed to **ASME IV Part HC**, and are therefore heating boilers. Power boilers may have cast iron fittings, such as water columns and low water cut-offs. However, the boiler itself is not made of cast iron.

Cast Aluminum: Cast aluminum is permissible under **ASME IV Part HA**, but not under **ASME I**.

Copper: Though **ASME I** permits copper as a construction material, there are very few (if any) power boilers constructed of copper. Most copper tubular boilers are therefore **ASME IV** heating boilers.

Pressure Gauge

ASME I PG-60.6 states, *"The dial of the pressure gage shall be graduated to approximately double the pressure at which the safety valve is set, but in no case to less than 1½ times this pressure."*

ASME IV HG-602 states, *"The scale on the dial of a steam boiler gage shall be graduated to not less than 30 psi (200 kPa) nor more than 60 psi (414 kPa)."* The scale on the pressure gauge can thus give a close estimation of the boiler's allowable working pressure, and determines whether it is a power or heating boiler.

Safety Valve

For the same kJ relief capacity, a heating boiler **safety valve** (**pressure relief valve**) has a much larger body than a power boiler safety valve. This is because low-pressure steam has a larger specific volume than high-pressure steam. The steam that must be relieved occupies greater volume, and requires a valve with a larger cross-sectional area to relieve the steam. If unsure, ALL safety valves must have visible nameplates, securely fastened to the valve body. A heating boiler in steam service will have a safety valve set point of no greater than 15 psi.

Bottom Blowoff Valves

Both heating boilers and power boilers require bottom **blowoff valves**. However, with few exceptions, power boilers must have two bottom blowoff valves, piped in series (**ASME I, PG-58**). Heating boilers only require single valves (**ASME IV, HG-715**).

Blowoff Vessel

The **CSA B-51 Code Paragraph 6.5** states, *"When the blowoff from a boiler having a working pressure exceeding 103 kPa (15 psi) is discharged into a sewer system, a registered blowoff vessel or other suitable registered device shall be placed between the boiler and sewer to reduce the temperature of the water entering the sewer system to 65°C (150°F) or lower."*

Chances are good that if a boiler blowoff line discharges to a **blowoff vessel**, the boiler is a power boiler designed to **ASME I**.

Pressure Controls

ASME CSD-1 CW-300 states, *"The upper set point limit or maximum fixed stop limit of the pressure control selected shall not exceed the maximum allowable working pressure of the boiler."*

Low-pressure steam boilers, therefore, have steam pressure controls that cannot be set to above 103 kPa (15 psi).

Gauge Glasses

Heating boilers in steam service must have one or more gauge glasses (**ASME IV, HG-603**). Power boilers shall have at least one gauge glass; however, if designed to operate over 3 MPa, they must have two gauge glasses (**ASME I, PG-60.1**). Regardless, the gauge glasses installed in power boilers are thicker, and may not be tubular. Most steam heating boilers use thinner-wall tubular gauge glasses. Heating and power boilers in hot water service do not have gauge glasses.

ASME I and **IV** both instruct designers to determine the lowest permissible water level for the boilers they manufacture. They differ in where the gauge glasses must be mounted in reference to the LPWL.

For heating boilers, **ASME IV HG-603** states, *"The lowest visible part of the water gage glass shall be at least 1 in. (25 mm) above the lowest permissible water level recommended by the boiler Manufacturer."* **ASME IV** requires the lowest permissible water level to be permanently marked on the boiler by the manufacturer.

For power boilers, **ASME I PG-60.1** states, *"The lowest visible water level in a gage glass shall be at least 2 in. (50 mm) above the lowest permissible water level, as determined by the boiler Manufacturer."*

To complicate matters further, **ASME I PFT-47** states, *"Boilers of the horizontal firetube type that exceed 16 in. (400 mm) in inside diameter shall be so set that when the water is at the lowest visible level in the gage glass there shall be at least 3 in. (75 mm) above the lowest permissible water level,"* and *"Horizontal firetube boilers that do not exceed 16 in.(400 mm) in inside diameter shall have the lowest visible level in the gage glass at least 1 in. (25 mm) above the lowest permissible water level."*

It is impossible to draw definitive conclusions by following the above. Some power boilers are legitimately equipped with single bottom blowoff valves. Some low-pressure boilers drain into blowoff vessels. Some power boilers do not discharge into blowoff vessels. Some power boilers are in heating boiler service, and are equipped with low-pressure controls and low-pressure safety valves.

