United States
Environmental Protection
Agency

Air Pollution Training Institute
MD 20
Environmental Research Center
Research Triangle Park, NC 27711

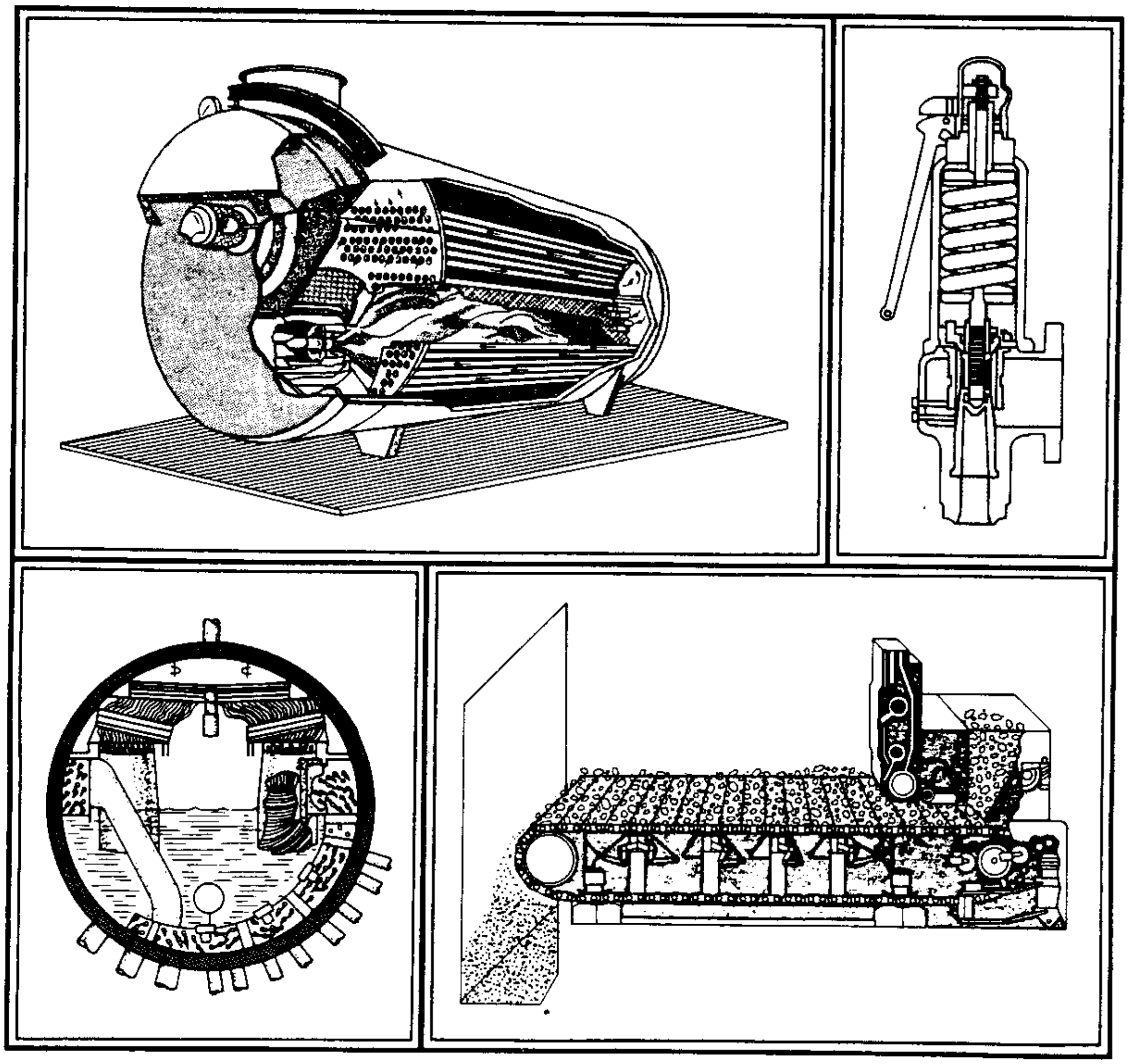
EPA 450/2-84-010
December 1984

Air

EPA

APTI
Course SI:428A
Introduction to Boiler Operation

Self-instructional Guidebook



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APTI Course SI:428A Introduction to Boiler Operation

Self-instructional Guidebook

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Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

Notice

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Table of Contents

Course Introduction

Description

Designed for engineers and other technical persons responsible for inspecting boilers, this course is an introduction to their operation. The course focuses on the major components of boilers and how boilers operate to produce steam, heat, or electricity. Major topics related to boilers include the following:

- Fire-tube and water-tube designs
- Combustion efficiency
- Supplying air and fuel
- Operation and maintenance
- Steam turbines, condensers, and cooling towers
- Air pollution emissions and control techniques

Course Goal and Objectives

Goal

To familiarize you with boilers—their operation, use of various fuels, common operation and maintenance problems, and components and add-on air pollution control devices which must be inspected.

Objectives

Upon completing this course, you should be able to—

1. briefly describe the overall operation of a boiler,
2. recognize the difference between a fire-tube and a water-tube boiler,
3. calculate boiler efficiency using various figures and tables,
4. briefly describe how air and fuel are introduced into a boiler,
5. recognize various boiler auxiliary equipment and their use, and
6. list three potential air pollution emissions from boilers and at least three control devices used to reduce these emissions.

Prerequisite Skills

- Completion of SI:422 (3rd edition), *Air Pollution Control Orientation*
- Completion of SI:431, *Air Pollution Control Systems for Selected Industries*

It is also recommended that you complete the APTI course series SI:412A, *Baghouse Plan Review;* SI:412B, *Electrostatic Precipitator Plan Review;* and SI:412C, *Wet Scrubber Plan Review;* particularly if you are evaluating plans for the installation of a boiler and associated air pollution control devices.

Requirements for Successful Completion

In order to receive 2.0 Continuing Education Units (CEUs) and a certificate of course completion, you must achieve a final examination grade of at least 70%.

Reading Materials

This text—supplementary reading materials are not required. English units are used in this document to help simplify calculations. Both metric and English units are used in Lesson 6 because the New Source Performance Standards are given in both sets of units. Appendix B contains conversion factors to convert English units into metric units.

Using the Guidebook

This book directs your progress through the course. Each lesson contains a goal and objectives, text, and review exercises. To complete a review exercise, place a piece of paper across the page, covering the questions below the one you are answering. After answering the question, slide the paper down to uncover the next question. The answer for the first question will be given on the right side of the page, separated by a line from the second question, as shown in Figure 1. All answers to review questions will appear below and to the right of their respective questions. The answer will be numbered to match the question. **Please do not write in this book.** Complete each review exercise in the lessons. If you are unsure about a question or answer, review the material preceding the question. Then proceed to the next section.

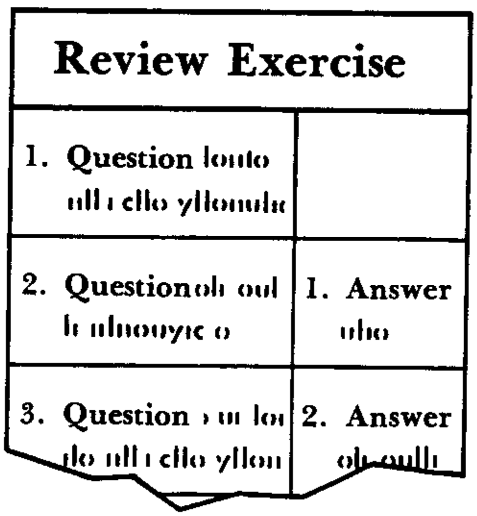

Figure 1. Review exercise format.

Instructions for Completing the Final Examination

Contact the Air Pollution Training Institute if you have any questions about the course or when you are ready to receive a copy of the final examination.

After completing the final exam, return it and the answer sheet to the Air Pollution Training Institute. The final exam grade and course grade will be mailed to you.

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Lesson 1

Boiler Fundamentals

Lesson Goal and Objectives

Goal

To familiarize you with the fundamental operation of a boiler.

Objectives

Upon completing this lesson, you should be able to—

1. define heat transfer and recognize the difference between three transfer methods,
2. distinguish between a water-tube and a fire-tube boiler,
3. list five tube sections of a boiler and identify their use, and
4. recognize the various ratings and classifications used to identify boilers.

