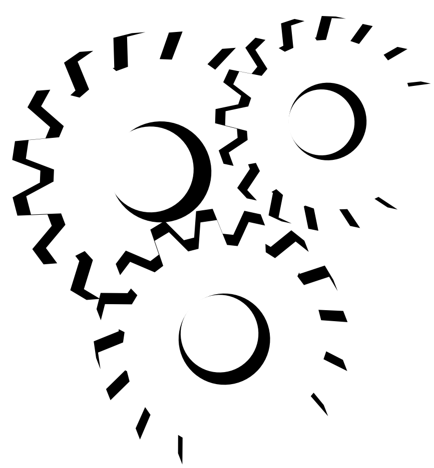
HOW POWER PLANTS WORK

Lesson One

Steam – The Primary Force



TPC Training Systems

11101

Lesson

1 Steam – The Primary Force

TOPICS

Energy for Power Plants
Converting Energy to Electricity
The Importance of Air in Combustion
Removing Ashes and Flue Gases
Heating the Air
Boiler Design
Controlling the Water Level
Feedwater Heater
The Economizer

OBJECTIVES

After studying this Lesson, you should be able to…

- Describe the basic concepts involved in converting energy to electricity through a steam power plant.
- Explain why air is important in combustion and describe how air is heated.
- Describe the basic design of a boiler.
- List the methods commonly used to create efficiency in a boiler.

KEY TECHNICAL TERMS

Respiration 1.06 process by which living things take in air to create energy

Combustion 1.06 process by which energy (in the form of heat) is created in a boiler

Turbine 1.11 engine powered by steam pressure on rotating vanes

Convection 1.38 automatic transfer of heat by circulating liquids or gases

Economizer 1.49 extra bank of tubes placed in a boiler to absorb more heat and increase the economy of the boiler

Steam and power plants serve industry by transforming energy from one form into another. That is, from fuel to steam to electricity. By the process of combustion, the chemical energy of the fuel is converted into thermal energy, then into mechanical energy, and possibly into electrical energy for many services within an industrial or utilities plant.

This Unit on basic power plant operation will acquaint you with the operational and maintenance requirements of steam power plants in general. In this Unit the development of a modern steam power plant is traced from its basic concept to its present form.

This Lesson describes and illustrates the basic principles of making steam and the basic components of a steam boiler. How various arrangements and additions of equipment improve a power plant system are explained one step at a time.

Whatever your job, the knowledge gained from this Unit will be valuable, because it will help you understand how a power plant functions.

Energy for Power Plants

1.01 When man learned to use fire and put vessels of water over it, he observed the steam-making process. More than 2,000 years ago, ingenious inventors designed simple mechanical methods of using steam power. Large scale use of steam-driven machinery did not begin until underground mines in Europe flooded because of a lack of power-driven pumps. The Industrial Revolution in the early 1800s led to the use of the steam engine, which was made to drive industrial machinery.

1.02 During the next 140 years, two significant but apparently unrelated developments occurred. Scientists learned about electricity and engineers designed the modern steam turbine. Early in this century, the steam turbine was used to generate electricity. One improvement followed another as the use of electricity doubled during each ten year period.

1.03 A steam power plant converts the potential energy of fuels into other forms of energy for everyday use. The term “potential energy’’ means the energy is in the fuel, waiting to be used. The energy in wood fuel is stored during the life of the tree. The buried fuels, coal, oil and gas, which are also called fossil fuels, have been waiting to be used for millions of years.

1.04 How did the energy get there? By the growth of green living plants. The green material, chlorophyll, allows a plant to use carbon dioxide from the air, water from the soil, and sunlight to synthesize complex chemical molecules such as sugar, starch and cellulose. These molecules are body building materials and stored energy. Non-green living things, including man, depend on the green plants for body building materials and energy. The chemistry of body building is very complex. The chemistry of energy use is easier to understand because it is the exact opposite of green plant synthesis. Oxygen in the air converts complex molecules into carbon dioxide (CO_2) and water (H_2O) and the stored energy is released.

1.05 The fossil fuels are believed to have been formed when plants were buried in the earth before decaying. They were subjected to pressure and heat. Then chemical changes occurred. The coal, oil, and gas that were formed retained much of the stored energy.

1.06 The energy originally came from the sun. In living bodies the use of air to release energy is called *respiration*. In the boiler at a steam power plant the same process is called *combustion*.

1.07 A boiler contains water. The energy released as heat by the process of combustion changes the water to steam. When the steam is used to drive a turbine, heat energy becomes mechanical energy. As the turbine turns the shaft of an electric generator, the energy becomes electricity for household and industrial use.

Converting Energy to Electricity

1.08 An illustration of a simple but inefficient boiler and turbine is shown in Fig. 1-1. The teakettle represents the boiler and the little windmill is the turbine. Real boilers and turbines are more complicated, but the principle is the same.

1.09 Also illustrated in the sketch in Fig. 1-1 is an electric generator. Early experiments with magnetism and electricity showed that when a magnet is rotated inside a coil of wire, an electric potential is generated in the coil. That potential causes electricity to flow through a light bulb, heating the filament, which gives off light. Thus, another form of energy came from the fuel, which originally came from the sun.

