Watertube Boilers

Learning Outcome

When you complete this module you will be able to:

Describe various watertube boiler designs, including large generating units.

Learning Objectives

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

1. Describe early designs and construction of watertube boilers.

2. Sketch and describe the design and construction of packaged watertube boilers.

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

INTRODUCTION

The watertube boiler differs from the firetube design in that the tubes contain water rather than combustion gases. In the watertube boiler, the combustion gases travel over the outside surfaces of the tubes and transfer their heat to the water within the tubes.

WATERTUBE BOILERS

Longitudinal Straight Tube Boilers

Fig. 1 illustrates one of the earliest straight tube boilers. The drum runs longitudinally in relation to the tubes. The straight inclined tubes run between vertical headers at the front and rear of the drum; these headers are connected to the drum at their top ends. The combustion gases make three passes across the tubes as indicated by the arrows in Fig. 1.

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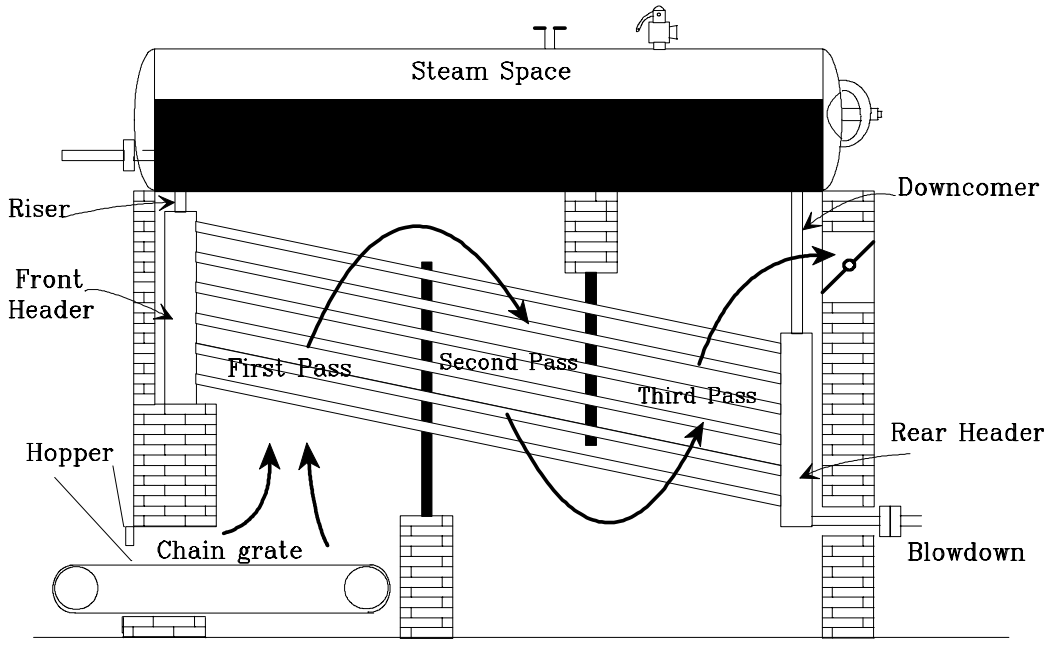

Figure 1
Straight Tube Design (Longitudinal)

The water circulates from the water space of the drum down the rear header, up the inclined tubes (at an angle of 15° to the steam drum), to the front header, and then back up to the drum.

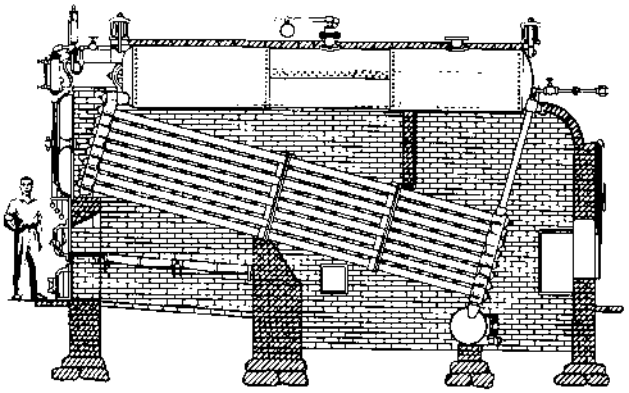

Figure 2
Babcock & Wilcox Boiler (1877)

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The early boiler shown in Fig. 2 had an elaborate setting. The brickwork structure serves to enclose the furnace and pressure parts of the boiler, and also forms a passage through which the combustion gases flow.

This type of boiler is suitable for pressures up to 2240 kPa and steam capacities up to 36 000 kg/h. Some of these boilers are still in service today, but none are being built for industry.

Fig. 3 illustrates a later design to increase the steam temperature of the longitudinal drum straight tube boiler by the installation of a superheater.

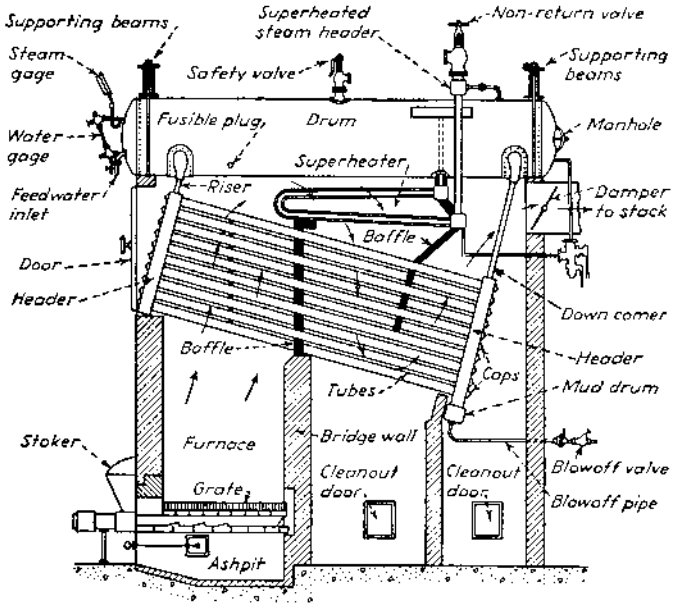

Figure 3
Longitudinal Drum-Boiler with Superheater

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Cross Drum Straight Tube Boiler

Another early watertube design has inclined straight tubes with the drum at right angles to the tubes (cross drum). The water circulates down to the rear headers from the drum, up the inclined tubes to the front headers and then back to the drum.

