STEAM-PLANT OPERATION

FIFTH EDITION

EVERETT B. WOODRUFF

HERBERT B. LAMMERS

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PREFACE
TO THE FIFTH EDITION

For nearly 50 years, this book, *Steam-Plant Operation*, has presented fundamental equipment and operating procedures to thousands of people interested and involved in steam plants. The basic ideas developed for this book were written by two practical men with extensive experience in the operation of steam plants and with an intimate knowledge of the people working in these plants. As a result, four previous editions have been published, from which many have benefited.

Everett B. Woodruff and Herbert B. Lammers devoted much of their lives to the improvement of power-plant operation, and their experience is continued in this Fifth Edition. It saddens me to say, however, that neither will see this Fifth Edition, as my father, Herbert B. Lammers, died in 1981 and Everett B. Woodruff died in 1982, shortly after revising much of this edition.

It gives me great pride to carry on the tradition that these men have established while meeting the challenge of presenting the latest power-plant equipment in the most fundamental and understandable way possible. This continual update on power-plant technology is blended with information on the older types of equipment for the purpose of illustrating fundamentals, of providing information required to answer questions asked on operating license examinations, and of providing operators with descriptions of older equipment remaining in service today and of its operation.

This edition not only has incorporated the latest features in boiler design, but has introduced, in a broader fashion, the equipment and operational characteristics of environmental control systems. This equipment has created an entire new set of problems for plant operators since environmental regulations require it to have high availability to prevent plant shutdown and/or monetary penalties.

I am grateful to the manufacturers who have provided information and illustrations on their equipment. Without their assistance, this book could not have been assembled.

THOMAS F. LAMMERS

CONTENTS

CHAPTER 1

BOILERS

1.1 THE BOILER. A boiler is a closed vessel in which water, under pressure, is transformed into steam by the application of heat. Open vessels and those generating steam at atmospheric pressure are not considered to be boilers. In the furnace, the chemical energy in the fuel is converted into heat, and it is the function of the boiler to transfer this heat to the water in the most efficient manner.

The *ideal* boiler embodies

1. Simplicity in construction, excellent workmanship, and materials conducive to low maintenance cost
2. Design and construction to accommodate expansion and contraction properties of materials
3. Adequate steam and water space, delivery of clean steam, and good water circulation
4. A furnace setting conducive to efficient combustion and maximum rate of heat transfer
5. Responsiveness to sudden demands and overloads
6. Accessibility for cleaning and repair
7. A factor of safety of at least code requirement

In general the boiler must be conservatively designed to assure reliable performance over the life of the plant. This conservative design is required because of all the variables that occur over the life of the plant, such as the use of different fuels and the occurrence of upset conditions.

A boiler should be designed to absorb the maximum amount of heat released in the process of combustion. This heat is transmitted to the boiler by *radiation*, *conduction*, and *convection*, the percentage of each depending upon boiler design.

"Radiant" heat is heat radiated from a hot to a cold body and depends on the temperature difference and the color of the body which receives the heat. Absorption of radiant heat increases with the furnace temperature and depends on many factors but primarily on the area of the tubes exposed to the heat rays.

"Conduction" heat is heat which passes from the gas to the tube by physical contact. The heat passes from molecule of metal to molecule of metal with no displacement of the molecules. The amount of absorption depends on the conductivity or heat-absorption qualities of the material through which the heat must pass.

"Convection" heat is heat transmitted from the hot to the cold body by movement of the conveying substance. In this case, the hot body is the boiler gas; the cold body, the boiler tube containing water.

In designing a boiler, each form of heat transmission is given special consideration. In the operation of a boiler unit, all three forms of heat transmission occur simultaneously and cannot readily be distinguished from each other.