Introduction

A boiler is a closed vessel containing water. Water is changed into steam when heated under controlled conditions. Fuels most commonly used as the heat source for a boiler are natural gas, oil, and coal—referred to as fossil fuels. In the boiler, chemical energy contained in the fuel is converted to thermal energy. Thermal energy heats water contained in boiler tubes or the shell to make steam. Steam can then be used for many industrial processes including refining petroleum, manufacturing automobiles, paper, chemicals, and for driving turbines to generate electricity.

Heat Transfer

Every boiler is designed to transfer as much heat as possible (produced from burning fuel) to the water contained in the boiler. Heat is transferred by conduction, radiation, and convection, although the amount of each will vary depending on the boiler design. *Conduction* is heat transfer by direct physical contact between a hot object and a cooler object, or from one part of an object to another part of the same object. Heat flows from the hot object to the cold object until there is no longer a temperature difference between the two objects in contact. The rate at which the heat is transferred will depend on the temperature difference between the two objects (or parts of the same object) and the heat carrying abilities of the material—called conductivity. Metals are very efficient conductors of heat. Fiborous materials such as fiberglass insulation are inefficient conductors of heat. In a boiler, heat is conducted through the metal in the shell and tubes.

Radiation is the transfer of heat through space from a hot object to a cooler one. Radiation does not require any physical contact between the two objects because radiated heat travels by electromagnetic vibrations. For example, heat is radiated from the hot coals in a camp fire to people sitting around the fire even though the air between the two remains relatively cool. The amount of heat absorbed by radiation depends on the temperature difference and the distance between the two objects, and the nature of the objects. The amount of heat absorbed increases as the temperature difference and distance between two objects decreases. In a boiler heat is radiated by the flames in the combustion zone, called the firebox. Heat is absorbed by the boiler tubes located in the firebox, and nearby areas of the furnace.

Convection is the transfer of heat by heated fluid. In the case of a boiler, the fluid is the hot gases produced by burning fuel. Heat is transferred from the hot gases to the cold boiler tubes containing water. Convection can be either natural or forced. Natural convection occurs as the heated fluid expands and rises. Cooler portions of the fluid move into the space vacated by the hotter fluid. This mixes the fluid, moving heat from one part of the fluid to another. In forced convection the heated fluid is moved by devices such as a fan or pump.

Boiler Designs

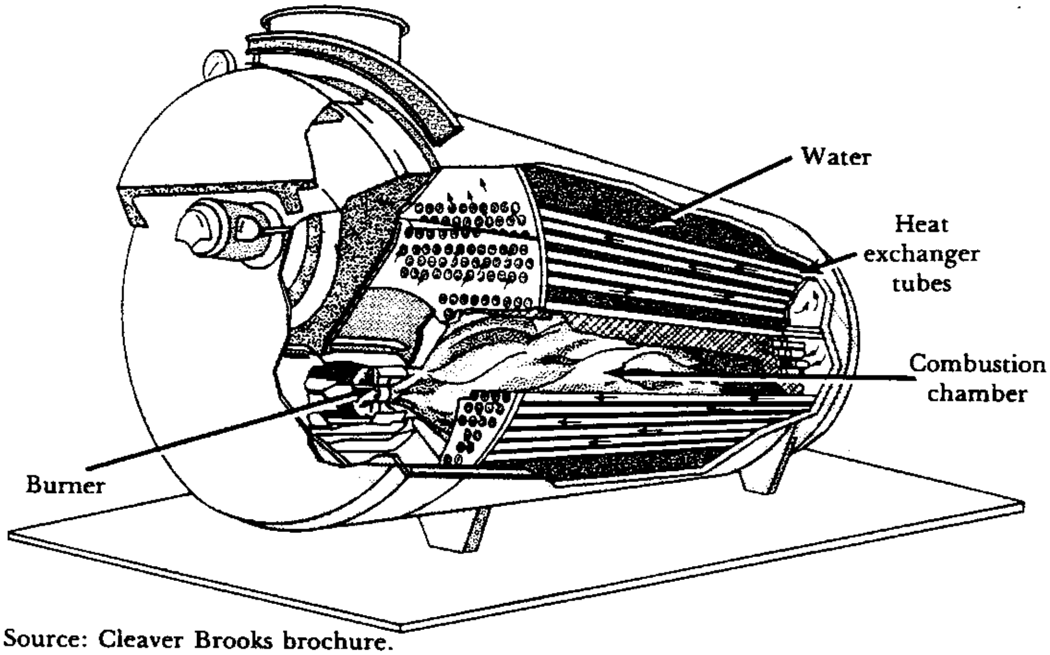
Boilers are either fire-tube or water-tube designs. In fire-tube boilers, hot combustion products pass through the inside of heat exchanger tubes while water, and eventually steam, are contained outside the tubes by an outer shell. In water-tube boilers, hot combustion products pass over tube sections containing water. Water in the tubes is boiled to make steam.

Fire-Tube Boilers

Many small- and medium-sized units are fire-tube boilers. They are usually packaged and sold with burners, blowers, and other equipment all mounted in the same framework. These units generally produce low-pressure steam or heat for small industries, commercial businesses, schools, hospitals, and other institutions.

Fire tubes are straight and connected at their ends by tube sheets. A large body of water, surrounding these tubes and contained in a large shell, boils into steam. The pressures of the steam produced are usually limited to 250 psig because large diameter shells cannot withstand very high pressures.

One common fire-tube boiler is the *horizontal return tubular* (HRT). Figure 1-1 shows a four pass HRT boiler. These boilers are usually designed to burn either natural gas or oil. The first pass occurs as the hot gases generated during combustion pass through the long furnace tube, or combustion chamber. The gases then move into the tubes at the bottom of the boiler for the second pass. In the third pass, the gases pass through the tube bank directly above the combustion chamber. Finally they reverse direction and pass through the bank of tubes in the top of the furnace and out the stack. HRT boilers vary in size; 4 to 15 ft in diameter and lengths of 6 to 40 ft.



Source: Cleaver Brooks brochure.

Figure 1-1. Typical four pass horizontal return tube boiler.

Another boiler, the *Scotch marine,* has one or more cylindrical furnaces. The furnace is usually a large-diameter tube made of corrugated metal. Some are fired from both ends and called double-ended Scotch boilers. Figure 1-2 shows a conventional Scotch marine boiler with the furnace and tubes contained within the shell. Combustion gases pass through the furnace into the tubes where they heat the surrounding water. Scotch marine boilers are similar to HRT boilers, except that they usually don't have as many tube passes. These units can be designed to burn either gas, oil, or coal. Scotch marine boilers have overall diameters from 3 to 8 ft and lengths of approximately 4 to 20 ft.

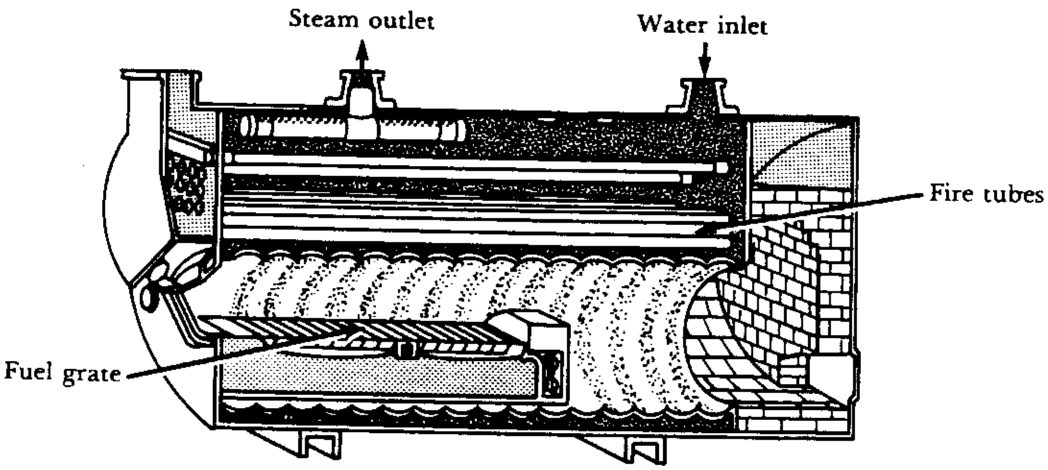


Figure 1-2. Typical Scotch marine boiler.