The cross drum has been built for capacities up to about 230 000 kg/h of steam and for pressures up to 10 000 kPa.

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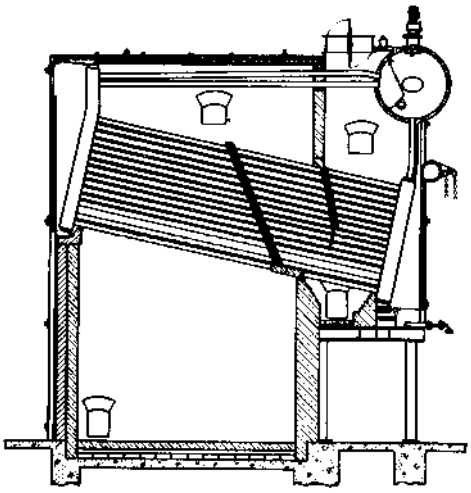

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Figure 4
Cross Drum Design

Its capacity can be much greater than the longitudinal drum type because, by lengthening the drum, more tube sections can be added thus increasing the heat transfer area. The number of tube sections used with the longitudinal drum type, however, is limited by the diameter of the drum.

While a great number of cross drum boilers are in use today, new boilers of this type are rarely installed.

BENT TUBE BOILERS

Watertube boilers of the bent tube design are capable of greater steam capacities, higher pressures, and greater versatility in arrangements such as floor space, head room, and more efficient use of the furnace. The furnace may be lined with watertubes (called a water-cooled furnace) to absorb more radiant heat from the fire. As well, the bent tube design permits more efficient use of superheaters, reheaters and other heat recovery components, and they can be built at lower cost.

Four-Drum Bent Tube Boiler

The four-drum boiler shown in Fig. 5 was the first bent tube type to be developed. It is known as the Stirling type and it features three upper drums and a lower mud drum. This early boiler was arranged for hand firing.

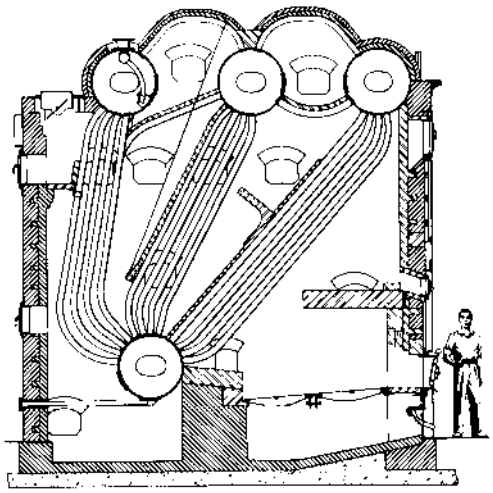

Figure 5
Four-Drum Boiler

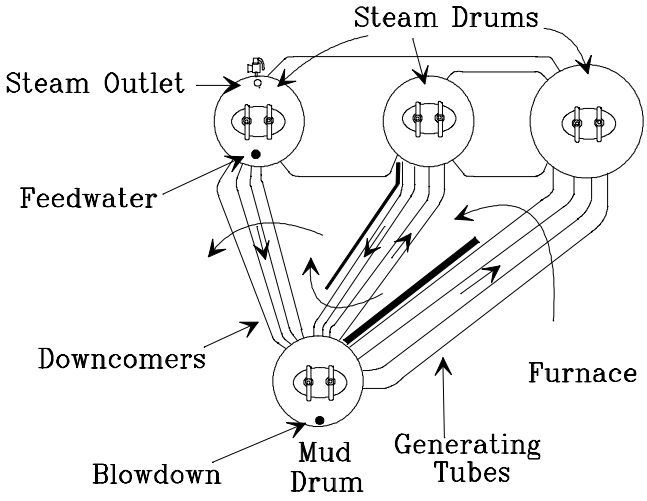

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Figure 6
Four-Drum Boiler

Three drums are connected by watertubes to the mud drum which is provided with a blowoff connection. The space above the water level in the three upper drums serves as a steam space and the three drums are interconnected by both steam and water circulating pipes.

The steam outlet is from the rear upper drum which has a safety valve and feedwater inlet connected. Water circulation is as illustrated in Fig. 6 and combustion gas is directed across the tube banks by means of brick baffles. Steelwork supports the three upper drums while the mud drum is freely suspended from the tubes. The furnace is constructed of brickwork and is not water-cooled. The capacity of this style of boiler is 45 000 kg/h of steam at 4820 kPa.

Three-Drum Bent Tube Boiler

This boiler is designed for areas where head room is limited. The space above the water level in the upper drum is steam space and both the steam outlet and feedwater inlet are located in this drum. The steam drum located on the right hand side is almost completely filled with water, i.e., there is only a small steam space. Crossover tubes connect the steam space and water space of the two upper drums.