Considerable progress has been made in boiler design from the standpoint both of safety and of efficiency of the fuel-burning equipment. More and more emphasis is being placed on efficiency, flexibility, and boiler availability. Boiler designs are being developed not only for the traditional utility and industrial applications but also for plants designed for cogeneration of electricity and process steam. Boilers are also being designed to burn low-grade coal, such as lignite, or to burn refuse-derived fuel. The newer boilers are designed to be fully automated; their design must also take into account the control equipment which is mandatory under environmental regulations (see Chap. 14).

Boilers are built in a variety of sizes, shapes, and forms to fit conditions peculiar to the individual plant and to meet varying requirements. With increasing fuel cost, greater attention is being given to improvement of the combustion efficiency. Many boilers are designed to burn multiple fuels in order to take advantage of the fuel most economically available.

Increased boiler "availability" has made units of increased capacity practical, and this has resulted in lower installation and operating costs. For the small plant, all boilers should preferably be of the same type, size, and capacity since standardization of equipment makes possible uniform operating procedures, reduces spare parts stock to a minimum, and contributes to lower overall costs.

The field of application is diversified. Boilers are used to produce steam for heating, process, and power generation and to operate steam engines, turbines, pumps, etc. This text is concerned with boilers used in stationary practice.

1.2 FIRE-TUBE BOILERS. Fire-tube boilers are so named because the products of combustion pass through tubes or flues, which are surrounded by water. They may be either *internally* fired (Fig. 1.1) or *externally* fired (Fig. 1.3). Internally fired boilers are those in which the grate and combustion chamber are enclosed within the boiler shell. Externally fired boilers are those in which the setting, including furnace and grates, is separate and distinct from the boiler shell. Fire-tube boilers are classified as vertical tubular or horizontal tubular.

The vertical fire-tube boiler consists of a cylindrical shell with enclosed firebox (Figs. 1.1, 1.2). Here tubes extend from the "crown sheet" (firebox) to the upper tube sheet. Holes are drilled in each sheet to receive the tubes, which are then rolled to produce a tight fit, and the ends are beaded over. Screwed stay bolts are used in the water leg (firebox to shell) with the ends riveted over.

In the vertical *exposed-tube* boiler (Fig. 1.1), the upper tube sheet and tube ends are above the normal water level, extending into the steam space. This type of construction reduces the moisture carry-over and superheats the steam leaving the boiler. However, the upper tube ends, not being protected by water, may become overheated and leak at the point where they are expanded into the tube sheet. The furnace is water-cooled and is formed by an extension of the outer and inner shell which is riveted to the lower tube sheet. The upper