A variation of a horizontal return tube boiler has a *refractory lined firebox*. In this unit, hot combustion gases pass through tubes located in the upper portion of the furnace. Water contained in the outer shell is heated as the hot gases pass through the tubes (Figure 1-3). These boilers occasionally burn coal but can also burn gas or oil. The sizes of these units are similar to Scotch marine boilers.

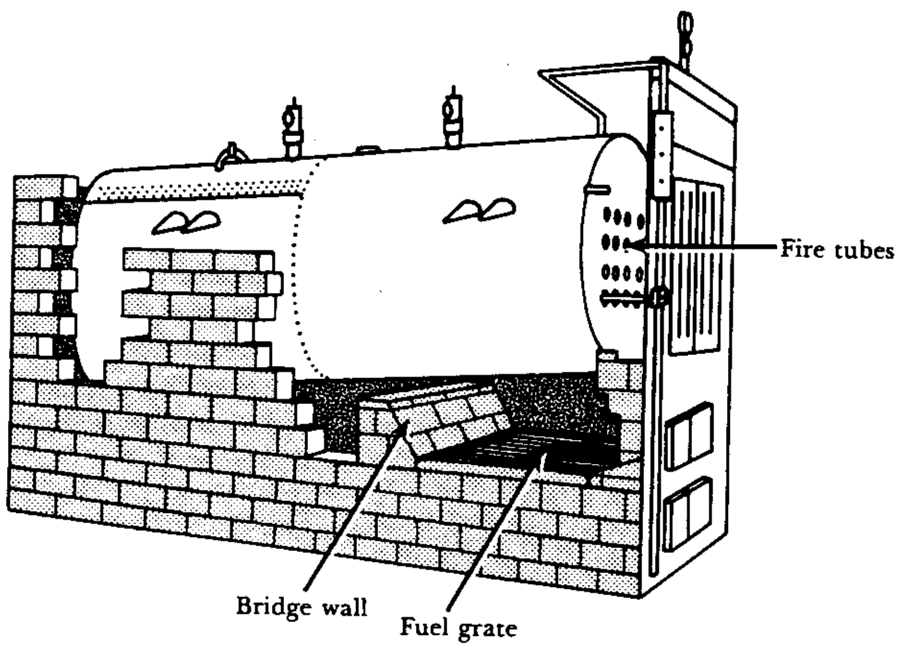


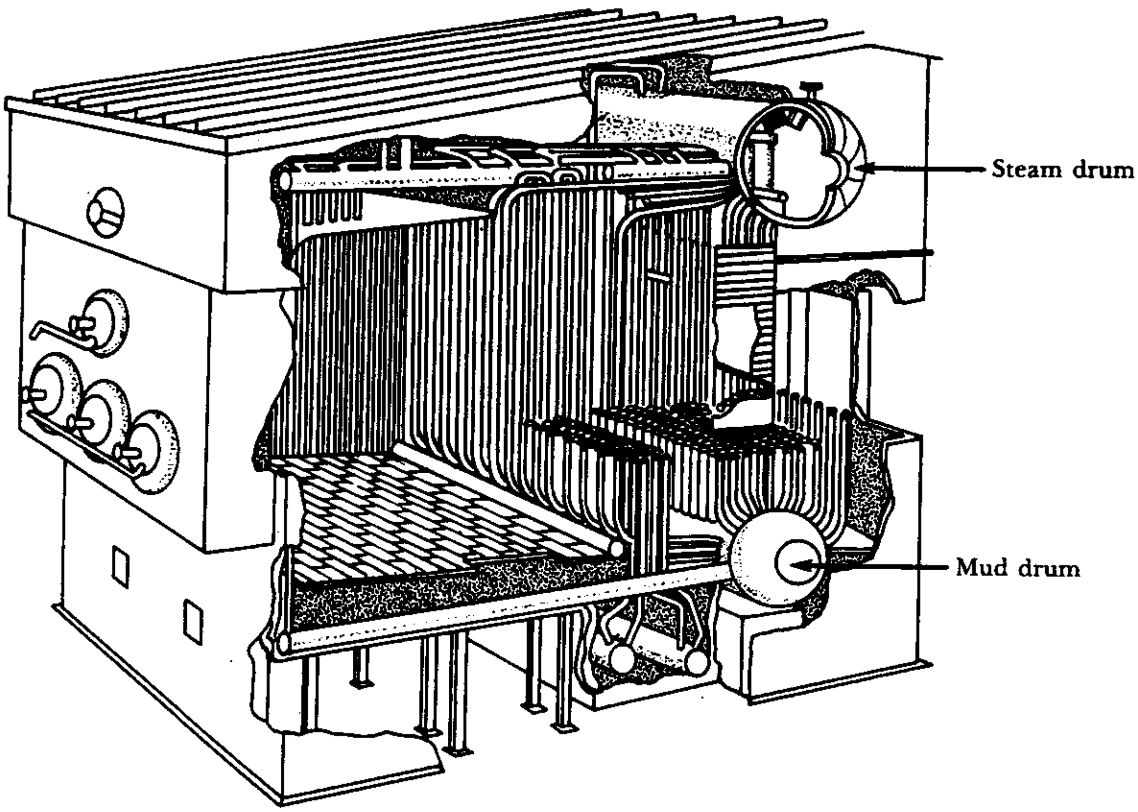
Figure 1-3. Typical fire-tube boiler with a refractory-lined firebox.

Water-Tube Boilers

Water-tube boilers are constructed in a wide range of sizes. All large steam generators are water-tube boilers. Hot combustion products pass over tube sections containing water. Water is boiled to make steam that is collected in *steam drums* in the furnace. These boilers are used when large amounts of high pressure steam are needed.

The cross-sectional area of each water tube is much smaller than that of the shell used in a fire-tube boiler. Therefore, water tubes can handle higher pressures and temperatures than can fire tubes. Pressure can be as high as 5000 psig and temperatures can be as high as 1000°F.

The layouts of the tubes and drums vary depending on their size and the type of fuel burned. Both bent and straight tubes can be connected to one or more drums. Figure 1-4 shows a water-tube boiler with two drums. The lower drum is usually called the mud drum and contains water. The upper drum, called the steam drum, contains both steam and water (condensed steam). Units such as these are usually assembled in the field.



Source: Babcock and Wilcox, 1978.

Figure 1-4. Typical water-tube boiler.

Figure 1-5 shows a water-tube boiler that has four drums. Water enters the top drum on the right-hand side of the boiler. This drum contains a mixture of steam and water. Water flows vertically through tubes called downcomers to the bottom drum (mud drum). Mud drums are occasionally called water-wall headers. Heated water moves up through tubes called risers to the center drum and then back to the top drum. Here, steam is separated, some of it condensing and falling back into this drum. Separated steam flows through a tube into a steam drum, located in the top left-hand corner of the boiler. Steam in the steam drum is drier because most of the moisture has been removed by steam separators.