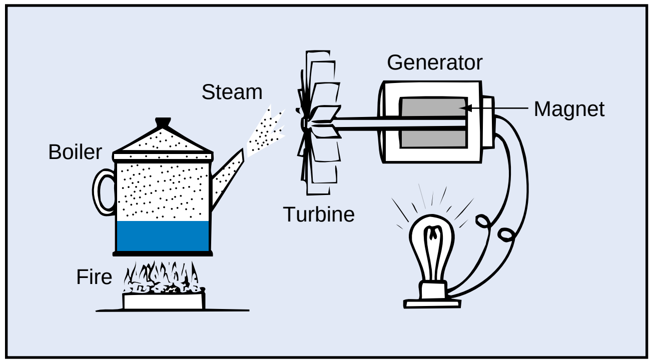
1.10 A magnet placed next to iron filings shows that an invisible field of force extends around the magnet, as shown in Fig. 1-2. When this field is moved at right angles to a wire, or a wire is moved at right angles to the field, an electric potential is generated in the wire. The magnet and the wire do not touch. In an actual generator the moving and stationary parts are so designed that an electric potential of several thousand volts can be generated.

1.11 For now you need only understand the basic concepts of electric power generation. The sun's energy is stored in fuels. Fuel burned in a boiler releases the energy as heat. Heat changes water to steam, which drives a machine called a *turbine*. As the turbine rotates on a shaft, the shaft moves a magnet at right angles to a coil of wire, thus generating electricity.

1.12 Although the simple power plant illustrated in Fig. 1-1 will not be seen in a modern, complex steam-turbine-electrical generating plant, the operating principles are there. The use of steam power in industry began when James Watt experimented with the steam engine. Many years passed before the steam turbine appeared. Since early in the 20th century, steam turbine generating equipment has become more complex and efficient. The use of electric power has doubled every ten years.

1.13 Fifty years ago a steam turbine electric power plant required more than three pounds of coal to produce one kilowatt-hour of electricity. Today, the national average is less than one pound of coal per kilowatt-hour. (A kilowatt-hour means using 1000 watts of power for one hour).

Fig. 1-1. Simple representation of boiler, turbine, and generator



1.14 This great increase of converted energy per pound of fuel is due to the gradual improvement of the power system, in both the types of equipment and the system as a whole.

The Importance of Air in Combustion

1.15 How is the operation of the system in Fig. 1-1 improved? Note how the fire under the boiler involves the fuel, the method of placing the fuel under the boiler, and the arrangement for burning the fuel properly. To better illustrate this, the diagram is extended, as illustrated in Fig. 1-3.

1.16 Figure 1-3 shows coal being transported by a belt conveyor to a hopper from which it drops onto a traveling grate stoker. The coal burns here when combustion air is supplied by a bellows.

1.17 The chemical reaction at the fire is combustion. The coal is heated to its ignition temperature in the presence of air. The carbon in the coal combines with the oxygen in the air and forms two carbon-oxygen compounds, carbon dioxide (CO_2) and carbon monoxide (CO). Both compounds are gases. The relative proportions of the two products depend upon the quantity of oxygen available and the effectiveness of the air and fuel mixture. When there is a significant amount of carbon monoxide present. the coal has burned only partially. When ample oxygen is available, the carbon monoxide reacts further to form carbon dioxide and releases more heat energy. It is always desirable to convert all the carbon into

Fig. 1-2. Iron filings reveal presence of magnetic field

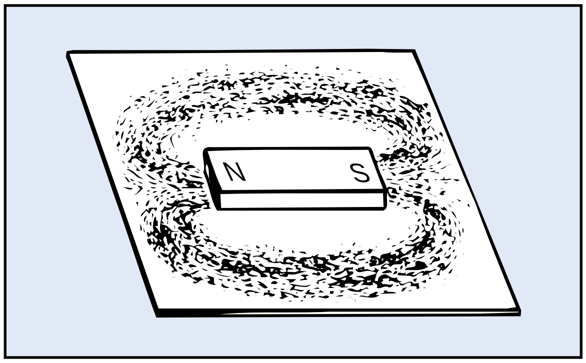
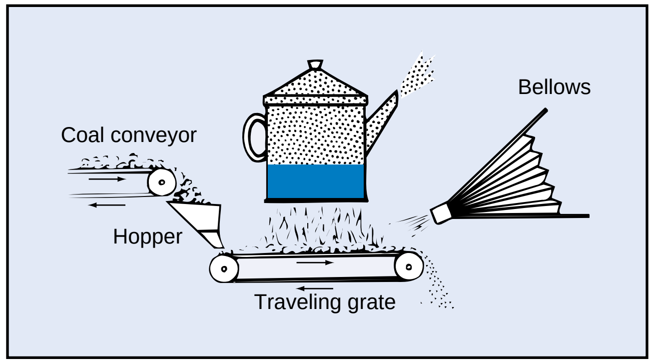


Fig. 1-3. Belt conveyor transporting coal to the furnace



carbon dioxide to obtain the maximum energy from the fuel.

1.18 Careful control of the air supply is very important. When the air supply has more oxygen than is actually needed to combine with the combustible components of the fuel, the excess oxygen will carry away energy that otherwise could be used to heat the water in the boiler. However, some excess air is necessary to ensure complete mixing and complete combustion.

1.19 In actual practice a little more air than the exact amount required is supplied. This extra air is commonly referred to as "excess air." The gases leaving the boiler are chemically analyzed to determine the amount of air to be supplied to the boiler.

1.20 Boiler operation involves materials handling problems. Theoretically, each pound of coal requires about 11 pounds of air. Approximately 80 percent of the air is nitrogen. Only about 20 percent is the oxygen needed for combustion. Large volumes of flue gas containing nitrogen, carbon dioxide, excess air, usually sulfur oxides from the coal, water vapor, and solid and liquid particles carried along as smoke leave the boiler through the stack. Ashes are removed from the bottom.

Removing Ashes and Flue Gases

1.21 Ashes and flue gases must be removed continuously from the boiler. Ash removal in the days of hand firing was simple but laborious. The fireman raked the ashes from the ashpit and carried them away in wheelbarrows. Ash removal had to be mechanized. So ash removal equipment and a chimney or stack for the removal of flue gases are added to the sketch, as shown in Fig. 1-4.