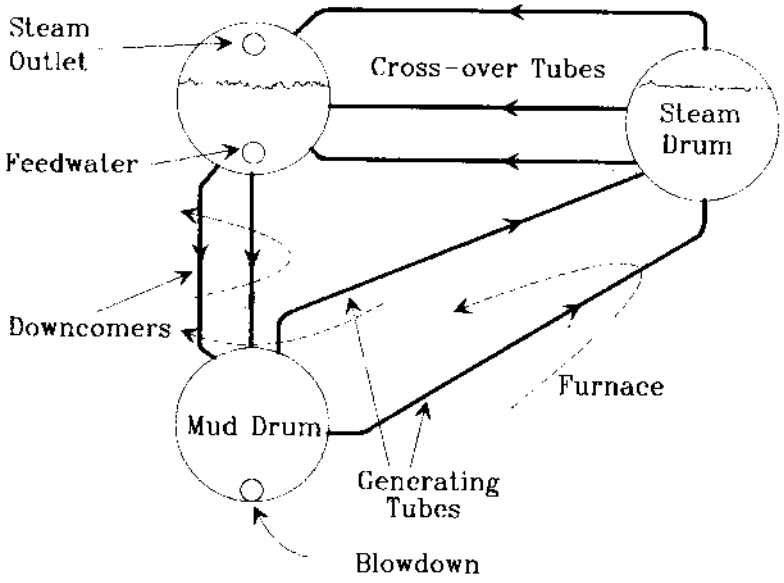

Figure 7
Three-Drum, Low-Head Boiler

The connection for the blowoff is made from the bottom of the lowest drum. The lowest drum hangs freely from the tubes while the two other drums are supported by steelwork. The furnace is constructed of brickwork and is not water-cooled. The boiler may be fired with oil, gas or coal.

Baffles are used to direct the hot gases. The water circulates through the downcomers from the uppermost drum to the lowest drum and then up the inclined tubes to the middle drum and from there to the upper steam drum. The capacity of this design is 18 000 kg/h at 3100 kPa.

Fig. 8 illustrates another type of bent tube three-drum boiler having two lower drums containing water and an upper drum containing steam and water. This boiler is very similar in construction to the previous boiler and is used in marine service as well as industrial plants.

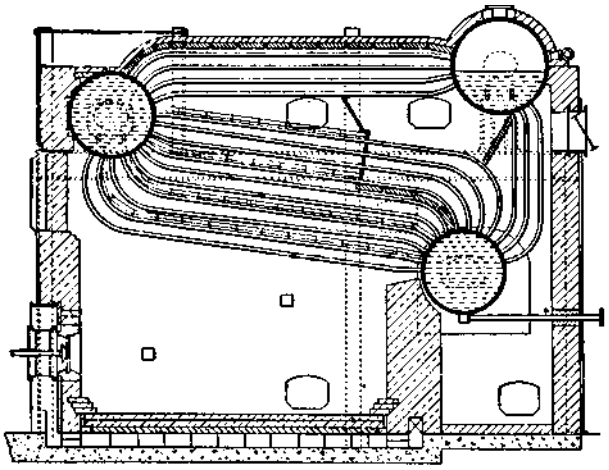

Figure 8
Three-Drum, Bent Tube Boiler

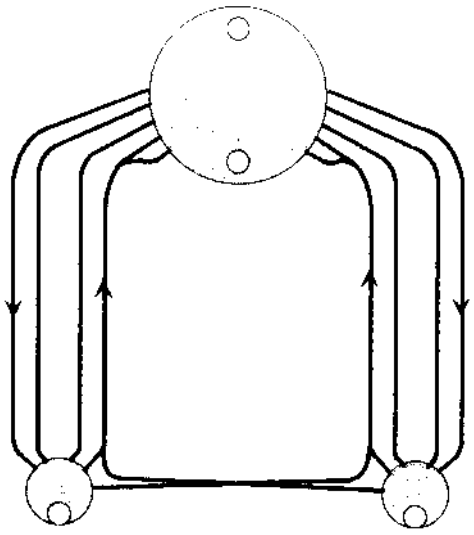

Figure 9
Schematic of Three-Drum "A" Boiler

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Two-Drum Bent Tube Boiler

An upper and lower drum are interconnected by a number of tube banks. The furnace is surrounded by water tubes, which is often referred to as an "integral-furnace" because the furnace tubes are an integral part of the water circulation circuit. The integral design, not restricted to the two-drum boiler, has advantages of allowing more compactness, greater heat transfer efficiency due to more tubes exposed to the radiant furnace heat, and higher overall boiler efficiency.

Coal, gas, and oil can be used as fuel, and the hot combustion gases from the fire are directed by means of baffles over the various tube surfaces, thus making two or three passes between the furnace and the uptake. See Fig. 10.

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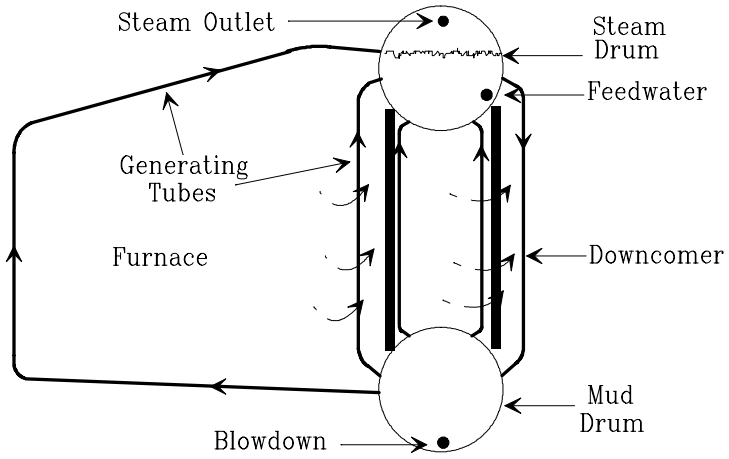