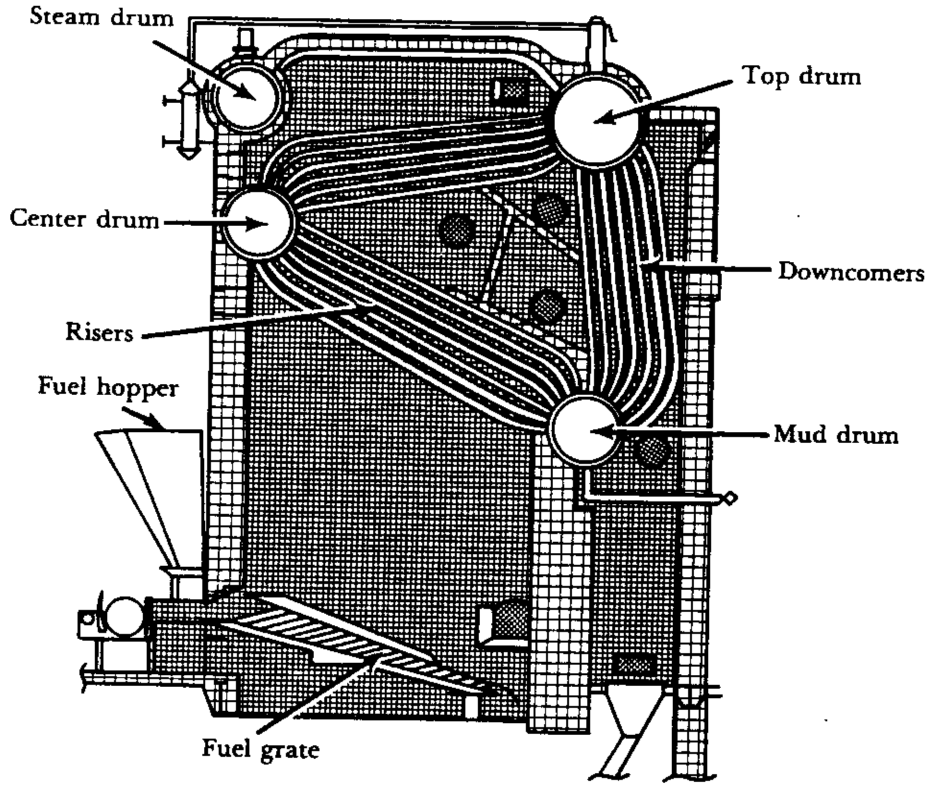
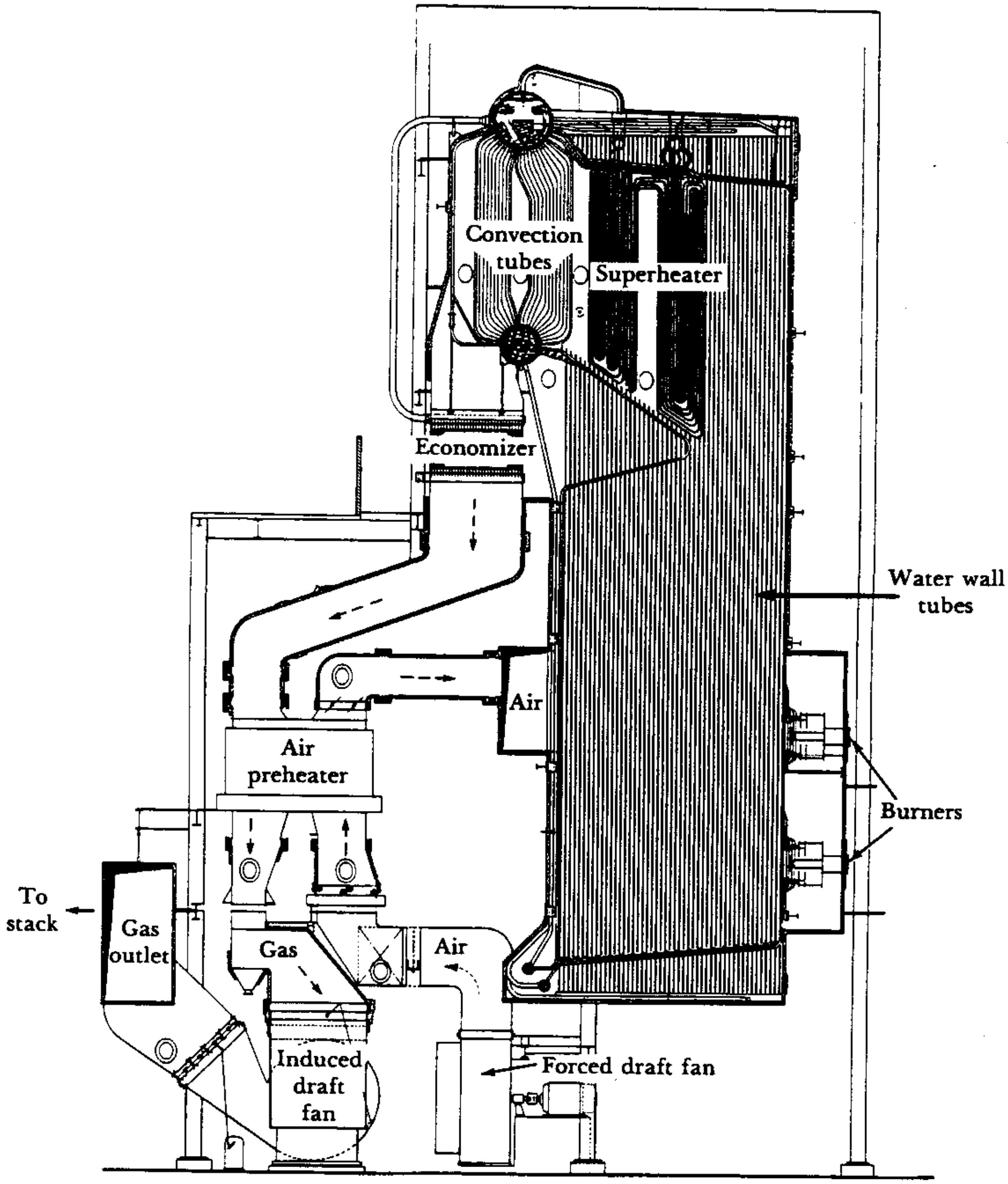


Figure 1-5. Water-tube boiler with four drums.

Large water-tube boilers that make steam for generating electricity are very complicated in design. Figure 1-6 shows the tube sections of a typical large water-tube boiler. Each section is designed to extract as much heat as possible from the flue gas. The five main tube sections of the boiler are the water walls (or fire walls), convection tubes, superheater, economizer, and air preheater.



Source: Babcock and Wilcox, 1978.

Figure 1-6. Water-tube boiler showing the various tube sections.

Water Walls

Most modern large water-tube boilers have tubes that completely surround the firebox or furnace, called *water walls* or *fire walls*. They are exposed to intense radiant heat in the firebox. Because these tubes contain water, they also help cool the walls of the furnace, thus eliminating the need for a thick refractory lining. Some boilers use tubes that are lined with refractory as shown in Figure 1-7. Others use water walls that are metal tubes with bars welded between them (Figure 1-8). Block insulation separates the metal tubes from the outside wall made of metal lagging. These are called membrane walls. Special refractory materials are occasionally used to help protect them from molten slag and resulting erosion. In addition, water walls and burners are carefully designed to prevent flames from impinging on tube surfaces which causes them to overheat and eventually burst.

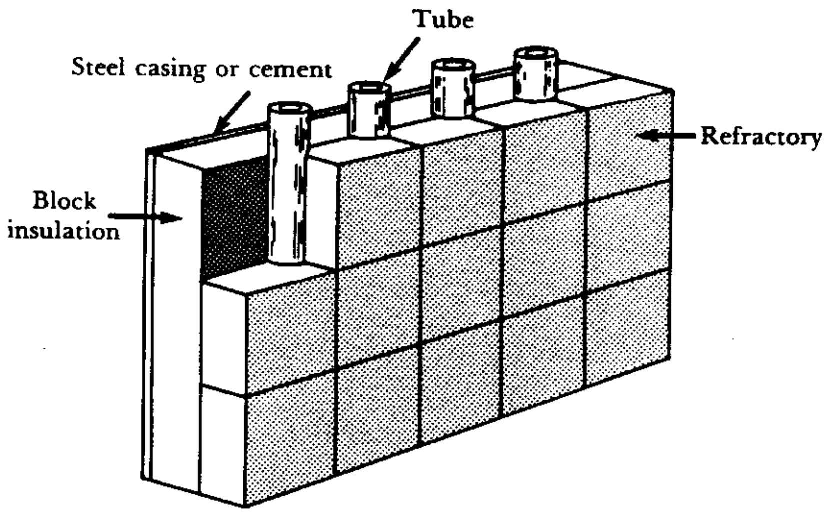
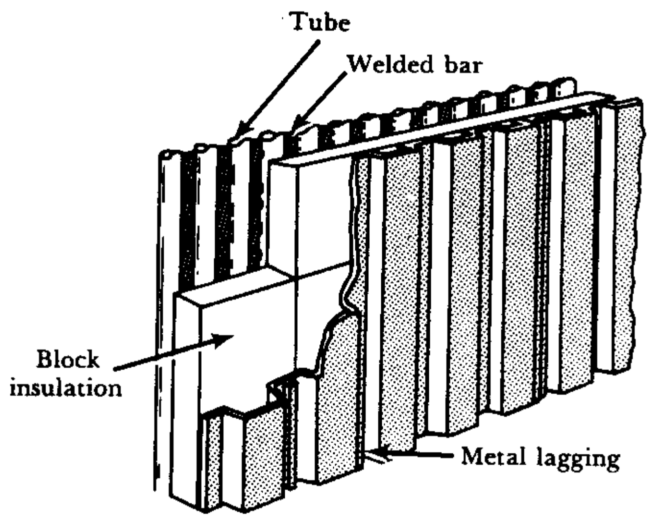


Figure 1-7. Water walls with partial refractory lining.