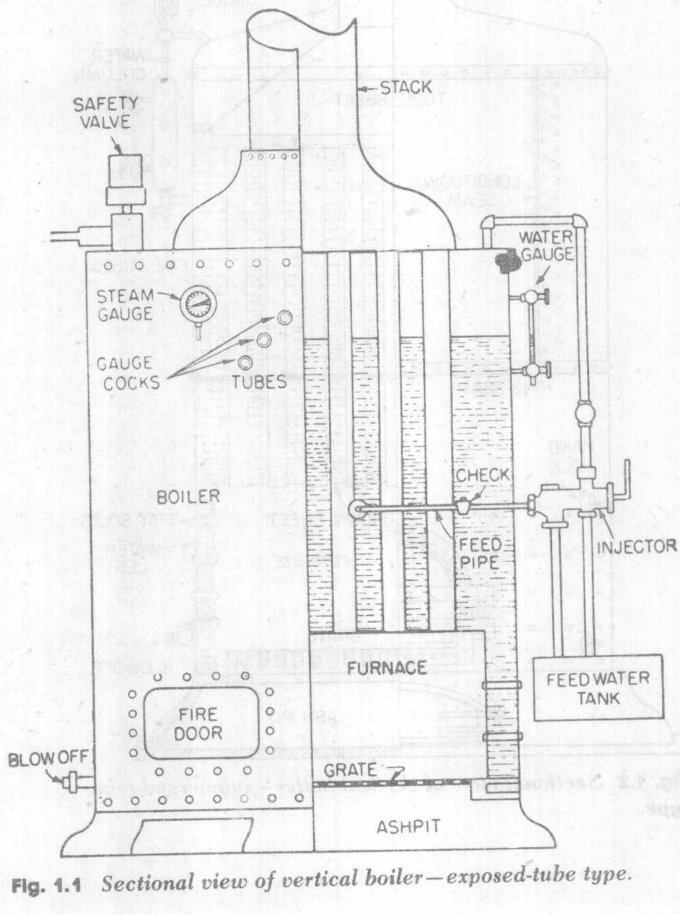

Fig. 1.1 *Sectional view of vertical boiler—exposed-tube type.*

tube sheet is riveted directly to the shell. When the boiler is operated, water is carried some distance below the top of the tube sheet, and the area above the water level is steam space.

In *submerged-tube* boilers (Fig. 1.2), the tubes are rolled into the upper tube sheet, which is below the water level. The outer shell extends above the top of the tube sheet. A cone-shaped section of the plate is riveted to the sheet so that the space above the tube sheet provides a smoke outlet. Space between the inner and outer sheets comprises the steam space. This design permits carrying the water level above the upper tube sheet, thus preventing overheating of the tube ends. The cone-shaped section is difficult to construct, requiring staying, and is subject to leaks.

Since vertical boilers are portable, they are used to power hoisting devices and operate fire engines and tractors as well as for stationary practice. They range in size from 6 to 75 hp; tube sizes range from 2 to 3 in in diameter,