Figure 10
Two-Drum Vertical Boiler with Waterwall Furnace

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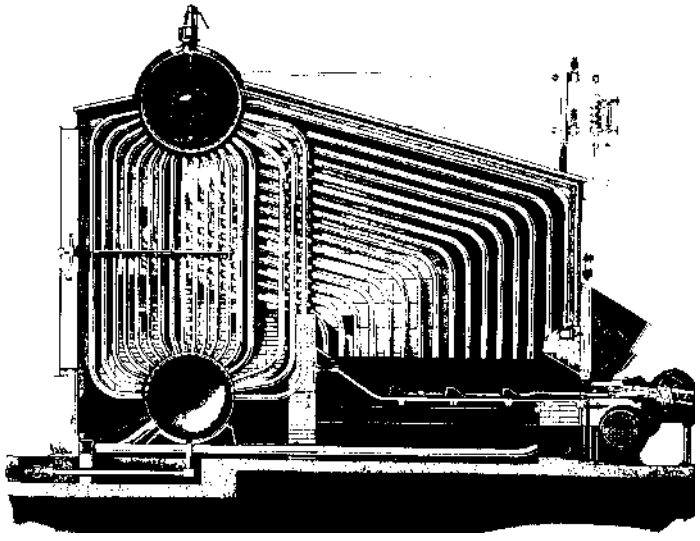


Figure 11
Two-Drum, Bent Tube, Integral Furnace Boiler

These boilers are suitable for medium-size industrial installations with capacities ranging from 4500 to 36 000 kg/h of steam, and pressures up to 3275 kPa.

PACKAGED WATERTUBE BOILERS

The bent tube watertube boiler is also produced as a packaged unit. That is, the boiler, burner, draft fan, feed pump, controls, and other accessories are all included as a unit and supplied by the boiler manufacturer.

These units have water-cooled furnaces, and the air for combustion is supplied under pressure from a forced draft fan. A steel casing covers the outside of the boiler and furnace, and prevents combustion gas leakage into the boiler room.

A simple skid-type steel foundation is included and the packaged boiler is bottom-supported. Bottom-supported means the mud drum is supported by a steel casing and the steam drum is supported by the tubes. The boiler is entirely built, assembled and tested in the factory before being shipped, thereby reducing the overall costs. Capacities range from 2300 to 45 000 kg/h of steam and pressure ranges from 1700 to 6200 kPa. A three-drum “A” packaged boiler is shown in Fig. 12. Bent tubes run from the upper drum to the two mud drums to form the furnace enclosure.

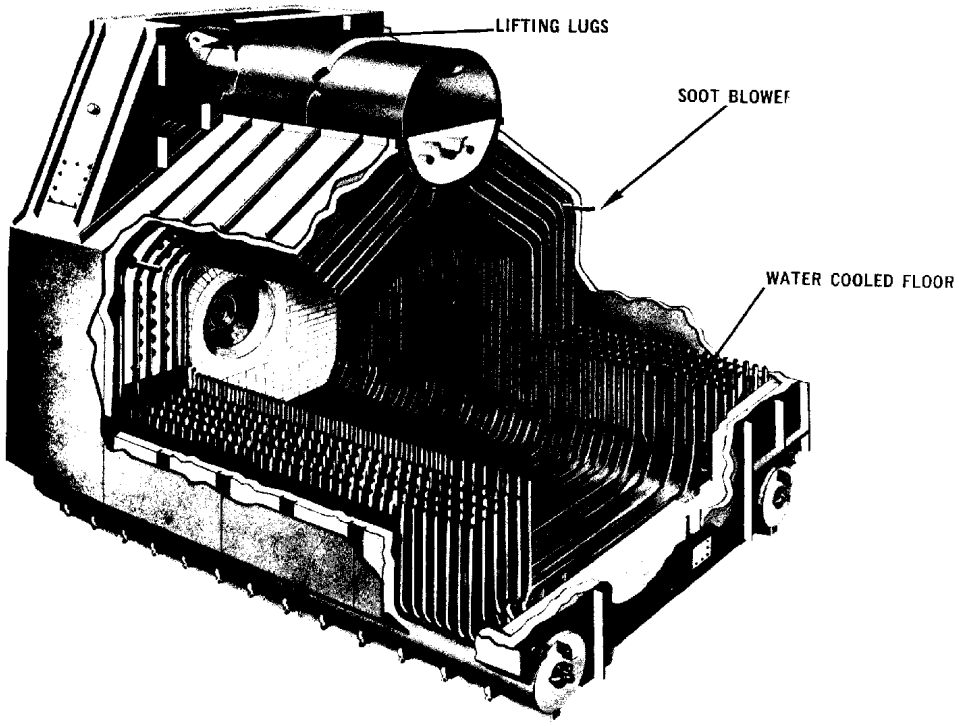
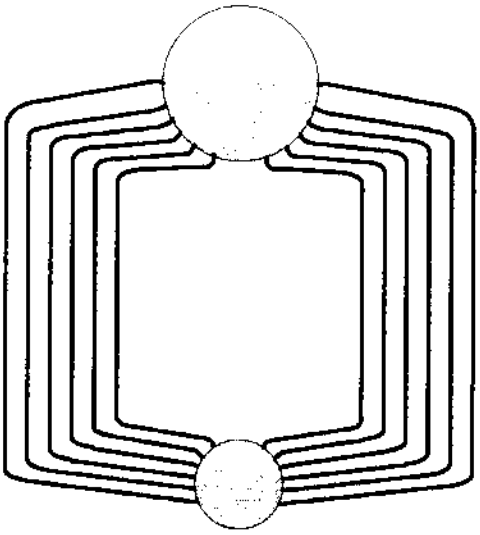


Figure 12
Packaged Watertube Boiler, "A" Type (Combustion Engineering))

The “O” type boiler, Fig. 13, has an upper and a lower drum. The tubes connecting these drums are arranged in an “O” shape to form a water-cooled furnace. Fig. 14 illustrates a superheater section as part of the packaged unit.