Heating the Air

1.22 Figure 1-4 contains another additional feature, the air heater. For combustion to occur the temperature in the burning zone must be kept above the ignition temperature of the fuel. The air delivered to the fire should be preheated to help maintain a high temperature in the furnace. Note that an air heater is attached to the bellows in the sketch.

1.23 How can the air be preheated? A candle is used as an example in Fig. 1-4, but this is not a practical method. There has to be some way to use heat

Fig. 1-4. Addition of chimney or stack, air heater, and ash conveyor

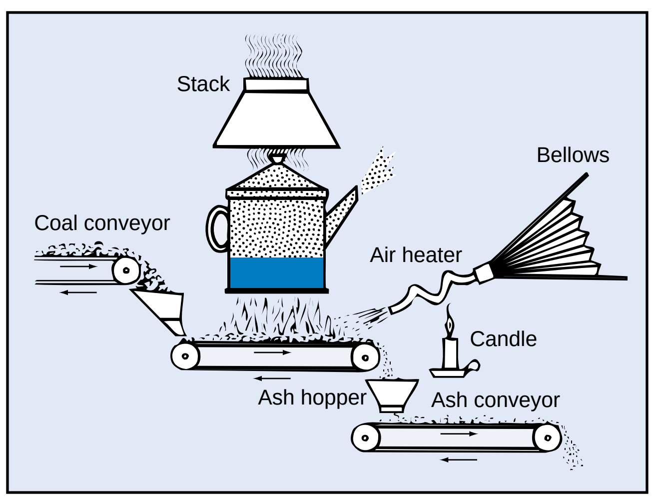
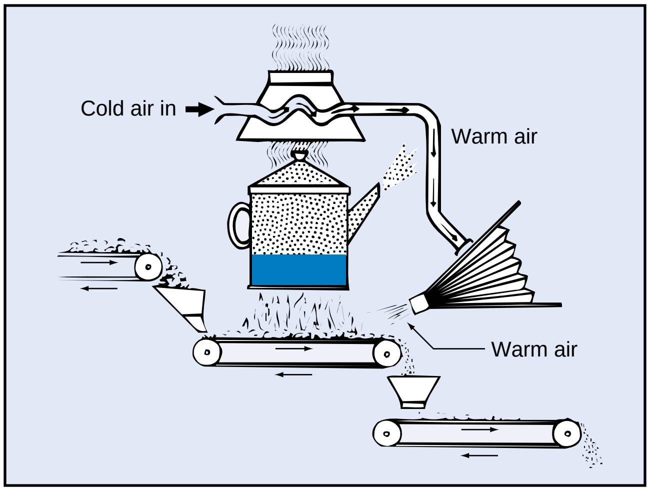


Fig. 1-5. Air heating coil in the stack



from the fire under the boiler to heat the air. Actually, there is a way to use heat that would otherwise be lost.

1.24 The hot flue gases go up the stack to waste. Figure 1-5 shows a heating coil placed in the stack and the bellows blowing air from the coil onto the fire. This system accomplishes a basic concept in the development of steam power—*do not waste heat*.

1.25 The preheating of air with hot flue gases seems simple, and it is. The reason for emphasizing preheating of the air in this way is to show with simple illustrations how engineers have tried to improve the efficiency of the system. Through a step by step process, engineers added something here, saved something there, and improved systems evolved. Power generation engineers have designed large plants that seem enormously complex. Much of the complexity disappears when the simple basic principles and sketches used here are remembered.

1.26 There are more specific engineering problems, of course. In the example just described, certain questions arise, such as, just how much heat exchange surface should the stack heater have to extract the maximum amount of heat? Is it possible to extract too much heat from the flue gases?

1.27 Consider the last question about removing too much heat from the flue gases. What will happen? The answer involves at least three facts that may seem, at first, to be unrelated to each other.

1. There is always a certain amount of water vapor in the flue gases, the air, and the fuel.

2. As the temperature of the gases is lowered, the moisture condenses to liquid water.

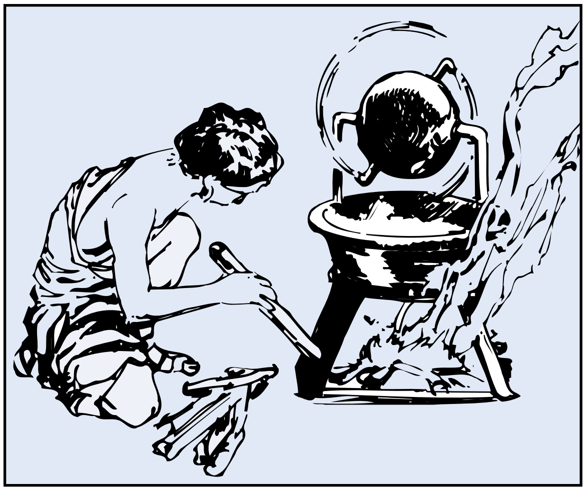
3. When there is sulfur in the fuel as there usually is, sulfur oxides form during combustion. Sulfur oxides plus condensed water form corrosive acids that damage metal and masonry parts wherever the temperature falls below the point of dew formation.

1.28 This single example is only one of many that reveals what the engineer encounters when he begins to refine the simple system with which we began. He may add something to improve it, only to find that the improvement causes other problems.