Neither power nor heating boilers in hot water service have gauge glasses, and their safety valves look similar. Therefore, when in doubt, **check the operating certificate provided by the jurisdiction, and verify the working pressure by comparing the information on the shell stamping to the certificate**.

Other differences between heating and power boilers are not apparent unless the boiler is dismantled for detailed inspection.

Drum Internals. Heating boilers in steam service only require basic steam separating equipment such as a dry pipe. Most have no steam separation equipment at all. This is because the difference between the specific volume of low-pressure steam and low-pressure water is greater than that of high-pressure steam and water. Low-pressure steam, therefore, disengages from the water surface quite readily, with little assistance. Large power boilers may require multi-stage steam separating equipment such as centrifugal separators and scrubbers.

Tube Attachment. Both heating and power boilers can use expanding and welding for attaching tubes to tubesheets (**ASME I**, **PWT-11** and **PFT-11**). However, in some heating boilers, O-rings or ferrules can be used to attach tubes (**ASME IV, HG-360**). This method of attachment is not permitted in power boilers.

These are only some of the code and construction differences between power and heating boilers. A detailed comparison of **Sections I** and **IV** of the **ASME codes** would reveal far more. As a general statement, the rules for the construction of power boilers are more complex, and result in stronger, more robust boilers.

Objective 2

Discuss the differences between power boiler and heating boiler operation.

ASME VI and VII

There are differences in the operation of power and heating boilers. It makes sense that boilers which present greater public and corporate risk must be designed, operated, and maintained to a higher standard.

Power boilers have more detailed rules with regards to their operation and maintenance. As well, jurisdictions regulate the operators of power boilers more stringently than operators of heating boilers.

The ASME BPVC sections that deal with boiler operation and maintenance are:

ASME Section VI – Recommended Rules for the Care and Operation of Heating Boilers

ASME Section VII – Recommended Guidelines for the Care of Power Boilers

System Checks

Boiler operation and boiler auxiliaries (including deaerators, fuel pumps, draft fans, feedwater pumps, and so on) must be checked more frequently in high-pressure plants. In some plants, rounds are performed hourly. Results of observations are recorded in log sheets and logbooks, and signed and dated by the shift engineer. **ASME VI** provides sample heating boiler log sheets in its Mandatory Appendix.

Water Treatment

Power boilers require tighter control of internal boiler water and external feedwater conditions. These boilers are more likely to foam or prime if water conditions are poor, causing tremendous damage to steam lines and attached equipment. Corrosion, overheating due to scale accumulations, and metal **embrittlement** are all caused by improper water treatment, and may result in disastrous boiler vessel explosions. This risk is far greater with power boilers.

ASME Section VI Part 9.08 categorizes the water treatment of heating boilers into three types:

1. *Class 1 – no treatment*
2. *Class 2 – seasonal or semi-seasonal with limited chemical control*
3. *Class 3 – Complete treatment with continuous chemical control*

Cast iron boilers are more tolerant of Class 1 water treatment, because cast iron is more resistant to corrosion than steel boilers. However, if no water treatment is performed, cast iron boilers can still scale up and overheat. If Class 1 water treatment is chosen:

a) The heating system must be tight and leak free.
b) All the condensate must return to the boiler.
c) There must be very little makeup water consumed.
d) The boiler waterside must be thoroughly cleaned, at least annually.

ASME VI recommends Class 2 water treatment as a safer alternative to Class 1 water treatment.

Figure 2 shows the damage that can occur to a cast iron sectional boiler that does not receive water treatment. The section is shown with the base of the section facing upward. The scale deposit is so thick that the cast iron overheated and broke apart. Water that issued from the section cooled the fire so that it produced excessive soot, seen on the fins of the castings.

Figure 2 – Cast Iron Section Damaged by Poor Water Treatment

Bottom blowoff of heating boilers may only be necessary once or twice a year if soft water is used. If harder water is used, blowdown may be required weekly (**ASME Section VI, Part 9.09**).

Water treatment in power boilers is extremely important and must be kept in close control. Water tests, chemical additions, bottom blowoff, and blowdown adjustments are done according to plant requirements. These activities may take place daily, every shift, or every hour, depending on the plant.