Source: Babcock and Wilcox, 1978.

Figure 1-8. Membrane water walls.

Water in the water walls forms steam bubbles which rise through tubes, called risers, and are collected in a steam drum located in the top part of the boiler. Some steam condenses out and drains back down to the bottom of the boiler through downcomer tubes. These tubes are usually not directly exposed to the fire in the firebox and are, therefore, relatively cool. The downcomers connect to water-wall headers located in the base of the furnace.

Figure 1-9 shows a simplified representation of a single circuit. The flow of water and steam in this arrangement occurs because of the difference in densities of water and steam. Water is denser and will flow down through the downcomers while steam bubbles up through the risers. The steam and water loops are made by using a number of drums, many riser tubes, and a few large downcomer tubes, depending on the boiler design. In large boilers, tube layout becomes quite complex. Downcomers are exposed to some heat and the force available for natural water circulation becomes smaller. Boilers producing high pressure steam generally use pumps to circulate the water from the downcomers into the water-wall headers.

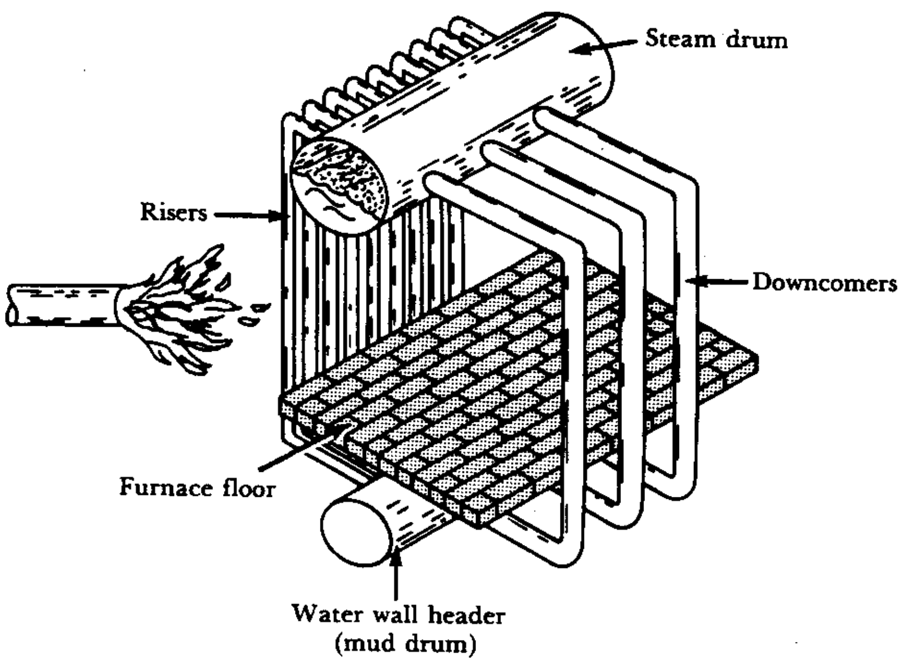


Figure 1-9. Simplified representation of a single circuit.

Convection Tubes, Steam Drums, and Superheaters

Hot flue gas is pulled through the boiler by an induced draft fan. Hot flue gas passes over tubes located in the upper portion of the boiler. Because heat is transferred by convection, these are called convection tubes. Water in the water wall tubes turns into steam and is collected in the steam drum or drums located in the convection section (Figure 1-10). Steam and water that may have condensed when reaching the steam drum are heated as hot flue gas moves over and around the convection tubes.

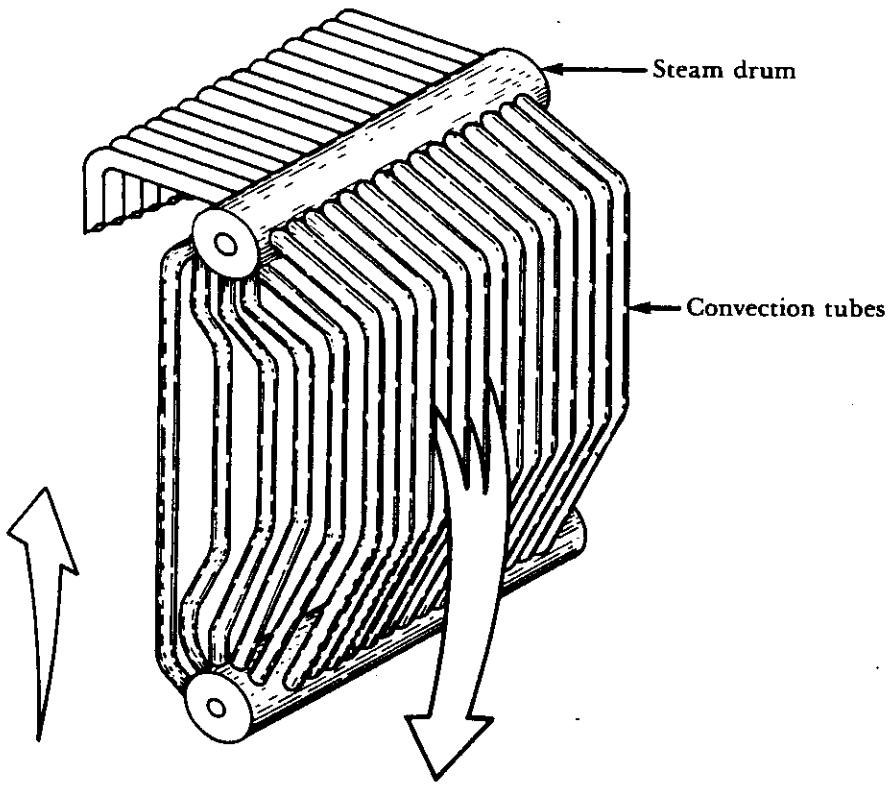
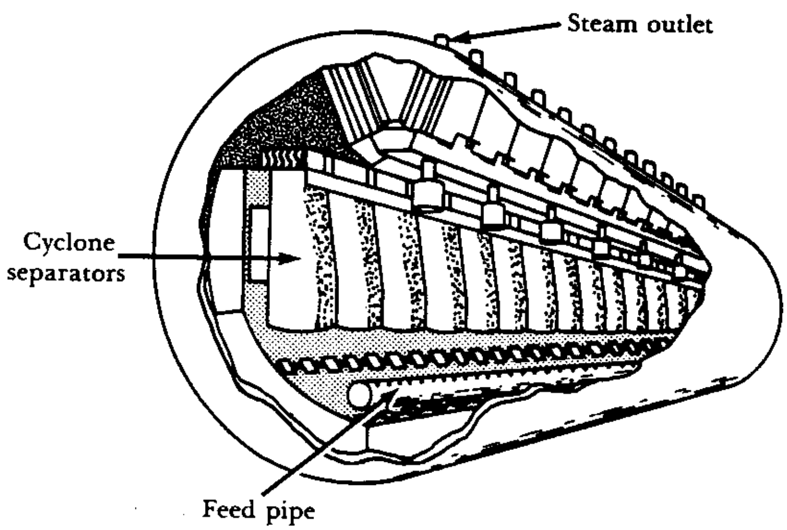


Figure 1-10. Convection section.

Steam drums used to collect and separate steam, are long and cylindrical. They contain approximately 50% steam and 50% water. Some of the water in the drum is condensed steam, the other is makeup water that is needed when steam is withdrawn for uses in the plant. A typical steam drum is shown in Figure 1-11.