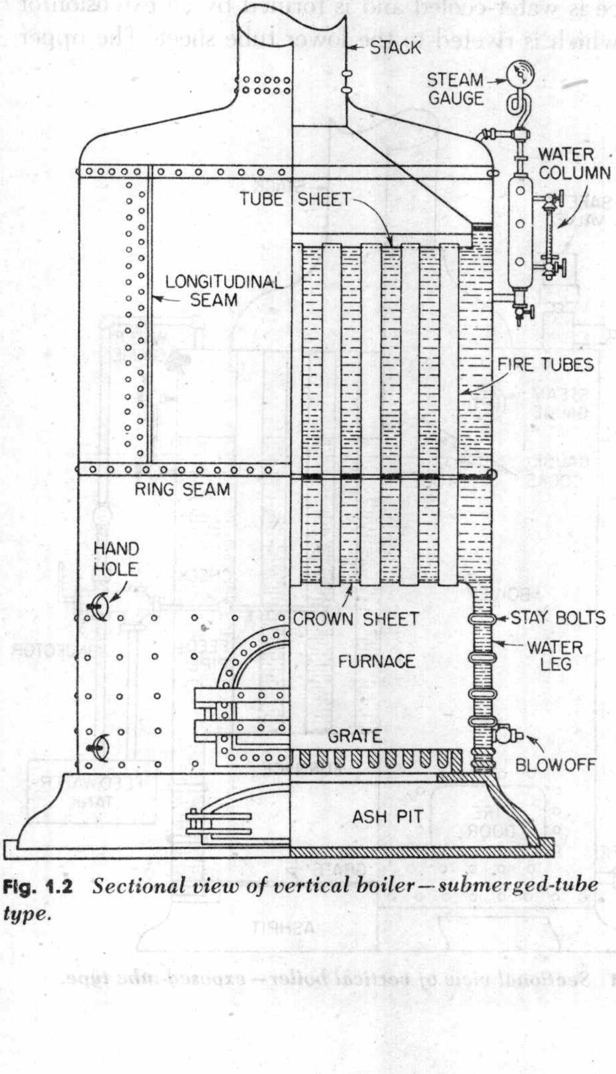

Fig. 1.2 *Sectional view of vertical boiler—submerged-tube type.*

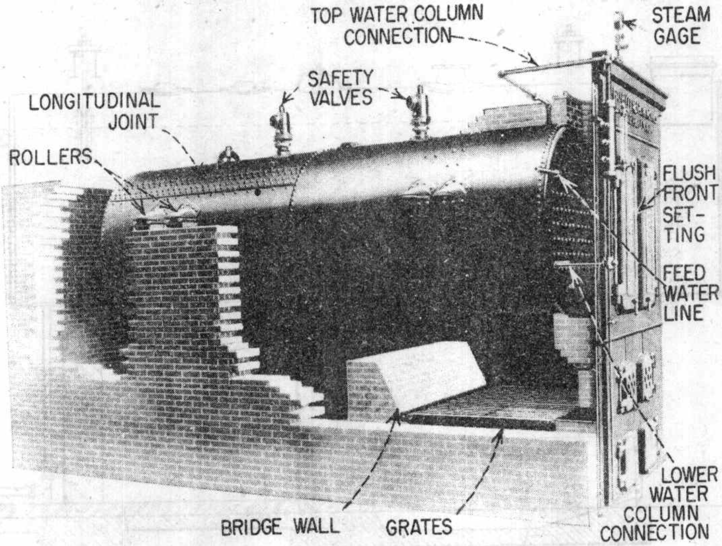

Fig. 1.3 *Horizontal-return tubular boiler and setting. (Erie City Energy, a division of Zurn Industries, Inc.)*

pressures to 100 psi, diameters from 3 to 5 ft, and height from 5 to 10 ft. With the exposed-tube arrangement, 10 to 15° of superheat may be obtained.

Vertical fire-tube boilers are rapid steamers, their initial cost is low, and they occupy little floor space. Boilers of this type usually employ a standard base. Combustion efficiency is improved when the boiler is elevated and set on a refractory base to secure added furnace volume. This is especially important if bituminous coal is to be burned and smoke is to be reduced to a minimum. If the boiler is stoker-fired, either raise the boiler or pit the stoker for the required setting height.

Horizontal fire-tube boilers are of many varieties, the most common being the horizontal-return tubular (HRT) boiler (Fig. 1.3). This boiler has a long cylindrical shell supported by the furnace sidewalls and set on saddles equipped with rollers to permit movement of the boiler as it expands and contracts. It may also be suspended from hangers (Fig. 1.4) and supported by overhead beams. Here the boiler is free to move independently of the setting. Expansion and contraction work no hardship on the brick setting, and thus maintenance is reduced.

The required boiler shell length is secured by riveting (Fig. 1.3) several plates together. The seam running the length of the shell is called a "longitudinal" joint and is of butt-strap construction. Note that this joint is above the fire line to avoid overheating. The "circumferential" joint is a lap joint. (See Chap. 2 for a description of butt and lap joints.)