Compared to the guidelines for heating boiler, ASME recommendations are far more stringent for power boilers. In **ASME VII C2.426**, boiler operators are advised as follows:

> *"It is important that the concentration of solids in the water be determined at least daily, and the blow down (continuous or intermittent) should be regulated to control the concentration within prescribed limits. A safe maximum water concentration in boilers can best be maintained by adjusting the continuous blowdown frequently on the basis of water analysis… If the boiler is not fitted with sampling connections, the boiler should be blown down at least once every 24 hr by slowly operating the blowdown valves through a full open and close cycle."*

Water treatment guidelines are only a few of the recommended practices found in **ASME VI** and **VII**. Manufacturers use the entire body of information in these two codes to develop the operation sections of boiler owner manuals. The same recommended practices also provide the basis for the boiler operating procedures in the PanGlobal textbooks.

Jurisdictional Requirements

Some Canadian jurisdictions allow power boilers to operate unsupervised, but only under special circumstances. Exempt boilers are limited to those with relatively low pressure, low capacity, and low water volume. Larger capacity steam boilers are never exempt from continuous supervision.

Jurisdictions may have altogether different staffing requirements for heating plants. A single Power Engineer may be permitted to operate and supervise several distinct heating plants. High-pressure plants often require four or more persons per shift.

There are also differences regarding who may or may not operate heating plants and power plants. Depending on the jurisdictional regulations, heating plants under a certain rating do not require Power Engineers to operate. For example, in Alberta, any heating plant over 750 kW may be supervised by a Fourth Class Power Engineer. Heating plants that are 750 kW or less do not require Power Engineers to operate. As well, in Alberta, a Fourth Class Power Engineer may be the Chief Power Engineer in a high-pressure power plant up to a size of 1000 kW. Plants 20 kW and below do not require Power Engineers to operate.

Because operating conditions are not as severe, and stresses are not as great in heating boilers, jurisdictions permit smaller heating plants to operate unattended. Many Canadian jurisdictions exempt hot water heating plants of all capacities from operator requirements. Small steam heating plants are also exempt. Steam heating plants of larger capacity may be permitted to operate unattended for certain periods of time. Such plants may be remotely monitored on a continuous basis. Physical rounds may only be performed weekly.

Chapter Summary

Though it is difficult to identify all of the differences between the construction and operation of power and heating boilers, be aware that the differences are significant. These differences affect how plants are operated and maintained. Knowing that parts suitable for heating boilers may be unsuitable for power boilers can reduce the risk of boiler failure and human injury, from using parts beyond their service rating.

Power boilers and heating boilers share many similar construction and operation methods. However, the higher pressures and temperatures of power boilers present higher risk. For this reason, power boilers are designed, operated, and maintained to higher standards than heating boilers. The different codes and regulations used during construction, installation, and operation are meant to mitigate these risks.

Unit Summary

Scotch, once-through, sub-critical, packaged, A-type, vertical, power and heating are just a few terms used to describe the wide variety of boiler designs. This is not an exhaustive list; however, it demonstrates the variety of purpose-built boilers in use today. Every boiler design has an application.

Boilers, properly designed, constructed, and operated, have powered industry and provided heat for generations. From the early 1700s, technology has seen the development of boilers with internal furnaces, firetubes, and watertubes. With advancements in design came advancements in boiler efficiency. Safety became a primary focus in boiler development. Codes standardized the design, manufacturing, installation, care, operation, and maintenance of boilers. With the implementation of various codes, boilers became increasingly safer.

Ultimately, without competent and knowledgeable operators, boilers remain unsafe. Jurisdictions have therefore adopted codes and inspection standards. Most importantly, though, jurisdictions have restricted the operation of many boiler types to only certified Power Engineers.

This unit covered all of the above, in order to provide a foundation for the development of certified and competent Power Engineers.

A self-assessment tool is available on MyPower LMS. Login using the unique user ID and password found on the inside front cover of Unit 1.

Notes

4th Class Edition 3.5 • Part A

UNIT A-11

Knowledge Exercises and Unit Glossary

Knowledge Exercises – Chapter 1

Name: ______________________________ Date: ______________________________

Instructor: ____________________________ Course: ____________________________

Objective 1

1. What is a boiler?

2. Explain the differences between a firetube boiler and a watertube boiler.

3. Explain why a boiler must have thorough circulation.

Objective 2

4. List the advantages of packaged boilers.

5. Packaged boilers are ____________ supported.

Chapter 1 (Cont.)