The Programmed Exercises on the next page will tell you how well you understand the material you have just read. Before starting the exercises, remove the REVEAL KEY from the back of your Book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

1-1. The fossil fuels are coal, ________, and ________.	1-1. OIL, GAS Ref: 1.03
1-2. The energy stored in fossil fuels came originally from ________.	1-2. THE SUN Ref: 1.06
1-3. The use of air to release stored energy in the bodies of people and animals is the process called ________.	1-3. RESPIRATION Ref: 1.06
1-4. In a boiler the heat energy of combustion changes ________ to ________.	1-4. WATER; STEAM Ref: 1.07
1-5. For combustion to occur in a boiler, it must be supplied with ________ and ________.	1-5. FUEL, AIR Ref: 1.16, 1.17
1-6. In an ideal combustion process, all of the carbon would be converted to ________.	1-6. CARBON DIOXIDE Ref: 1.17
1-7. Ash removal was formerly done manually, but is now done ________.	1-7. MECHANICALLY Ref: 1.21
1-8. The air preheater heats the incoming air with heat from the ________.	1-8. FLUE GASES Ref: 1.22-1.25

Fig. 1-6. An early device for using the power of steam



Boiler Design

1.29 The teakettle representing the boiler is only symbolic of the steam-generating part of the power plant. However, the design of a real boiler or steam generator involves the same basic principles.

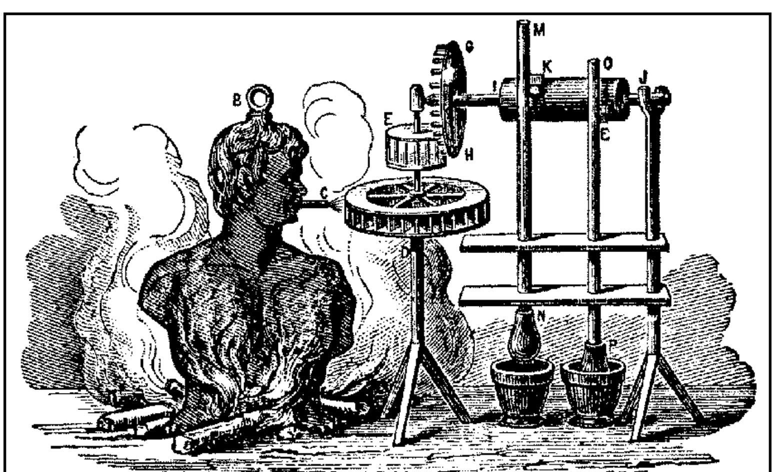
1.30 Actually, the teakettle is a reasonable representation of early steam boilers which were pots for holding the water. There is an interesting legend that James Watt observed the power of steam coming from the spout of his mother's teakettle, which led to his inventing the steam engine. History records earlier examples of interest in steam and in the methods of application.

1.31 In 200 B.C. a man named Hero made a fire under a cauldron of water. The steam was conducted by two tubes to a hollow ball, as shown in Fig. 1-6. The ball was pivoted at both side supports and had two discharge tubes, each bent at an angle. As steam issued from the bent tubes, the reaction force turned the ball. Many years later, in 1629, an Italian named Branca actually anticipated the boiler-steam turbine combination that is a major source of power today. This concept is illustrated in Fig. 1-7.

1.32 After the time of James Watt, the piston-type steam engine became the important steam-driven machine. Extensive use of the turbine did not re-emerge until the 20th century. However, the many uses of the steam engine for driving factory machines, locomotives, ships and farm machinery inspired the design of boilers that were more than just a pot of boiling water. There was a need for more metal surface through which heat from the fire could reach the water. One solution was to have metal tubes going from the firebox through the pot, so hot gases traveled in the tubes to the stack. Boilers of this design are called fire-tube boilers.

1.33 When the tubes extend upward from the firebox, the design is a vertical fire-tube boiler, as shown in Fig. 1-8. In a locomotive boiler, and a few still exist, the fire tubes extend forward toward the stack on the front end, as in Fig. 1-9. Industrial plant boilers, as illustrated in Fig. 1-10 on page 12, were often made with the steel cylinder pot lying on its

Fig. 1-7. Branca's steam turbine



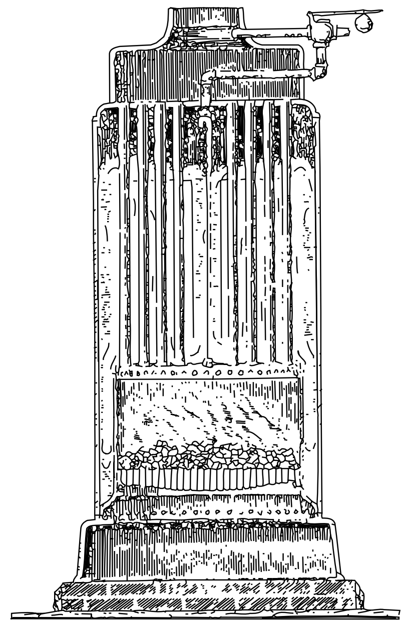
side and supported by brick work. In this type of boiler the tire traveled underneath the cylinder to the rear and returned through fire tubes to the breeching in the front. These were called horizontal return tube boilers.

1.34 At first the basic weakness of this type of boiler was the pressure exerted on the large steel shell of the pot. Steam pressure pushed on every square inch of the inside surface. Years ago the shell was usually made with steel sheets lapped over and riveted at the seams. The design severely limited the pressure of the steam to be produced. The engineers and boilermakers had to find an answer to the problem, and they did.

1.35 The engineers put the water in the tubes and the fire outside. Now the cylinder holding the water has a diameter of two or three inches instead of several feet. Each linear foot of tube has only a few square inches of internal surface for the steam to press against. So the steam pressure can safely be allowed to go much higher. The water-tube boiler has become the standard design for power generation.