A return tubular boiler (Fig. 1.4) has its plates joined by fusion welding. This

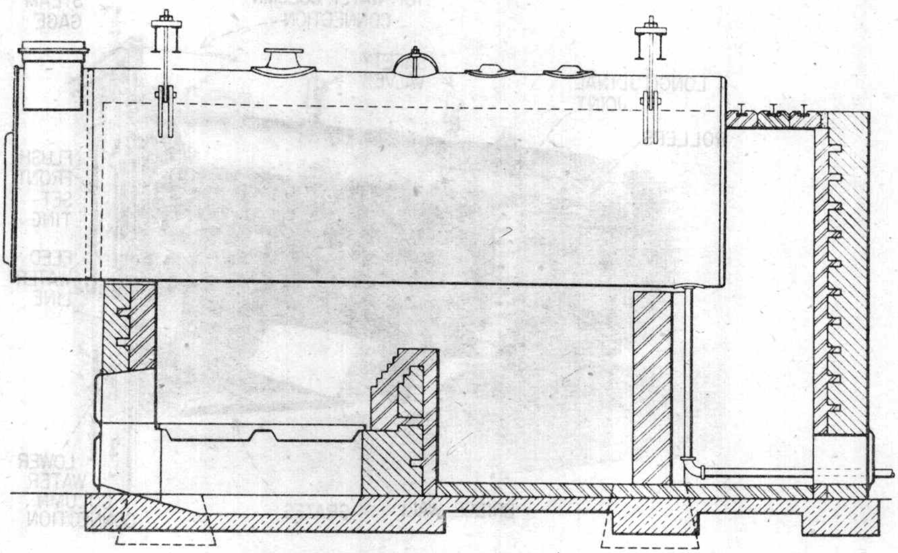

Fig. 1.4 *Horizontal-return tubular boiler and setting—overhanging front.*

type of construction is superior to that of a riveted boiler since there are no joints to overheat. As a result, the life of the boiler is lengthened, maintenance is reduced, and at the same time higher rates of firing are permitted.

The boiler setting includes grates (or stoker), bridge wall, and combustion space. The products of combustion are made to pass from the grate, over the bridge wall (and under the shell), to the rear end of the boiler. Gases return through the tubes to the front end of the boiler, where they connect to the breeching or stack. The shell is bricked in slightly below the top row of tubes to prevent overheating of the longitudinal joint and to keep the hot gases from coming into contact with that portion of the boilerplate above the waterline.

The conventional HRT boiler is set to slope 1 to 3 in from front to rear. A blowoff line is connected to the underside of the shell at the rear end of the boiler to permit drainage and removal of impurities. It is extended through the setting, where blowoff valves are attached. The line is protected from the heat by a brick lining or protective sleeve. Safety valves and water column are located as shown in Fig. 1.3. A *dry pipe* is frequently installed in the top of the drum to separate the moisture from the steam before the steam passes to the steam outlet.

Tubes and flues are used in the HRT boiler as a means of increasing the heating surface and steaming capacity. They provide additional strength for the tube sheets. Sizes below 4 in are usually referred to as "tubes"; those above 4 in, as "flues." For tube size, we designate the external diameter; for flue size, the internal diameter.

Tubes are rolled into the tube sheet by means of an expander and then beaded over, whereas flues are riveted in place. The size of the tube or flue depends upon the type of fuel used, the draft loss desired, etc. Tube spacing and staggering are resorted to in an effort to improve the water circulation.

Still another type of HRT boiler is the horizontal four-pass forced-draft packaged unit (Fig. 1.5), which can be fired with gas or fuel oil. In heavy oil-fired models, the burner has a retractable nozzle for ease in cleaning and replacing.

Gases from the combustion chamber reverse at the rear to pass downward to the tubes directly beneath the chamber. Again they reverse to pass through the tube bank above the combustion chamber and reverse and pass through the top tube section to the stack.

Such units are available in sizes of 15 to 600 hp with pressures of 15 to 250 psi. They are a source of high- or low-pressure steam or hot water. These units are compact, requiring a minimum of space and headroom; are automatic in operation; have a low initial cost; and do not need a tall stack. For these reasons they find application and acceptance in many locations. By reason of their compactness, however, they are not readily accessible for inspection and repairs.

The Scotch marine boiler (Fig. 1.6) is a fire-tube return tubular unit. It consists of a cylindrical shell containing the firebox and tubes. The tubes surround the upper portion of the firebox and are rolled into tube sheets on each end of