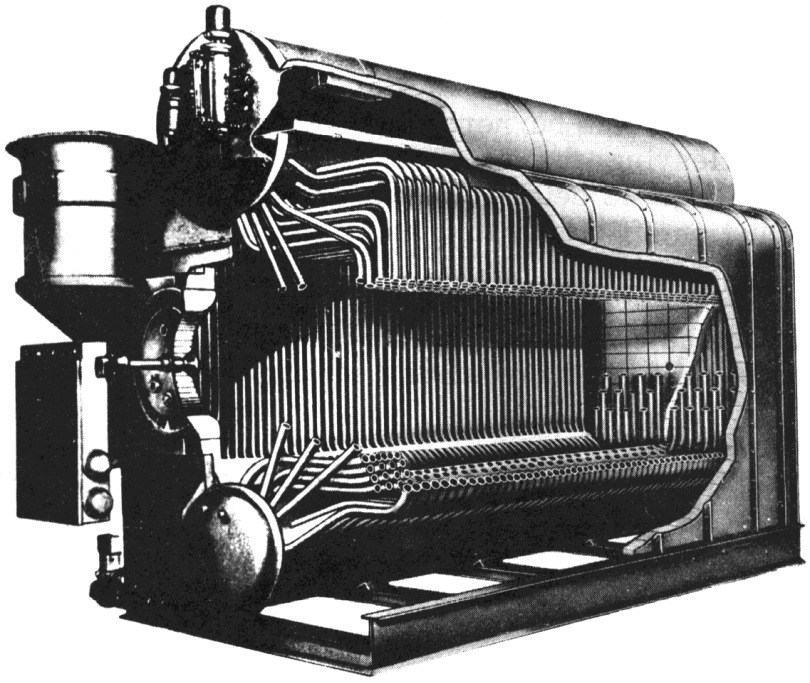


Figure 13
"O" Type Boilers

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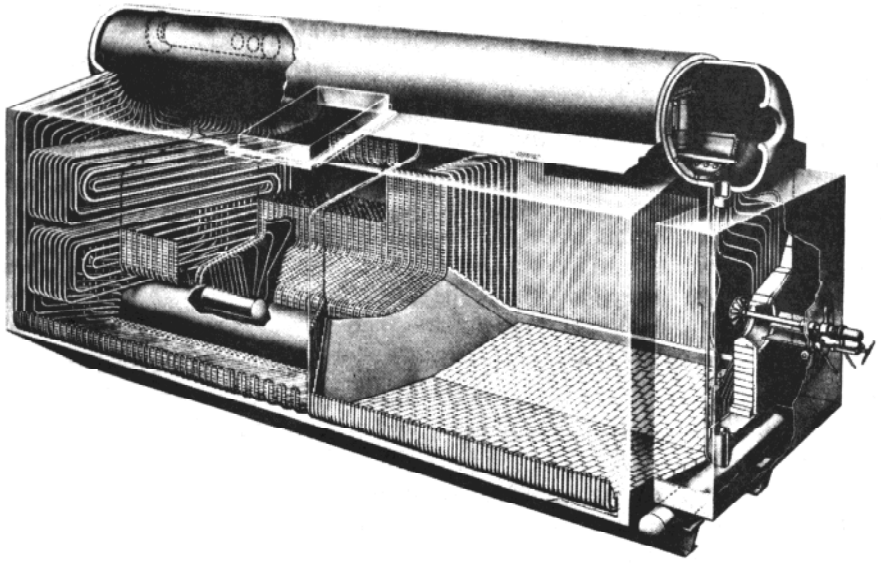

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Figure 14
"O" Type Boiler with Superheater

The “D” type (Fig. 15) allows the burners to be located in the end walls or between the tubes in the buckle of the “D”, at right angles to the drum.

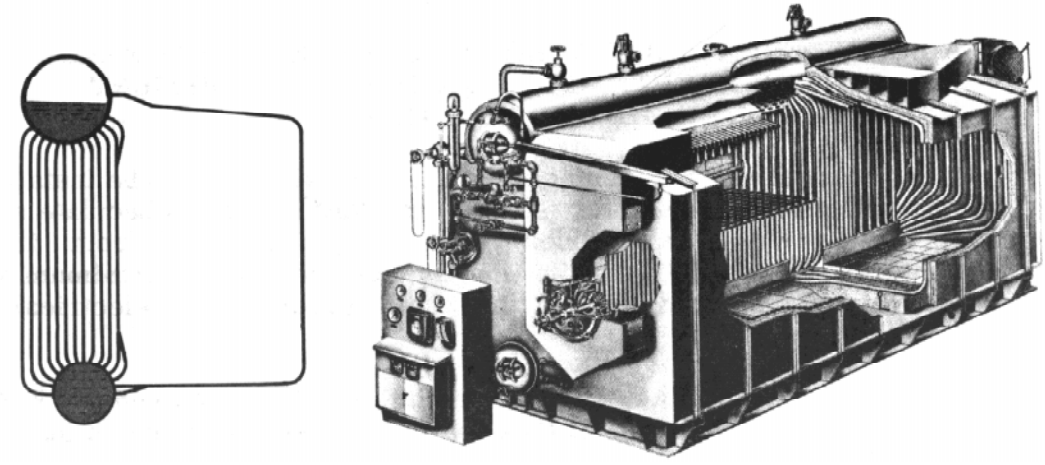

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Figure 15
"D" type Boiler

Fig. 16 shows a “D” type packaged watertube boiler with the accessories and control panel in position. These packaged units are bottom-supported, and it is necessary to provide a special foundation with concrete footings or piers to eliminate excessive vibration in the boiler setting which can cause failures of the insulation, casing and supports. Fig. 17 illustrates the supports.