1.36 Manufacturing, erection, and maintenance methods had to change, and like the changes in any industry, the process was gradual. At first the tubes were straight, as in Fig. 1-11 on the following page, since these were easier to make and clean out with tools when scale formed inside, as in the teakettle. The tubes were connected to headers at each end and

Fig. 1-8. Vertical fire-tube boiler



sloped upward to allow the steam to rise. A cylinder was needed to provide space for the steam to collect and separate from the water, but the cylinder problem did not disappear. This cylinder could be smaller than the shell of the fire tube boilers, and the wall thickness could be increased. Improved welding methods were used to make smooth welded seams instead of riveted lap seams.

1.37 The next significant change was switching from straight tubes to bent tubes, which allowed more flexibility in their arrangement. Since this is

Fig. 1-9. Locomotive boiler

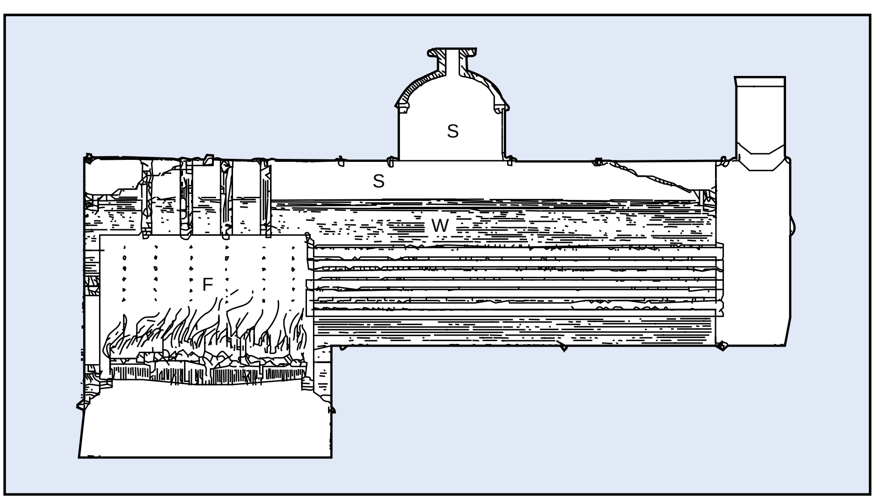
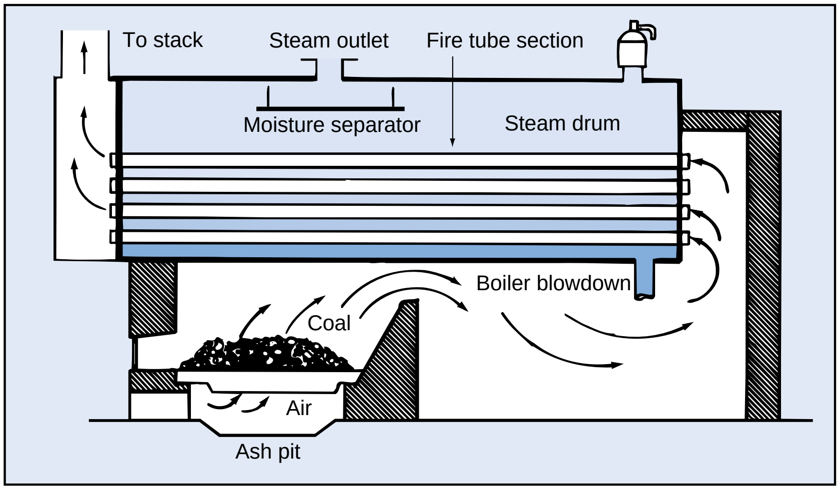


Fig. 1-10. Horizontal return tube boiler



still the basic design of power boilers, it is shown in Fig. 1-12. Note the two steel drums. The upper drum collects steam and the lower drum allows the water to circulate. The water tubes extend between the two drums and are positioned in the furnace so they are directly exposed to the fire. The hot gases from the fire travel through the bank of tubes on the way to the stack.

1.38 Some of the heat from the fire is in the form of radiation which is known as sunlight and infrared waves. Like the sunlight, the fire radiation is absorbed by whatever material is in its path, in this case the first row of water tubes. The other rows of tubes absorb heat from the flowing gases. Heat carried by the hot gases is called *convection* heat. The tubes in the path of the hot gases are called the *convection section* of the boiler. Heat goes through each tube wall to the water by the process of *conduction*.

1.39 As boiler design has developed, more tubes have been added around the furnace walls to enlarge the surface exposed to radiation, as in Fig. 1-13. They are called *water walls*. The terms "radiant section" and "convection section" or "convection pass" are commonly used in talking about boilers. It is