Source: Babcock and Wilcox, 1978.

Figure 1-11. Typical steam drum.

Heated feedwater enters the steam drum through internal feed pipes located along the entire length of the drum bottom. Perforated holes in the feed pipes allow water to flow into the steam drums. Figure 1-12 shows components of a steam drum in more detail. Steam and water are usually separated by *cyclone separators,* open at the top and bottom. Steam and water from the water-wall tubes enter the base of each cyclone separator. Water is thrown to the side of the cyclone by centrifugal force and drains to the bottom of the drum. Steam first passes through baffles or chevron blades at the top of the cyclone, then through drying screens or chevron blades at the top of the drum. As the steam touches the screens or chevron blades, additional moisture will cling to the surfaces and be removed. Steam is now drier before it enters the superheater.

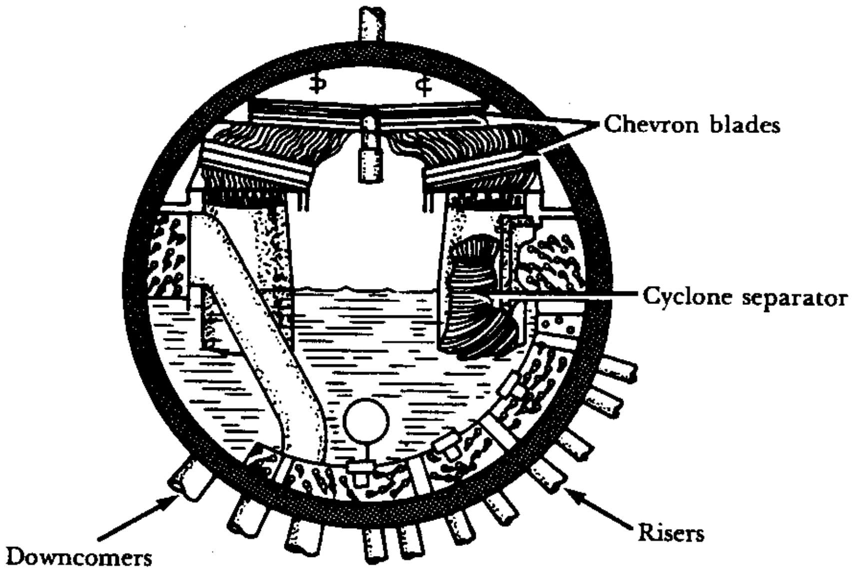


Figure 1-12. Detail of steam drum.

Steam leaves the steam drum at approximately 650°F. In some cases, the steam would be ready to be used in an industrial process. However, in boilers used in power plants and many industrial processes, steam is heated to higher temperatures in tube sections called *superheaters* (Figure 1-13). Steam leaving superheaters can have temperatures as high as 1000°F. Many boilers have a number of superheaters. Each is named for its location in the boiler. For example, steam from the steam drum usually passes into a primary superheater, or convection superheater. This superheater is heated by convection heat—thus its name—convection superheater. Steam then goes to a radiant superheater that receives radiant heat directly from the fire in the furnace—thus its name. Steam can then go into pendant superheaters that hang from the roof of the boiler. These are also called reheaters because steam that has made one pass through the turbine is reheated in this tube section. Superheated steam has several advantages over ordinary steam. It is hotter; therefore, boiler efficiency is increased. Also, since superheated steam is drier, it does not easily condense into droplets that can corrode and errode turbine parts.

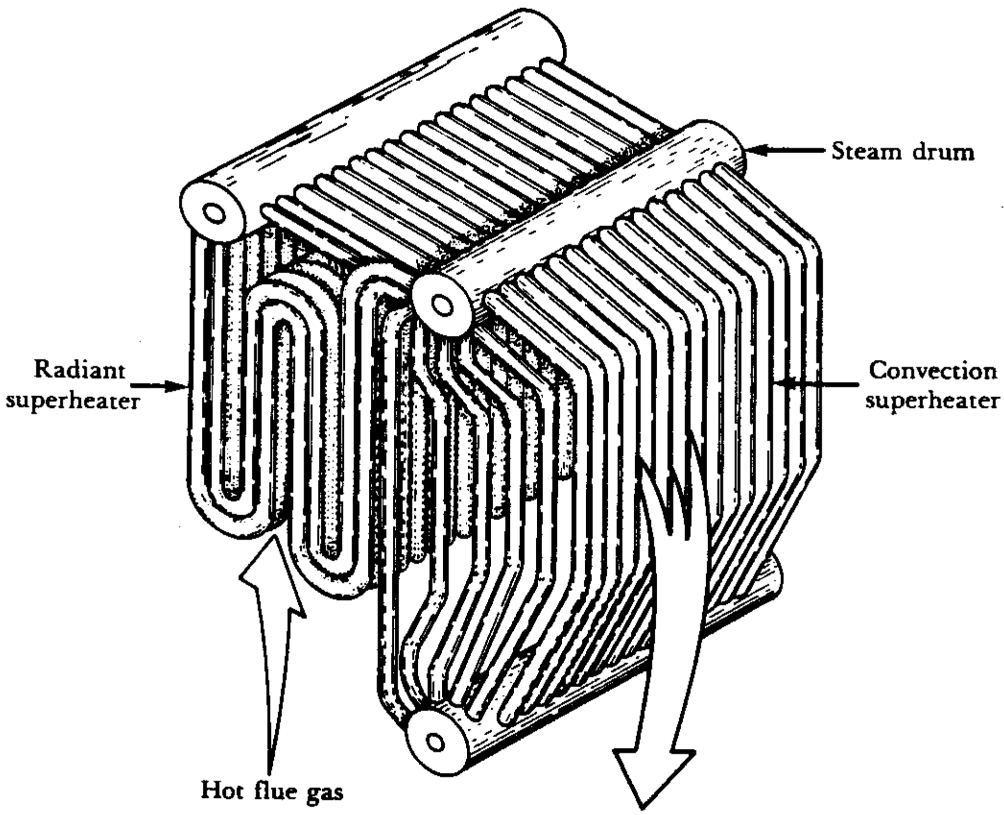


Figure 1-13. Superheaters.

Economizer

Boiler feedwater, or makeup water, is heated in a tube section called an economizer before it is delivered to the steam drum. As we said earlier, steam is drawn from the steam drums to the turbine as the demand for electricity increases, or to the plant as the demand for process steam increases. To replace this, an equivalent amount of water, called makeup water, or feedwater, is pumped through economizer tubes where it is heated before it enters the steam drum (Figure 1-14). Water leaving an economizer reaches a temperature of at least 212°F. In boilers used in power plants, the feedwater coming into the economizer is preheated by feedwater heaters to get it to very high temperatures. Water temperature leaving an economizer/feedwater heater system can be as high as 600°F.

Economizer tubes usually have fins that help promote heat transfer from the hot flue gas to the water flowing through the economizer. Heated water from the economizer is collected in the outlet header. A header is a long pipe or tube with holes in its sides to allow water (or steam in the case of a steam header) to be evenly collected or distributed. From the outlet header, feedwater flows into the steam drum.