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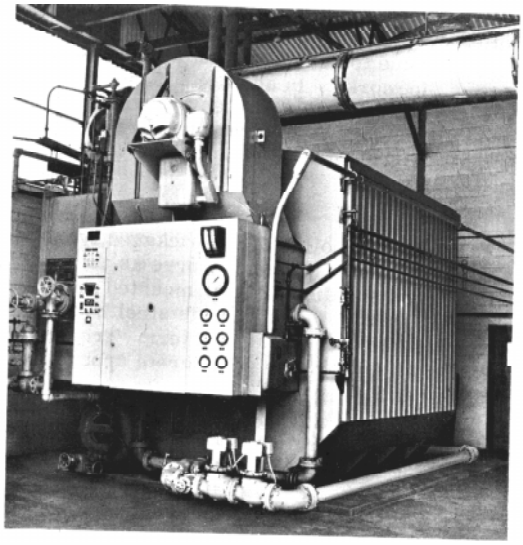

Figure 16
Installed Packaged Boiler "D" Type

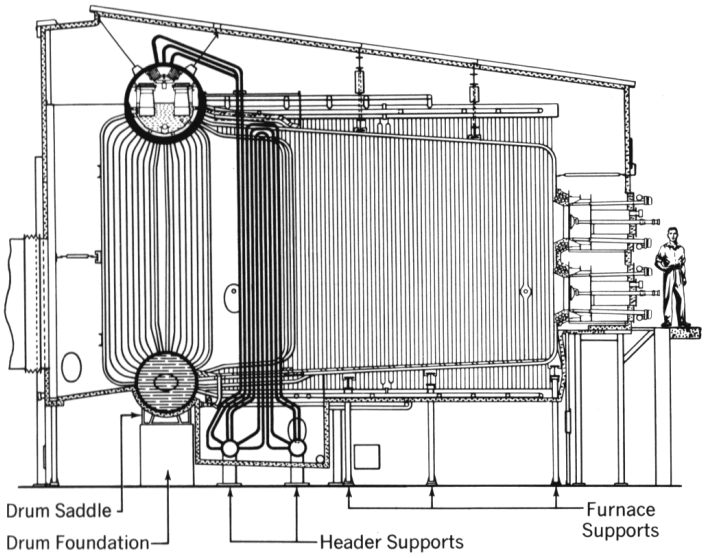

Figure 17
Bottom-Supported Unit (Large Unit)

Flues, ducts and casings are similarly stiffened by bars or structural shapes to prevent excessive vibration.

Advantages of the Packaged Boiler

1. Relatively low cost – construction costs are lower since the entire boiler is built and assembled in the factory, rather than in the field. The term "shop assembled" is often used.

2. Shipping costs are lower, since the unit is transported as a single unit, complete with fuel system, draft equipment, and controls.

3. The boiler can pre-tested in the shop before delivery to site, ensuring quality and inspections are approved.

4. On-site installation is reduced to a minimum, with only positioning of the boiler and connection of external auxiliary systems and piping required. Commissioning and start-up times are greatly reduced.

5. Compact and versatile in design. Can be made to occupy relative small floor areas.

STEAM GENERATING UNIT

A steam generating unit consists of all the elements which contribute to the production of steam. Usually the steam is at high temperature and high pressure and is generally used to supply large turbines which drive generators for the production of electrical power.

The elements of a typical steam generator include the boiler, superheater, reheater, economizer, air heater, fuel equipment, draft fans, and ash removal equipment.

The boiler itself consists of sections where water is converted into steam, although the term "boiler" is sometimes used to describe the entire unit.

Figs. 18, 19, and 20 illustrate three steam generators.

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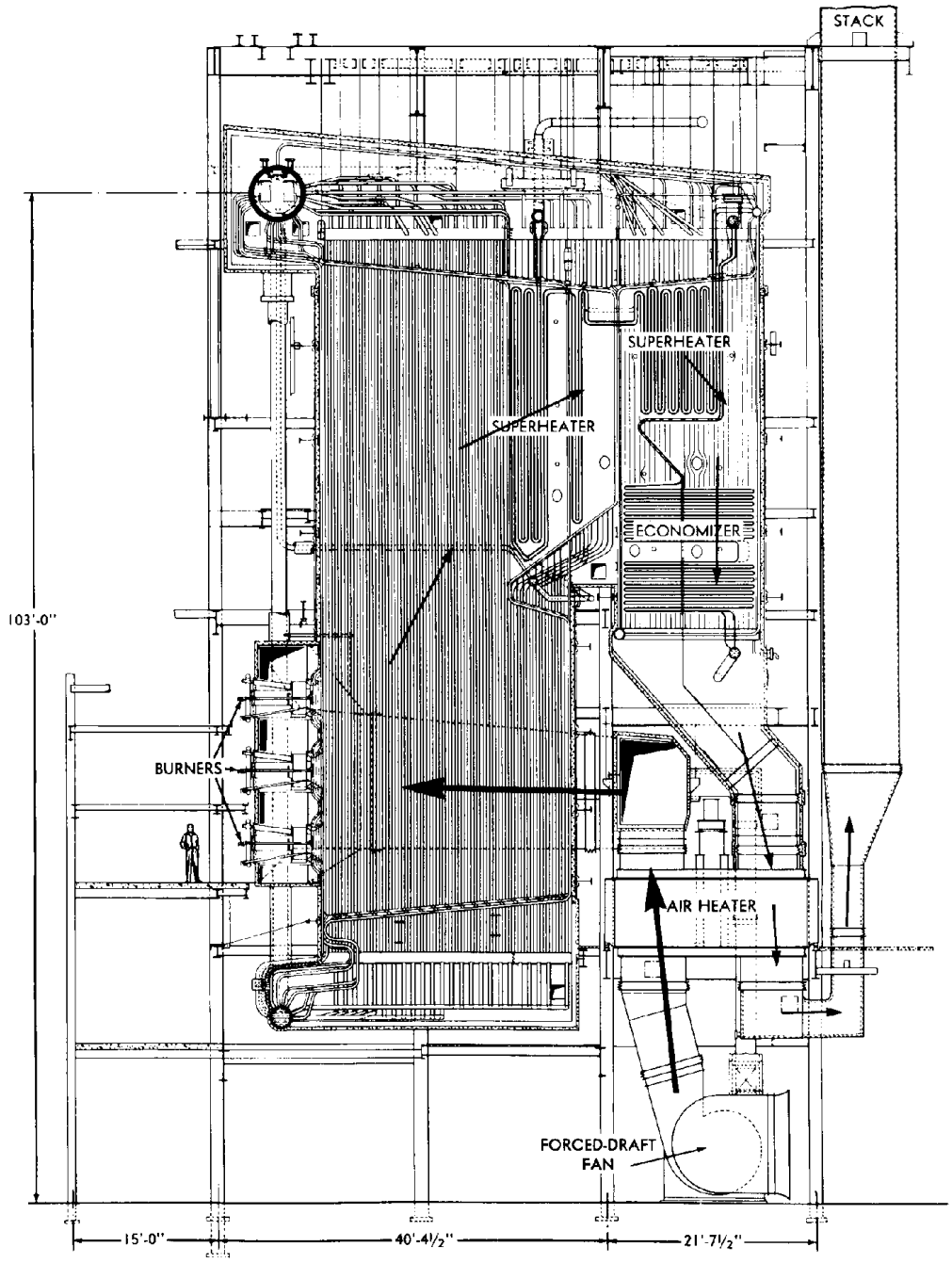