Fig. 1-11. Water tube boiler with straight tubes

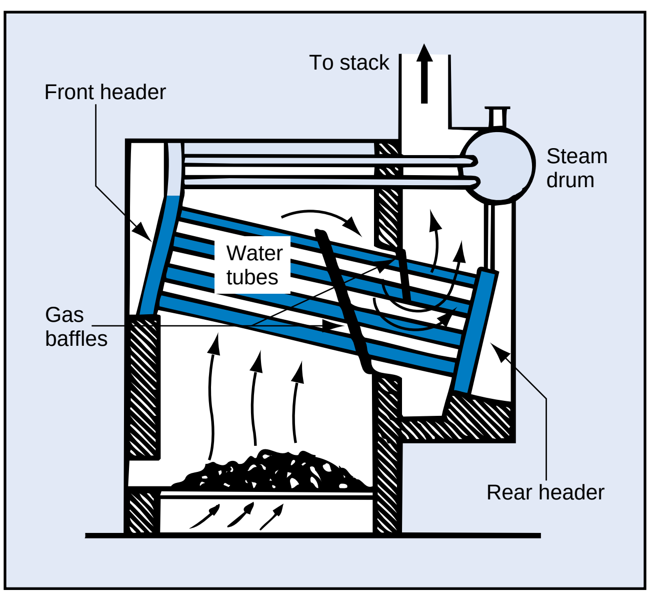
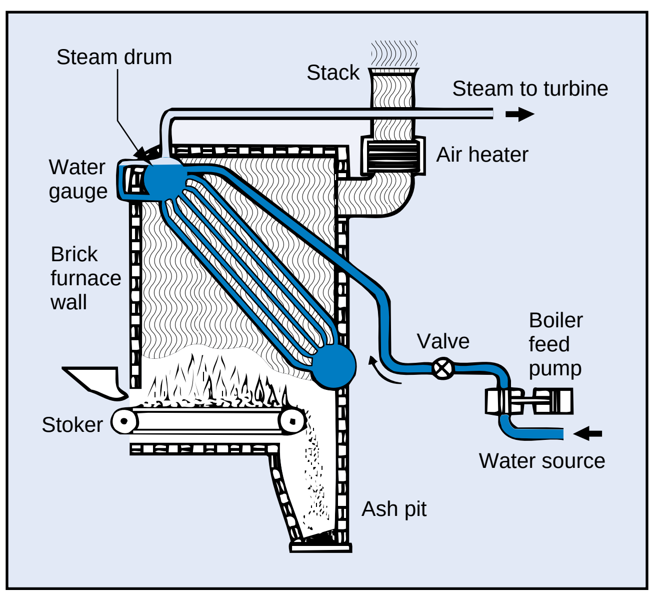


Fig. 1-12. Bent-tube, two-drum boiler



helpful to know the meanings, but the diagrams in this lesson will be kept simple. In Fig. 1-12 note that the steam collects in the upper drum and travels to the turbine through a main steam line. As steam leaves the boiler, a boiler feed pump adds an equivalent amount of water. The boiler feed pump must overcome the boiler pressure to force the water into the upper drum.

Controlling the Water Level

1.40 In the operation of any boiler a minimum level of water must be maintained in the upper drum. This ensures that the tubes exposed to the fire are always filled with water. The water absorbs the heat from the fire and changes into steam, thus keeping the tubes from overheating. Otherwise, the temperature would approach the melting point of the metal, and the tubes would burst from the internal pressure. However, the water level should not be so high in the drum that the water will be carried along by the departing steam. This would cause severe damage to the turbine blades. So the water level can be constantly observed, a transparent viewing glass is fitted to the steam drum, as shown in Fig. 1-14 on the following page.

1.41 When the amount of water entering the boiler is equivalent to the amount of steam leaving, the water level remains the same. However, variations in power demand cause variations in the steam flow, the fuel supply, the rate of combustion, and the rate of evaporation. All these variations cause changes in the water level. Before present automatic controls these varying and unpredictable conditions required the boiler operator to constantly watch the water level. When the water level dropped, he had to carefully open the feedwater control valve; when the level rose, he closed the valve by the necessary amount.

1.42 This constant vigilance by operators was subject to human error, and boiler accidents resulted. There was a need to develop feedwater regulators to control the water flow automatically as the water level in the boiler steam drum rose and fell. If the water supply was accidentally stopped while the fire continued to burn, the boiler would run dry in a few minutes. The feedwater regulators for large, modern, high-pressure boilers must be as foolproof as engineering skills can make them, for reasons of safety and because they protect millions of dollars worth of equipment.