Objective 3

6. Explain the differences between packaged boilers, shop-assembled boilers, and field-erected boilers.

Objective 4

7. The main cylindrical component of a firetube boiler is called the ________________. The main cylindrical component of a watertube boiler is called the _______________.

8. Name four types of heads used in watertube boilers.

9. Why do drums and shells have nozzles?

10. Why are the ends of firetubes beaded over?

Knowledge Exercises – Chapter 2

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. List six advantages of firetube boilers.

2. Explain why firetube boilers are not manufactured to operate at higher than 2.4 MPa.

3. The locomotive boiler is a ___________-pass design. The HRT boiler is a _____________-pass design.

4. Describe a Scotch boiler.

Chapter 2 (Cont.)

Objective 2

5. What is a gas pass?

6. Explain the advantages and disadvantages of designing firetube boilers with multiple passes.

7. With a simple sketch, illustrate the flue gas flow in a three-pass firetube boiler.

Chapter 2 (Cont.)

8. With a simple sketch, illustrate the water circulation in a firetube boiler.

Objective 3

9. What are the advantages of corrugated and ring-reinforced furnaces over plain furnaces?

10. Why are diagonal stays preferable to through stays?

11. What is the purpose of a telltale?

Knowledge Exercises – Chapter 3

Name: ______________________________ Date: ______________________________

Instructor: ______________________________ Course: ______________________________

Objective 1

1. List five advantages of watertube boilers over firetube boilers.

2. Explain how natural circulation takes place in a watertube boiler.

Objective 2

3. What is the function of an internal feedwater pipe?

4. Describe how these steam drum internals work:

   a) Baffle

Chapter 3 (Cont.)

b) Cyclone separator

c) Chevron dryer

Objective 3

5. Sketch and describe the three primary designs of packaged watertube boilers. Indicate the direction of the water circulation in these boilers.

a)

Chapter 3 (Cont.)

b)

c)

Chapter 3 (Cont.)

Objective 4

6. Explain the purpose of each of the following components of a steam generating unit.

   a) Superheater

   b) Economizer

   c) Air heater

7. Explain why high-pressure boilers require forced circulation.

8. What is an OTSG?

Knowledge Exercises – Chapter 4

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. Describe the advantages of electric boilers.

2. Describe the disadvantages of electric boilers.

Chapter 4 (Cont.)

3. How can the use of electric boilers in a power plant augment the use of fossil fuel fired boilers?

Objective 2

4. The type of electric boiler that passes current through the boiler water is the ______________________ type.

5. Only the ______________________ type of electric boiler requires a low water cut-off.

6. Explain how the firing rate of a jet-type electrode boiler is controlled.

7. Explain how the firing rate of an immersion type electric boiler is controlled.

Knowledge Exercises – Chapter 5

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. Describe the construction of a flexible tube watertube boiler.

2. What are the advantages of a flexible tube watertube boiler?

Objective 2

3. Explain why multiple boiler heating plants are preferable to using a single boiler.

Chapter 5 (Cont.)

4. Explain the construction of a cast iron sectional boiler. List two advantages and one disadvantage of cast iron boilers.

5. What is the purpose of extended heating surfaces in a cast iron sectional boiler?

6. What is the difference between a multiple boiler heating plant and a modular boiler heating plant?

Objective 3

7. Name three types of firetube heating boiler designs.

Chapter 5 (Cont.)

8. In a hot water heating system, what happens when the return water gets too cool?

Knowledge Exercises – Chapter 6

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. Why are power and heating boilers designed and constructed differently?

2. What is the only way to be positive that a boiler is a power or a heating boiler?

3. ASME Section I boilers are stamped with the letter _______, whereas Section IV boilers are stamped with the letter _______.

4. A boiler must provide hot water at 1300 kPa, at a temperature of 140°C. This boiler must be designed according to ASME BPVC Section ______.