Figure 18
Steam Generating Unit
(Courtesy of Babcock & Wilcox)

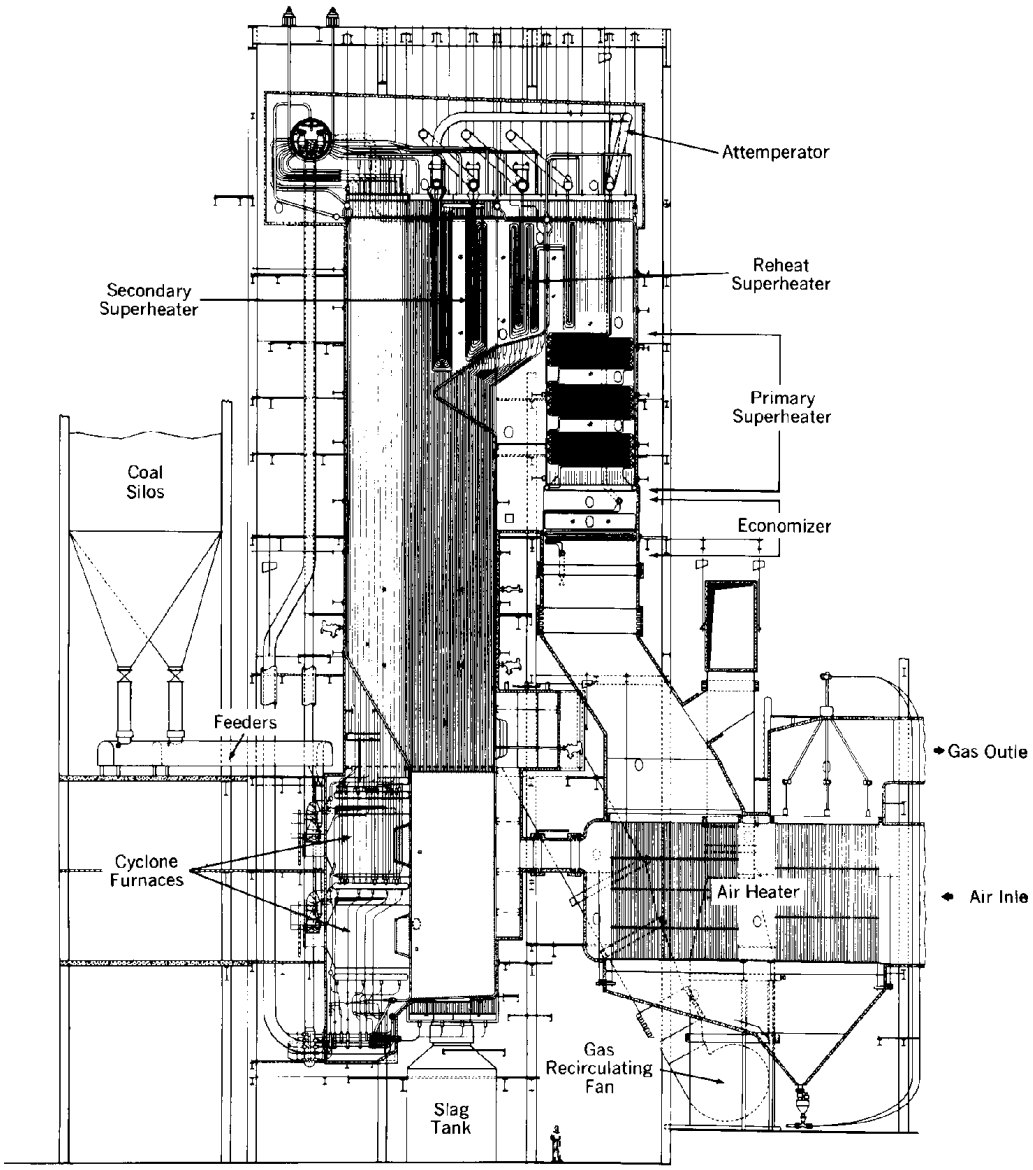

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Figure 19
Radiant-Type Steam, Generator (Boiler)