Fig. 1-13. Bent tube boiler with water walls

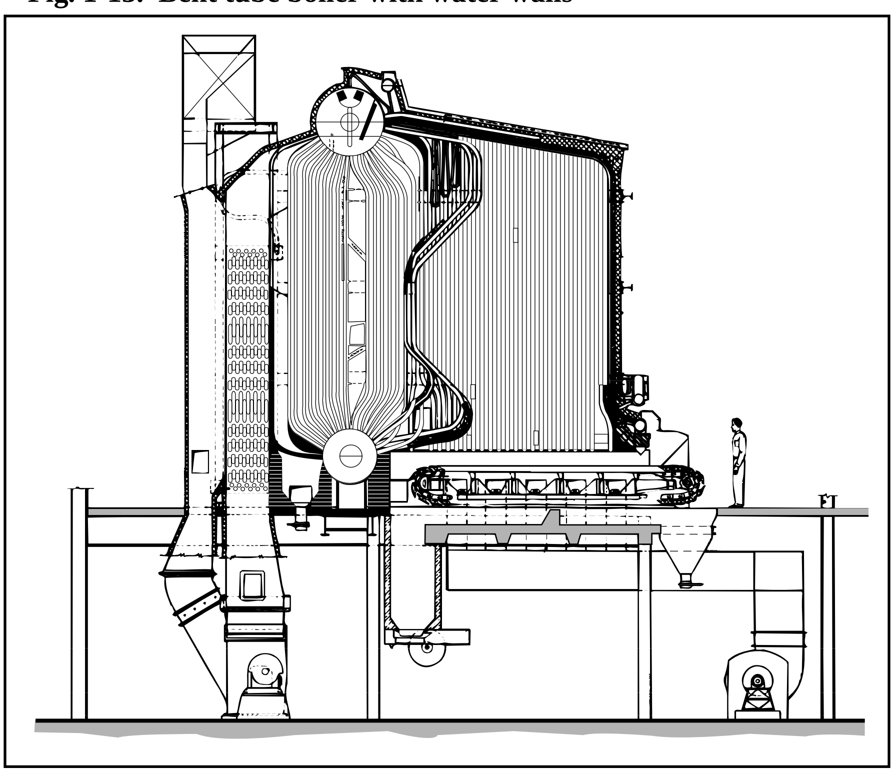


Fig. 1-14. Feedwater control

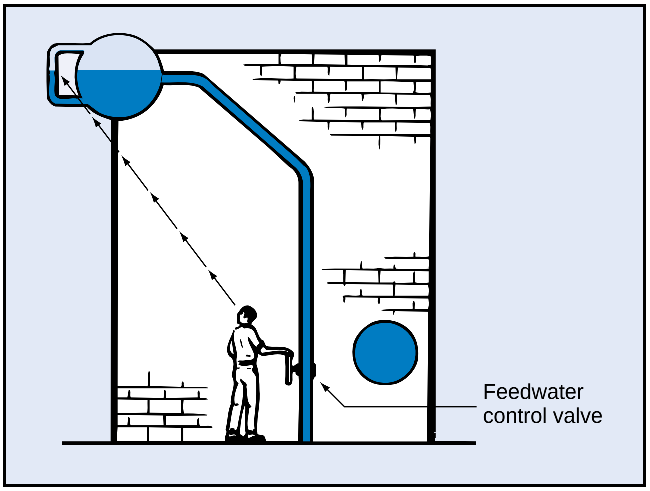
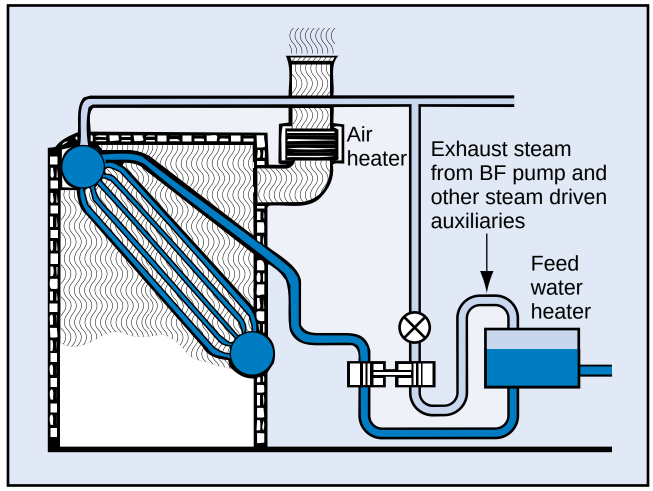


Fig. 1-15. Feedwater heating



Feedwater Heater

1.43 It is unwise to pump cold water into a hot boiler. To do so would lower the temperature of the water in the boiler and reduce the rate at which steam is made.

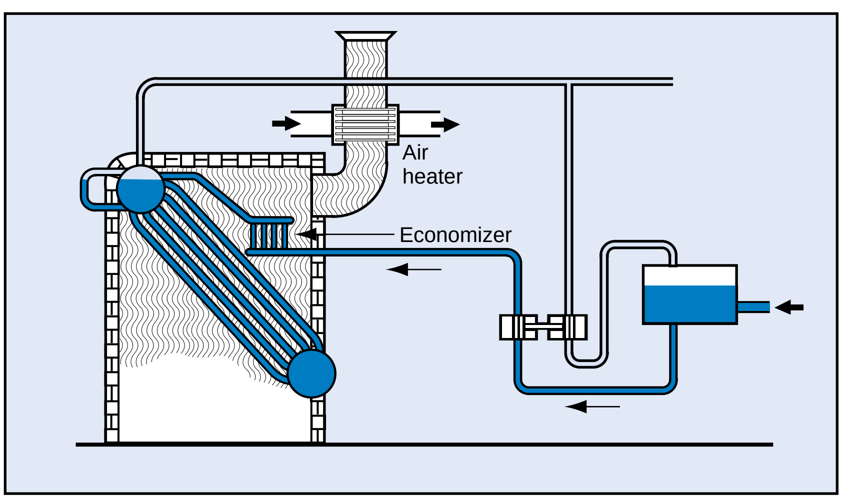
1.44 Also, because of the considerable temperature difference between the hot and the cold water, thermal expansion-contraction stresses in the boiler structure might be set up. Therefore, the water must be heated to nearly boiler water temperature before it is pumped into the boiler. The cold water is first pumped through a feedwater heater.

1.45 The feedwater heater could be heated by a separately fired furnace, but, as in the case of the air heater, it is more economical to use heat that would be wasted. For example, if the boiler feed pump is a steam-driven pump, the exhaust steam can be used to heat the water. This costs almost nothing. So, a heater, shown in Fig. 1-15, is added. Again, this sketch only illustrates the concept. The feedwater can also be heated by other methods.

1.46 The sketch in Fig. 1-15 shows a line from the feedwater pump to the feedwater heater, called an open heater, which in this case is a tank. In the tank steam comes in direct contact with the water. The open feedwater heater is one example of how energy has been saved by using heat which otherwise would have been wasted.

1.47 Closed heaters, in which steam and water do not come into direct contact, are also used in power

Fig. 1-16. The economizer



plants. Closed heaters operate at pressures above atmospheric pressure. Some heat is salvaged from the flue gases by the air heater. There are also other more specialized heat-saving methods.

The Economizer

1.48 Another method of saving heat is to modify the boiler by setting aside one section of the tubes to heat the water after it passes through the feedwater heater, but before it is delivered to the boiler, as in Fig. 1-16.