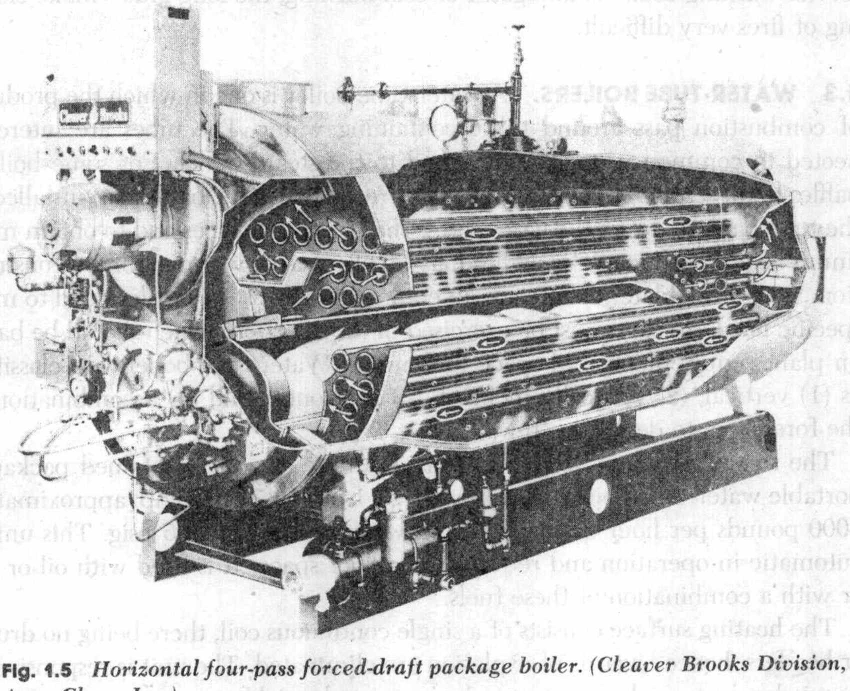

Fig. 1.5 *Horizontal four-pass forced-draft package boiler. (Cleaver Brooks Division, Aqua-Chem, Inc.)*

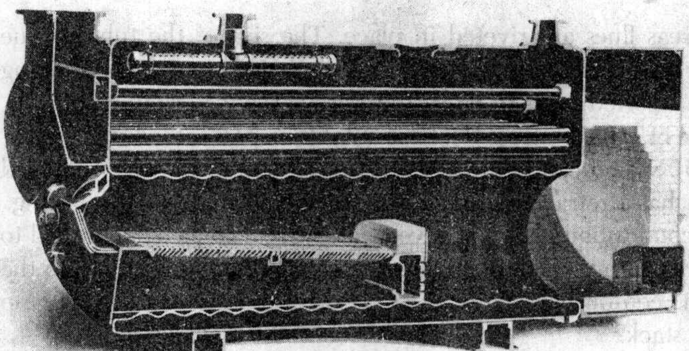

Fig. 1.6 *Scotch marine boiler.*

the boiler. Combustion gases pass to the rear of the furnace, returning through the tubes to the front, where they are discharged to the stack.

The water-cooled furnace and limited furnace volume of the Scotch marine boiler make smokeless combustion difficult when firing bituminous coal unless over-fire air or steam jets are employed.

Scotch marine boilers are self-contained, do not require a setting, and are internally fired. They are portable packaged units requiring a minimum of space and headroom. Units of this type are to be found in marine and stationary service burning coal, oil, and gas. For coal burning, the long grates make cleaning of fires very difficult.

1.3 WATER-TUBE BOILERS. A water-tube boiler is one in which the products of combustion pass around tubes containing water. The tubes are interconnected to common water channels and to the steam outlet. For some boilers, baffles to direct the gas flow are not required. For others, baffles are installed in the tube bank to direct the gases across the heating surfaces and to obtain maximum heat absorption. The baffles may be of refractory or membrane construction, as discussed later. There are an endless variety of boilers designed to meet specific needs, so care must be exercised in the selection, which should be based on plant requirements and space limitations. Water-tube boilers are classified as (1) vertical, (2) vertically inclined, (3) horizontal, and (4) a combination of the foregoing, to describe a few.

The steam generator (Fig. 1.7) is an example of a self-contained packaged portable water-tube boiler available in sizes from 16.5 to 175 hp [approximately 6000 pounds per hour (lb/h) of steam] with pressures to 295 psig. This unit is automatic in operation and requires little floor space. It is fired with oil or gas or with a combination of these fuels.

The heating surface consists of a single continuous coil, there being no drums or headers; hence hazards of explosion are eliminated. The unit is responsive to steam demands, and pressure can be generated quickly.