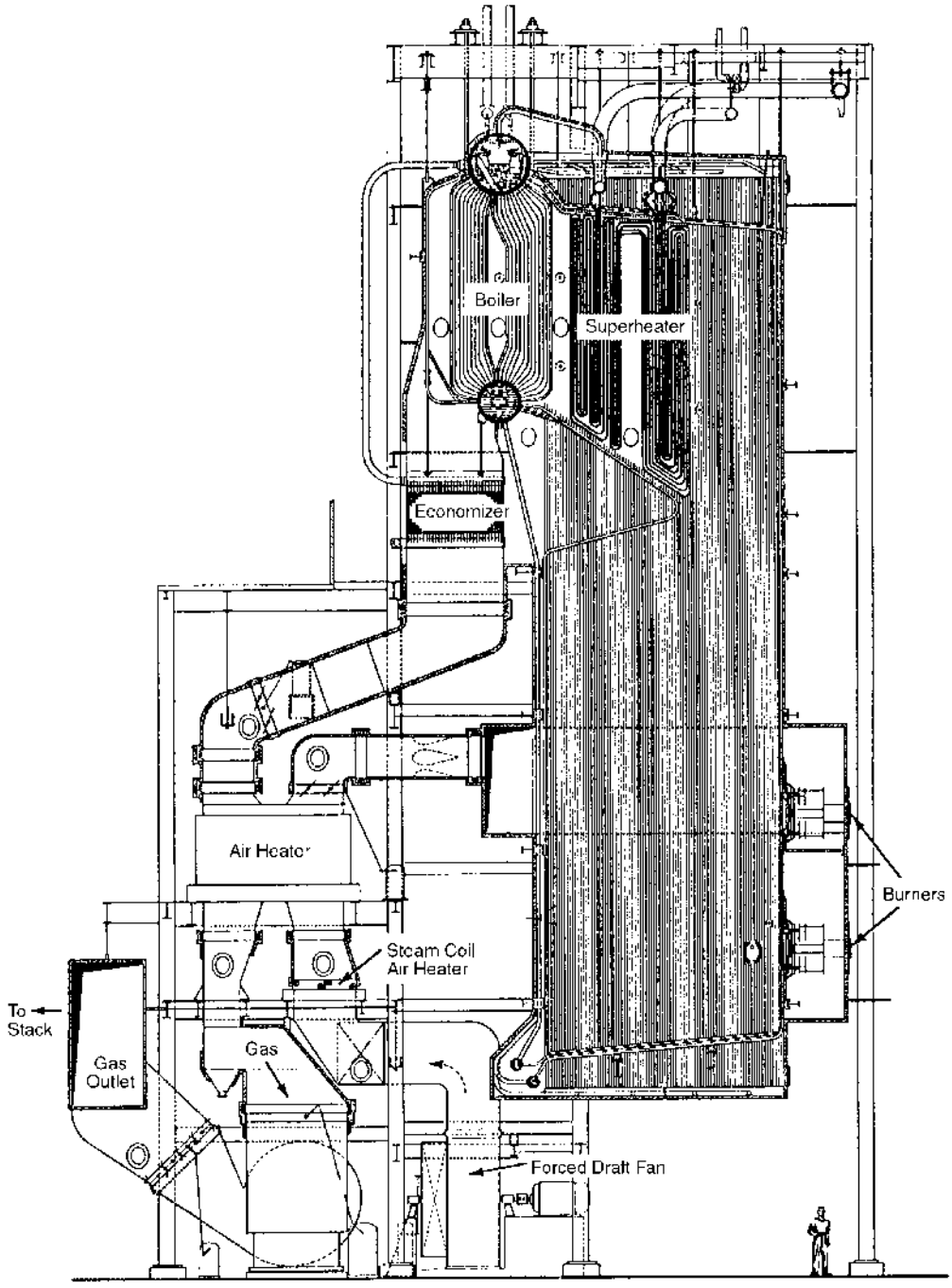

Figure 20
Steam Generating Unit, Arrangement of Forced and Induced Fans

STEAM GENERATOR COMPONENTS

Superheater

When steam is required for either power generation or a process, at a temperature higher than that of saturation, a superheater is installed. Dry saturated steam is taken from the steam drum, passed through a superheater section consisting of a bank of tubes located at the furnace outlet, and heated to the desired temperature. Various stages of superheating are usually incorporated in these large units to ensure that the chance of condensation of the steam in the latter stages of a steam turbine are minimized. Superheated steam also increases the overall plant efficiency in driving turbines.

Reheater

A reheater consists of a bank of tubes located within the furnace outlet or radiant area of the furnace. It reheats the superheated steam drawn from a medium pressure stage of the turbine to further reduce the chance of condensation. The reheated steam is returned to the remaining stages of the turbine.

Economizer

Economizers are added to the boiler system to further reduce the flue gas temperature leaving the unit to as low a value as possible, thereby maximizing the use of the fuel.

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The feedwater flowing through the bank of economizer tubes absorbs the heat from the flue gas, thereby increasing the feedwater temperature before it enters the drum.

Air Heater

The purpose of an air heater is to preheat the combustion air for the burners, improve combustion efficiency, and assist in the burning of the pulverized coal. Heat from the combustion flue gases, upon leaving the economizer section and before entering the stack, is further reduced in temperature by the air heater.

Fuel Equipment

The fuel burning equipment delivers the fuel to the furnace and provides a method of ignition. Pulverizers are included as part of the fuel burning equipment. Pulverized coal is the most economical fuel to use and most efficient method of burning.

Forced Draft Fan

The forced draft fan supplies the preheated air for combustion.

Induced Draft Fan

The induced draft fan exhausts the combustion gases from the unit.

Ash Removal Equipment

The by-products from the burning of coal, either fly ash or wet ash, must be removed. The removal of the ash may be by either pneumatic or hydraulic equipment.

Reference Material

For more information on this topic, the following are recommended:

1. Babcock & Wilcox. *Steam/its generation and use.* 39th ed. New York: Babcock & Wilcox; 1978

2. Singer, Joseph G., ed. *Combustion - Fossil Power Systems.* 3rd ed. Windsor, CT: Combustion Engineering Inc.; 1981.