Objective 2

5. What is the basic difference between Sections VI and VII of the ASME code, and what do these codes pertain to?

6. Power boilers require two gauge glasses when operating ___________ _______ MPa.

7. Cast iron sectional boilers are exclusively used as ________________ boilers.

8. The code that covers the care and operation of heating boilers is __________________.

Unit A-11 Glossary

Term	Definition
Air heater	A heat exchanger, located near the flue gas exit of a boiler. Air heaters transfer heat from the flue gas, or from steam, to the combustion air entering the boiler, to improve combustion efficiency.
Air preheater	See *air heater*.
American society of mechanical engineers (ASME)	An organization that publishes construction rules for boilers and pressure vessels, to ensure equipment safety over a reasonable service life. Canadian provinces enforce ASME codes as law.
ASME	See *American Society of Mechanical Engineers* (ASME).
Blowoff valve	A specially designed, manually operated valve connected to a boiler for the intermittent discharge of boiler sediment, for lowering a boiler's water level, or for draining a boiler.
Blowoff vessel	A pressure vessel that intercepts, cools, and depressurizes boiler blowoff water, in order to protect municipal sewer systems.
Boiler and pressure vessel code (BPVC)	A collection of codes published by the ASME, used for the safe design and construction of boilers and pressure vessels.
Boiler bank	A group of watertubes that form part of a water boiler circulatory system, and to which heat is transmitted mainly by convection from the products of combustion.
BPVC	See *boiler and pressure vessel code* (BPVC).
Bubbling bed	A fluidized bed in which the fluidizing velocity is less than the terminal velocity of individual bed particles, where part of the fluidizing gas passes through the bed as bubbles.
Chevron dryer (scrubber)	Series of diagonal baffles installed in a steam flow path, designed to separate fine droplets of moisture from the steam by means of inertial impaction on the surfaces of the baffles.
Circulating fluidized bed boiler	A fluidized bed boiler in which the fluidizing velocities exceed the terminal velocity of individual bed particles. This results in the entrainment of unburned and smoldering fuel particles from the boiler furnace, to be reintroduced to the furnace according to boiler steam demand.
Circumferential joint	A welded or riveted seam that runs the circumference of a boiler or pressure vessel shell.
Coil tube boiler	A once-through boiler made of coils of steel or copper tube that are exposed to the heat of combustion.
Condensing boiler	A heating boiler designed to extract additional heat from flue gas by lowering it to below its condensation temperature.
Copper tubular boiler	A coil tube heating boiler with tubes constructed of copper.
Course	A cylindrical pressure vessel component to which heads or other courses are attached.
Cyclone separator	A steam drum internal that uses centrifugal action to separate steam and moisture particles.
Diagonal stay	A brace used in firetube boilers between a flat head or tube sheet and the shell.
Dissolved solid	A solid impurity in solution with water. In boilers, calcium and magnesium salts are scale-forming dissolved solids.
Downcomer	A tube or pipe in a boiler circulating system through which fluid flows downward.

Term	Definition
Drum	A cylindrical shell closed at both ends, designed to withstand internal pressure.
Dry pipe	A perforated or slotted pipe or box inside a steam drum, and connected to the steam outlet, used to remove moisture particles from the steam.
Dry-back boiler	A multiple-pass firetube boiler with a rear door protected only with refractory.
Economizer	A heat recovery device designed to transfer heat from the products of combustion to boiler feedwater.
Electrode	A conductor that passes electric current into or away from another substance.
Ellipsoidal head	A formed head that is dished to a cross-section having the shape of a half ellipse. Ellipsoidal heads are used in boiler and pressure vessel construction to enclose drums or headers.
Embrittlement	The loss of boiler metal ductility and elasticity, due to the action of concentrated water impurities on stressed boiler components.
External downcomer	A downcomer located external to the boiler setting.
Externally fired	A boiler having its furnace outside of the shell or drum, and surrounded by a brickwork enclosure or setting. In this type of boiler, the furnace is not surrounded by water.
FBC	See *fluidized bed combustion* (FBC).
FD fan	See *forced draft fan* (FD Fan).
Field-erected boiler	A boiler substantially completed outside of a manufacturing facility.
Firebox boiler	A multiple-pass packaged firetube boiler with an internal furnace, the rear of which is a tubesheet directly attached to a shell containing tubes. The first-pass bank of tubes is connected between the furnace tube sheet and the rear head. The second-pass bank of tubes, passing over the crown sheet, is connected between the front and rear end enclosures.
Fireside	In a boiler, the side of a heat transfer surface exposed directly to high temperature combustion products.
Firetube	A straight boiler tube, surrounded by water and steam, through which the products of combustion pass.
Flexible watertube	A watertube boiler design with highly flexible serpentine riser tubes.
Flue gas	The gaseous products of combustion in the flue to the stack.
Fluidized bed	A process where a bed of granular particles are maintained in mobile suspension by an upward flow of air or gas.
Fluidized bed combustion (FBC)	A process where a fuel is burned in a bed of granular particles that are maintained in mobile suspension by the flow of air and combustion products.
Foaming	The continuous formation of bubbles with sufficiently high surface tension, so they remain as bubbles above the disengaging surface. This interferes with the natural steam disengagement process and can result in priming.
Forced draft fan (FD fan)	A fan that supplies combustion air, under pressure, to fuel burning equipment.
Handhole	An access opening in a boiler or pressure vessel, usually less than 150 mm in its longest dimension.
Head	In pressure vessels, the plate that seals the end of a cylindrical shell or drum.