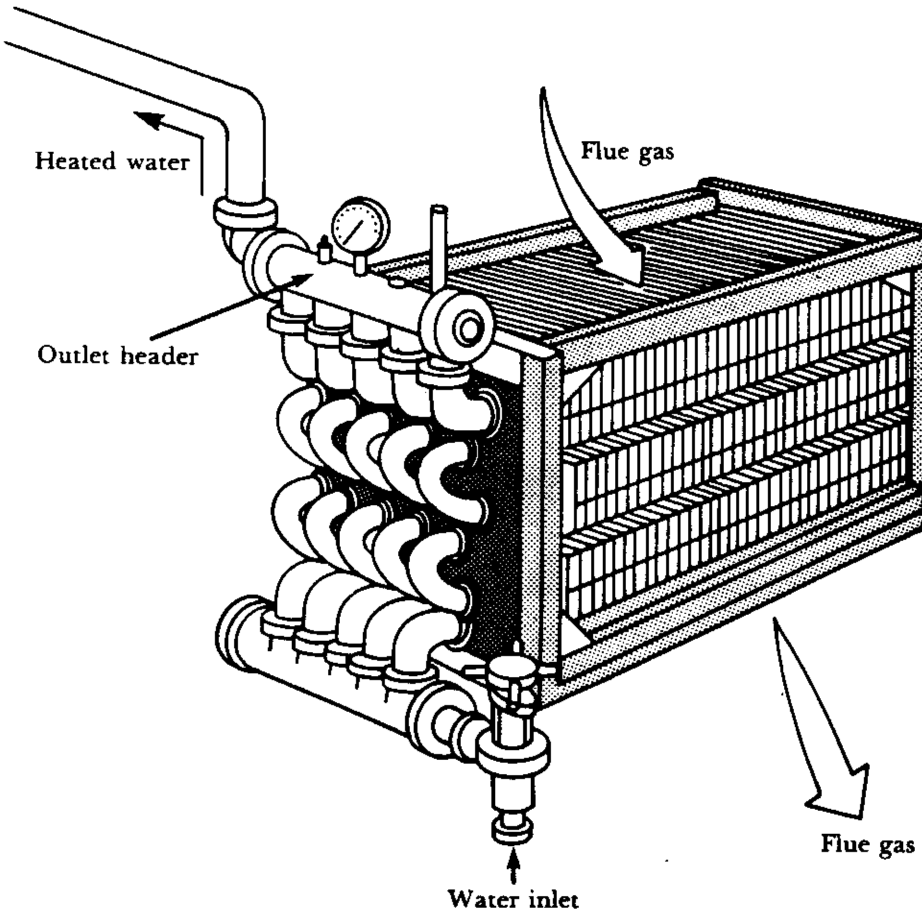


Figure 1-14. Economizer.

Air Preheater

An air preheater is a tube section that preheats the air used for burning the fuel in the furnace. It is usually placed after the economizer and before or after the air pollution control equipment in a boiler system. The most widely used are ***tubular***, *rotary*, and *Rothemuhle* air preheaters.

A tubular air preheater has a number of small tubes, 1 to 2 in. in diameter, through which the flue gas flows. Cool air is forced over and around the tubes by a small forced draft fan (Figure 1-15). The hot flue gas passing through the tubes transfers heat to the "cool" air. Warmed air leaving the air preheater is sent to burners where it is used to burn fuel.

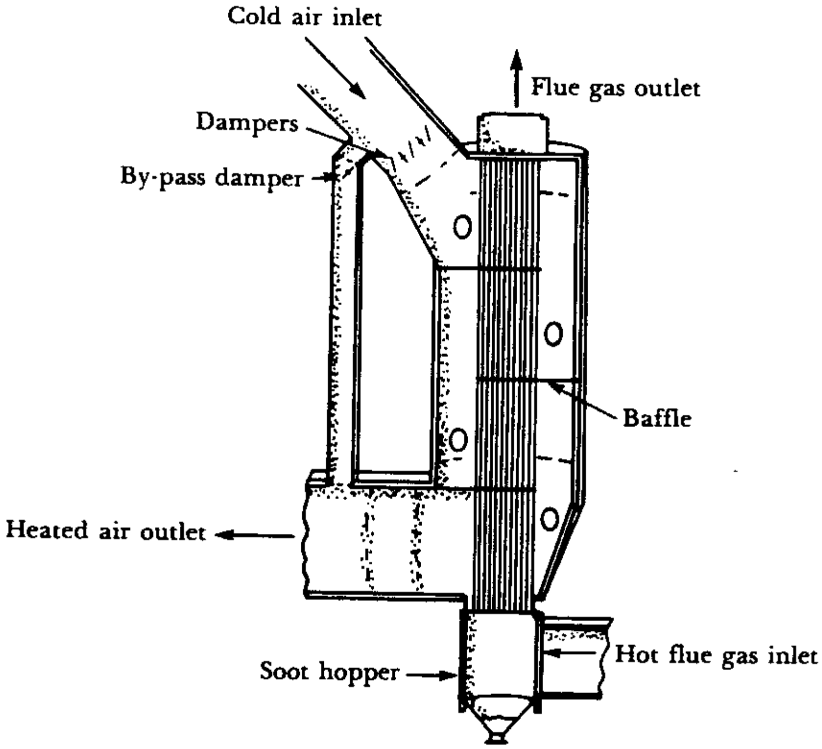


Figure 1-15. Tubular air preheater.

Many modern large water tube boilers use rotary, or regenerative, air preheaters. Regenerative air preheaters are large heat exchanger wheels that contain heat absorbing materials (Figure 1-16). In these devices, hot flue gas flows through one portion of the wheel while cool, clean combustion air passes through the remaining portion. Heat is stored in the absorbing material through which the hot flue gas flows. As the wheel revolves, the cold combusion air passes through these hot surfaces and becomes heated. This preheated air is sent to the burners and is burned with fuel in the firebox. The absorbing material of the wheel is constructed of corrugated sheet metal plates. The plates, arranged in a honeycomb matrix, provide both maximum heat transfer and air flow between the plates. These devices are more efficient than shell-and-tube heat exchangers.

The Rothemuhle regenerative air preheater consists of a stationary heating element and two rotating air hoods. Hot flue gas enters a large duct surrounding the air preheater. The flue gas flows over a portion of the heating surface not blocked by the hoods, thus heating it. The air hoods rotate slowly around the stationary heating surface causing the cool air to become heated (Figure 1-17).

Air preheaters can improve the overall boiler efficiency from 2 to 10%. Preheated air accelerates combustion by producing rapid ignition of fuels. It also allows using a low amount of excess air (see Lesson 2), thereby increasing boiler efficiency.

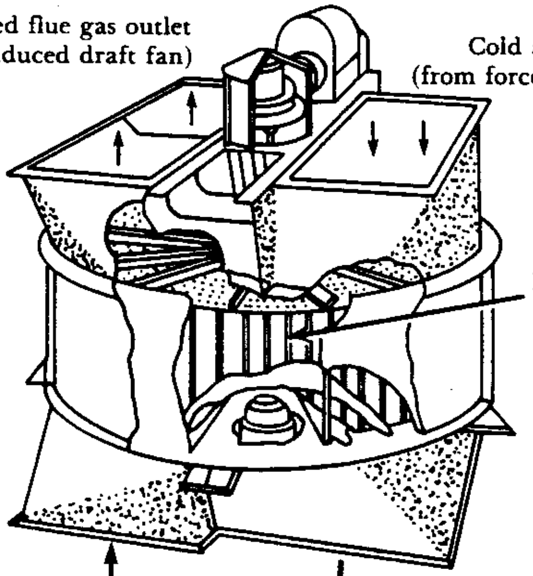
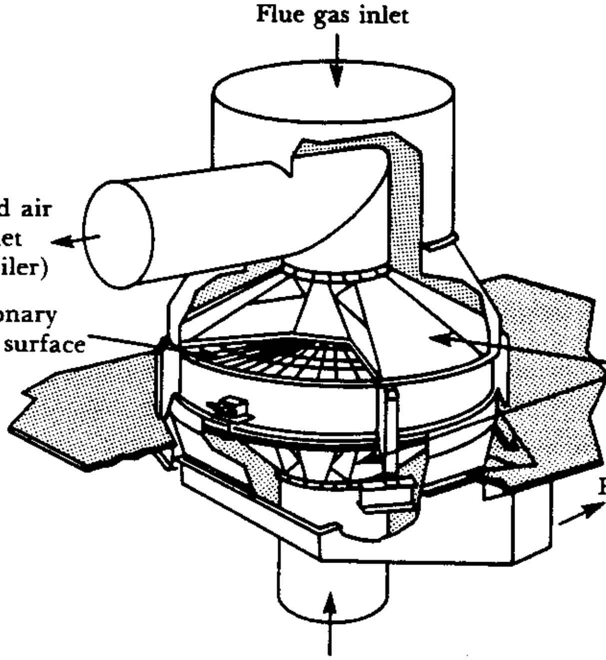


Figure 1-16. Rotary air preheater.



Source: Babcock and Wilcox, 1978.

Figure 1-17. Rothemuhle regenerative air preheater.