1.49 Here a separate bank of tubes is added through which the feedwater passes before it goes into the boiler drum. The bank of tubes is placed in the path of the gases traveling towards the air heater and the stack. Much of the heat from the fire has been absorbed by the boiler tubes, but not all. The exit gases still have a temperature of about 600°F (316°C). By placing the extra tube bank in the path of the gases, more heat is absorbed; and consequently, the economy of the boiler is increased. This bank of tubes is known as an *economizer*.

1.50 With this arrangement, the water in the open feedwater heater can be heated to a temperature of about 212°F (100°C) by the waste steam from the feed pump and other services or auxiliaries. The economizer raises the temperature of the feedwater so it approaches the temperature of the water in the boiler. The next lesson explains what happens to the steam after it leaves the boiler through the high pressure steam line.

1-9. The demand for steam grew as more uses were found for the ________.	1-9. STEAM ENGINE Ref: 1.32
1-10. Four boiler tube designs that are used in steam generating units are ________, ________, ________, and ________.	1-10. VERTICAL FIRE, HORIZONTAL RETURN, STRAIGHT WATER, BENT, WATER-COOLED Ref: 1.33, 1.39
1-11. The standard design for power generation is the ________ steam boiler.	1-11. WATER-TUBE Ref: 1.35
1-12. Heat carried by the hot gases in a boiler is called ________ heat.	1-12. CONVECTION Ref: 1.38
1-13. The water level in a modern boiler drum is controlled by an automatic ________.	1-13. FEEDWATER REGULATOR Ref: 1.42
1-14. To prevent thermal stress in the boiler, the feedwater going to the boiler must be preheated to nearly ________ temperature.	1-14. BOILER WATER Ref: 1.44
1-15. Closed feedwater heaters operate at pressures above ________ pressure.	1-15. ATMOSPHERIC Ref: 1.47
1-16. To save heat, the water passes through a feedwater heater and then through an ________.	1-16. ECONOMIZER Ref: 1.48, 1.49

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. What kind of energy is stored in fuels?

- ☐ a. Electrical
- ☐ b. Heat
- ☐ c. Light
- ☐ d. Potential

1-2. Which of the following is a fossil fuel?

- ☐ a. Gas
- ☐ b. Sunlight
- ☐ c. Water
- ☐ d. Wood

1-3. Which of the following is directly involved in producing energy in a steam power plant?

- ☐ a. Air
- ☐ b. Carbon monoxide
- ☐ c. Inorganic material
- ☐ d. Light

1-4. In this century, the rate of consumption for electricity has doubled every _______ years.

- ☐ a. 5
- ☐ b. 10
- ☐ c. 15
- ☐ d. 20

1-5. The main product derived from combustion is

- ☐ a. carbon compounds
- ☐ b. nitrogen
- ☐ c. sulfur compounds
- ☐ d. water vapor

1-6. What is the percentage of oxygen in the air?

- ☐ a. 10%
- ☐ b. 20%
- ☐ c. 33%
- ☐ d. 50%

1-7. Heat for preheating the combustion air in a boiler comes from the

- ☐ a. deaerator
- ☐ b. economizer
- ☐ c. feedwater heater
- ☐ d. flue gases

1-8. Which of the following conditions contributes to corrosion by flue gases?

- ☐ a. Combustion
- ☐ b. Condensation
- ☐ c. Heat
- ☐ d. Presence of carbon

1-9. Heat that is carried by the hot gases in a boiler is called ________ heat.

- ☐ a. ambient
- ☐ b. conduction
- ☐ c. convection
- ☐ d. induction

1-10. Which device improves the efficiency of a boiler?

- ☐ a. Ash conveyor
- ☐ b. Boiler feed pump
- ☐ c. Economizer
- ☐ d. Moisture separator

SUMMARY

The energy used in today's power plants is derived from fossil fuels such as coal and oil. The potential energy of these fuels is converted to mechanical energy when it is burned in a boiler. The boiler converts water to steam, which drives a turbine that is usually connected to an electric generator.

Air supplied to a fuel creates the chemical reaction called *combustion*, which causes the fuel to burn. It is important to supply fuel with a specific proportion of air to ensure proper combustion without wasting potential energy.

Combustion also creates ashes and flue gases, which must be continuously removed from the boiler. Flue gases are a valuable source of heat that can be reused to warm the air being added to the boiler.

Boiler design has evolved through the years from the early vertical fire tube type, in which the steam tubes extended upward from the firebox. In the horizontal return tube boiler, the tubes lay on their sides. The type of boiler most commonly used today is the water tube type.

The efficient operation of a boiler is dependent upon several factors. Just as the air intake of the boiler must be controlled, water level must be maintained in the tubes so that they do not burn up in the heat of the fuel; conversely, the water must be converted to steam at a rate that ensures no water will enter the turbine in liquid form.

A feedwater heater improves the efficiency of the boiler by preheating the water before it enters the hot boiler tubes. Once again, the source of the heat can come from exhaust steam, which otherwise would be wasted. Another option is to add an *economizer*, which is an extra bank of tubes set into the path of the hot flue gases to further heat the water before it enters the boiler.

Answers to Self-Check Quiz

1-1. d. Potential. Ref: 1.03

1-2. a. Gas. Ref: 1.03

1-3. a. Air. Ref: 1.06

1-4. b. 10. Ref: 1.12

1-5. a. Carbon compounds. Ref: 1.17

1-6. b. 20. Ref: 1.20

1-7. d. Flue gases. Ref: 1.24, 1.25

1-8. b. Condensation. Ref: 1.27

1-9. c. Convection. Ref: 1.38

1-10. c. Economizer. Ref: 1.49

Contributions from the following sources are appreciated:

Figure 1-7.	Cornell University Press
Figure 1-8.	Cornell University Press
Figure 1-9.	Cornell University Press
Figure 1-13.	Riley Stoker Corp.