Term	Definition
Header	A chamber that collects or distributes fluid to or from multiple parallel flow parts.
Heating boiler	A low-temperature, low-pressure hot water or steam boiler, designed in accordance with ASME BPVC Section IV.
Heating surface	The parts of a boiler through which heat is transferred from the combustion of fuel, to water or steam; the part of the boiler that has heat and combustion gases on one side, and water or steam on the other.
Hemispherical head	A formed head that is dished to the shape of a half-sphere, used in boiler and pressure vessel construction to enclose drums or headers.
Horizontal return tubular (HRT)	An externally fired firetube boiler consisting of a shell, with tubes inside the shell attached to both end closures. The products of combustion pass under the bottom half of the shell and return through the tubes.
HRT	See *horizontal return tubular* (HRT).
ID fan	See *induced draft fan* (ID Fan).
Induced draft fan (ID fan)	A fan that exhausts hot gases from a furnace, as the combustion products develop.
Insulation	Material that is a poor conductor of heat, used to retard or slow down flow of heat through wall or partition.
Internal furnace	A furnace that is located within the boiler and is surrounded by water.
Lagging	A covering, usually metallic that protects insulating material, on boilers, pipes, or ducts.
Locomotive boiler	A single-pass internally fired horizontal firetube boiler with an internal furnace, the rear of which is a tube sheet directly attached to a shell containing tubes through which the products of combustion leave the furnace.
Longitudinal joint	A welded or riveted seam that runs the length of a boiler or pressure vessel shell.
Lowest permissible water level	The lowest water level at which a boiler can be operated without sustaining damage due to overheating, as determined by the boiler manufacturer.
Manhole	A circular or elliptical opening through which a person may enter a boiler or pressure vessel, in order to conduct maintenance, inspection, or repair.
MAWP	See *maximum allowable working pressure* (MAWP).
Maximum allowable working pressure (MAWP)	The maximum pressure a boiler, pressure vessel, or pressure piping system can be safely operated at, according to its design.
Membrane tube	A wall constructed of closely spaced waterwall tubes welded to an intermediate fin, to form a continuous airtight structure.
Mud drum	A large cylindrical pressure vessel, installed at the lowest point of a watertube boiler, used for collecting sediment.
Once-through boiler	A watertube steam boiler with no internal water recirculation when in operation.
Once-through steam generator (OTSG)	A forced circulation watertube boiler, where all water that passes through the boiler is converted to steam. A once-through steam generator has no internal recirculation when in operation.
OTSG	See *once-through steam generator* (OTSG).
Packaged boiler	A boiler that is entirely shop-fabricated and tested, complete with all required auxiliaries, such as burners and controls, and sold as a package.