Boiler Sizes and Ratings

Boilers are usually grouped by capacity on another classification such as the pressure at which it operates. Capacity refers to the heat or steam output of a boiler. The terms used to express capacity depend on the size of the boiler. Boiler manufacturers designate the capacity of medium and large boilers in terms of pounds of steam generated per hour at a specific temperature and pressure. Small boilers are usually designated by the total square feet of heating surface, horsepower (hp), or percentage of rating (TPC Training Systems, 1975).

The total heating surface refers to all heat exchanger surfaces exposed to the hot flue gas on one side and the water or steam on the other side. Boilers are also rated by boiler horsepower—one boiler hp is equal to a heat output of 33,475 Btu per hour. The rated hp of a boiler depends on the boiler design and its amount of heating surface. Occasionally boilers are designated by the percentage of rating—the actual capacity divided by the rated capacity. This designation is used when a boiler produces more steam than the rated capacity. Thus, if a boiler produces two times the amount of its rated capacity, it operates at 200% of rating.

Boilers are also classified by the pressure at which they operate. The five common groupings are: below 900 psi, 900 to 1000 psi, 1200 to 1500 psi, 1800 to 2500 psi, and 3500 to 5000 psi. Fire-tube boilers usually operate between 50 and 250 psi. Water-tube boilers operate at higher pressures. Large power plant boilers can operate with pressures as high as 5000 psi.

Boilers are also rated by their heat input capacity. The heat input capacity is the amount of heat, in units of British Thermal Units per hour (Btu/hr), Joules per hour (J/h), that is generated by burning fuel in the furnace. Boilers are also rated in terms of Megawatts (MW) of thermal energy produced. A boiler rated at 73 MW has a heat input of approximately 250×10^6 Btu/hr. Many air pollution control agencies adopt regulations to limit the air pollution emissions in units of ng/J or $lb/10^6$ Btu.

Comparing Fire-tube and Water-tube Boilers

Fire-tube boilers are usually smaller, occupy a minimum of floor space, have a lower initial cost, and require very little installation time than do water-tube boilers. However, they do have some disadvantages. The water volume is very large and circulation is poor, making them slow to respond to changes in steam demand. The drums, or shells, containing the water are very large and cannot be economically built to withstand higher operating pressures. Pressures are usually less than 250 psi. Drums and joints are exposed to the furnace, increasing the likelihood of explosion. The pressure, temperature, and the amount of steam that can be produced are not as high as with water-tube boilers.

Both fire-tube and water-tube boilers are constructed as packaged boilers. Packaged boilers are shop assembled with burners, tubes, fans, and controls built into the boiler as one unit. These units can be placed into service very quickly. The packaged units have automatic controls, thus reducing labor costs. Because these units are compact, they can be difficult to get inside of for maintenance. Packaged units generally must burn liquid or gaseous fuels.

Water-tube boilers are available in various sizes to produce high-pressure, high-temperature steam. Because these units use small diameter tubes, they can produce high-pressure steam without a great risk of explosion. They can also respond rapidly to changes in steam demand. Water-tube boilers usually have more elaborate settings and controls, and the cost per pound of steam is usually higher than for a similar-sized fire-tube boiler. Large water-tube boilers are usually field erected, making the installation more difficult and time consuming. Water-tube boilers can be designed to burn solid, liquid, or gaseous fuels, whereas fire-tube boilers usually burn only liquid or gaseous fuels. Table 1-1 lists the general ratings of fire-tube and water-tube boilers and their various applications.

Table 1-1. General ratings of boilers.

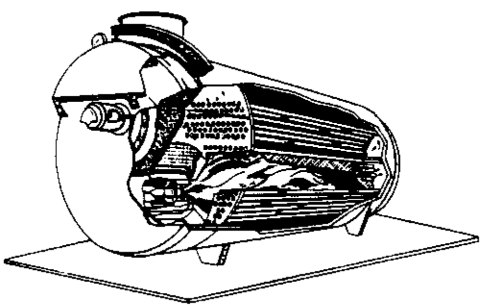
Application	Boiler design	Rating (psi)
Residential and small commercial	fire-tube water-tube	50- 250 50- 900
Commercial and small industrial	fire-tube water-tube	50- 250 50-1800
Industrial	water-tube	900-2500
Utility	water-tube	2500-5000

Summary

Selecting a boiler involves evaluating many factors including availability, initial costs, operating and maintenance costs, labor, space, and the pressure and temperature of steam needed for the process. One of the most important factors is the fuel to be burned—its type and cost. During the life of the boiler, the fuel costs can be two to six times the initial cost of the boiler. It is very important to operate the boiler as it was designed to help keep the fuel costs low and improve overall boiler efficiency. These topics will be discussed in the following lessons.

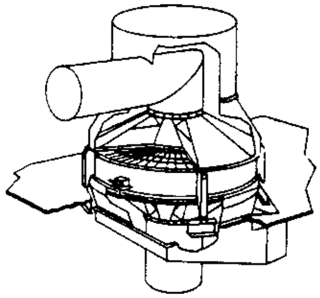
Review Exercise

1. In __________ boilers, combustion products pass through the inside of heat exchanger tubes while water and steam are contained outside the tubes by an outer shell.	
2. In __________ boilers, hot combustion products pass over tube sections that contain water. Water is boiled to make steam that is collected in steam drums.	1. fire-tube
	2. water-tube

3. The ________ is a section of tubes that heats the feed-water before it is delivered to the boiler. a. convection b. economizer c. superheater d. air preheater	
4. True or False? The temperature of steam in the superheater can be as high as 538 °C (1000 °F).	3. b. economizer
5. Heat transfer through space from a hot object to a cooler one is called a. conduction. b. convection. c. radiation.	4. True
6. Heat transferred by hot flue gas flowing over and around boiler tubes is called a. conduction. b. convection. c. radiation.	5. c. radiation.
7. The following illustration is of a a. Scotch marine boiler. b. horizontal return tube boiler. c. fire-tube boiler with a refractory-lined firebox. d. packaged water-tube boiler. 	6. b. convection.
8. In water-tube boilers, the tubes surrounding the firebox are called a. superheaters or convection tubes. b. economizers or air preheaters. c. water walls or fire walls.	7. b. horizontal return tube boiler.
	8. c. water walls or fire walls

9. In a water-tube boiler, water forms into steam, moves through tubes called __________, and is collected in a __________. a. risers, steam drum b. downcomers, steam drum c. risers, downcomer	
10. True or False? Boilers producing high-pressure steam generally use pumps to circulate the water from the downcomers into the water-wall headers.	9. a. risers, steam drum
11. Heated feedwater enters the steam drum through internal feed pipes located along the length of the drum a. top. b. bottom. c. back wall.	10. True
12. In a steam drum, steam and water are usually separated by a. packed beds. b. cyclone separators. c. water pools.	11. b. bottom.
13. True or False? Water-tube boilers can have a number of superheaters called convection, pendant, and radiant superheaters.	12. b. cyclone separators.
14. For many water-tube boilers, steam is drawn from the boiler as makeup water is pumped through a(n) __________ where it is heated before it enters a(n) a. preheater, economizer. b. superheater, mud drum. c. economizer, steam drum.	13. True
15. True or False? In a tubular air preheater, cool combustion air is heated by a revolving heat wheel.	14. c. economizer, steam drum
	15. False

16. The following illustration is of a
    a. rotary air preheater.
    b. tubular air preheater.
    c. economizer.
    d. Rothemuhle regenerative air preheater.



17. Boilers are usually rated by
    a. boiler horsepower.
    b. operating pressure.
    c. heat input capacity.
    d. all of the above

18. Fire-tube boilers operate at higher/lower pressures than do water tube boilers.

16. d. Rothemuhle regenerative air preheater.

17. d. all of the above

18. lower

References

Babcock and Wilcox. 1978. *Steam—Its Generation and Use.* New York: The Babcock and Wilcox Company.

Beachler, D. S., Jahnke, J. A., Joseph, G. T., and Peterson, M. M. 1983. *Air Pollution Control Systems for Selected Industries—Self-Instructional Guidebook.* APTI Course SI:431. EPA 450/2-82-006.

TPC Training Systems. 1975. *Generating Steam in the Power Plant.* Barrington, Illinois: Technical Publishing Company.

Woodruff, E. B. and Lammers, H. B. 1977. *Steam-Plant Operation.* New York: McGraw-Hill Book Company.