Term	Definition
Power boiler	A high-temperature, high-pressure hot water or steam boiler, designed in accordance with ASME BPVC Section I.
Pressure relief valve	A safety device designed to protect a boiler, pressure vessel, or pressure piping system against pressure in excess of design pressure. This category of devices includes pressure relief valves, safety relief valves, and relief valves.
Primary superheater	The superheater, in a system of superheaters connected in series, which receives saturated steam from the steam drum.
Push nipple	A smooth piece of pipe, tapered at both ends, which is used to connect radiator or cast iron boiler sections together, using the nipple's taper to create a tight seal.
Recuperative air heater	A tubular heat exchanger that transfers heat from high temperature flue gas to an incoming stream of combustion air.
Refractory	Temperature-resistant ceramic material used in boiler furnaces to protect metal surfaces around burners, line fireboxes, seal openings, or make baffles.
Regenerative air heater	A heat exchanger with a surface that is alternatively exposed to hot exhaust gas and incoming ambient air. Heat is absorbed from the outgoing hot gas stream and subsequently released from the same surfaces to the incoming air stream.
Reheater	A heat transfer apparatus for heating steam after it has given up some of its original heat in doing work in the high-pressure section of a steam turbine.
Riser	A tube through which steam and water pass from a lower header or drum to one above it.
Safety valve	An automatic pressure-relieving device actuated by the static pressure upstream of the valve. It is characterized by full-opening pop action. It is used for gas or vapour service including steam.
SAGD	See *steam-assisted gravity drainage* (SAGD).
Scotch boiler	A cylindrical steel shell with one or more cylindrical internal steel furnaces located in the lower portion of the shell, and with a bank or banks of tubes attached to both end closures. In stationary service, the boilers are either of the dry-back, or wet-back type. In marine service, the boilers are generally of the wet-back type.
Scrubber	See *chevron dryer.*
Secondary superheater	The superheater, in a system of superheaters connected in series, which receives superheated steam from the primary superheater.
Service rating	The application a device or fitting is suited for. Service rating considers combinations of pressure, temperature, and chemical resistance.
Setting	The brickwork surrounding the furnace in some older boiler designs. In modern boilers, the setting includes the water walls, insulation, refractory, and outer cladding that encloses the furnace.
Shop-assembled boiler	A boiler that requires some assembly outside of the manufacturing facility.
Shell	The outer cylindrical portion of a pressure vessel.
Sludge	Accumulated residue resulting from impurities in water as it boils.
Stay	A metal part, usually in the shape of a rod that helps brace and support flat boiler surfaces, preventing them from bulging.
Stay tube	A firetube that supports a flat tubesheet.

Term	Definition
Staybolt	A bolt threaded through or welded at each end, into two spaced sheets of a firebox to support flat surfaces against internal pressure.
Steam drum	A large cylindrical pressure vessel, installed at the highest point of a watertube boiler, used to separate steam from water.
Steam generating bank	See *boiler bank*.
Steam generating unit	A unit to which water, fuel, and air or waste heat are supplied, and in which steam is generated. It can consist of a boiler furnace, and fuel burning equipment. It may also include, as component parts, water walls, superheaters, reheaters, economizers, air heaters, or any combinations thereof.
Steam-assisted gravity drainage (SAGD)	The use of high-pressure steam to enhance heavy oil recovery from underground formations.
Stoker	A device consisting of a mechanically operated fuel feeding mechanism and a grate; used for the purpose of feeding solid fuel into a furnace, distributing it over a grate, admitting air to the fuel for the purpose of combustion, and providing a means for removal or discharge of refuse.
Supercritical steam generating unit	A steam generating unit designed to operate at pressures greater than 22.09 MPa, which is the critical pressure of water.
Superheater	A group of tubes which absorb heat from the products of combustion to raise the temperature of the steam passing through the tubes above its saturation temperature.
Telltale	A small hole drilled into the end of a stay, which leaks when the stay is cracked or excessively corroded. Also, a hole in a reinforcing pad, that leaks when the plate underneath the reinforcing pad is damaged.
Through stay	A brace used in firetube boilers between the heads or tube sheets.
Tie rod	A threaded tension member used to hold together sections of heat exchangers (such as cast iron sectional boilers, cast iron radiators, or plate-type heat exchangers).
Torispherical head	A formed head that is dished to two distinct radii, used in boiler and pressure vessel construction to enclose drums or headers.
Tubesheet	A flat or curved metal plate, found in boilers and other heat exchangers, with holes arranged for the attachment of tubes.
Uptake	The duct that connects to a boiler at its flue collar outlet, and conveys flue gas to a chimney.
Vertical firetube boiler	A single-pass firetube boiler with a cylindrical shell, having tubes connected between the top head and the tubesheet, which forms the top of the internal furnace. The products of combustion pass from the furnace directly through the vertical tubes.
Water-cooled furnace	A furnace that is constructed with tubes throughout its enclosure, and has water circulating through the tubes for cooling purposes.
Waterside	In a boiler, the side of a heat transfer surface exposed directly to water, steam, or a two-phase mixture of water and steam.
Watertube	A boiler tube with water and steam on the inside, and heat applied to the outside.
Waterwall	A series of tangent watertubes used to construct the furnace of a steam generating unit.

Term	Definition
Wet-back boiler	A firetube boiler with a water leg covering the rear end of the furnace and tubes, so that the furnace is completely water cooled. The products of combustion leaving the furnace are redirected to enter the next gas pass.
Windbox	A chamber below a stoker grate or surrounding a burner, through which pressurized combustion air is introduced to a boiler furnace.

Additional Workspace

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