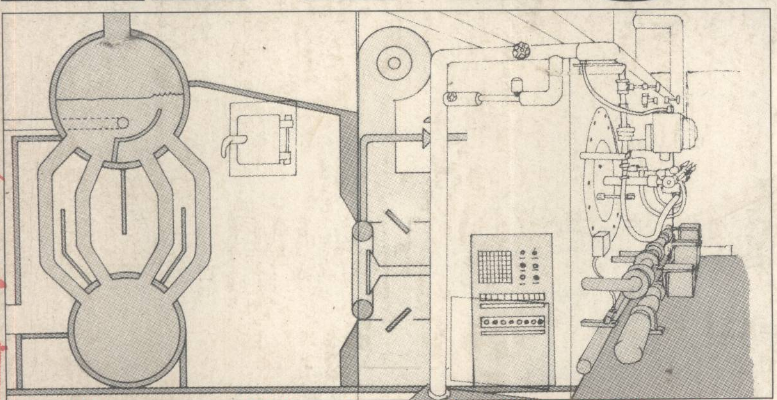
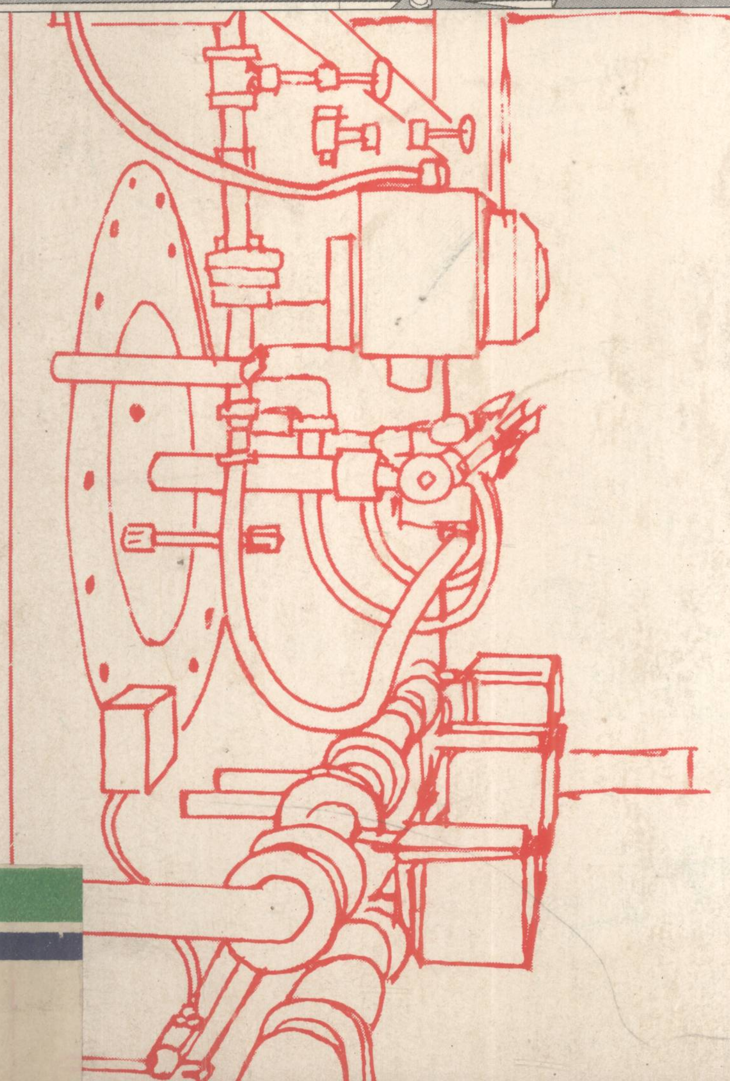
IMPROVING BOILER EFFICIENCY



Samuel G. Dukelow



Improving Boiler Efficiency

by S.G. Dukelow

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Preface

Since many of its members throughout the world are involved extensively with boiler systems, the Instrument Society of America has arranged with Kansas State University, the originators of this book, to reproduce *Improving Boiler Efficiency* by Samuel G. Dukelow as a service to its members and the instrumentation community at large. It is a welcome adjunct to the Society's growing library of materials relating to boilers and boiler control. These materials include

- A film series featuring control procedures for ensuring maximum boiler energy efficiency and safety. . . .
    1. Boiler Control for Energy Efficiency: An Overview
    2. Boiler Feedwater Control: Basic Principles
    3. Basic Principles of Boiler Combustion Control: Gas, Oil and Auxiliary Fuels
    4. Basic Principles of Boiler Combustion Control: Coal and Other Solid Fuels
    5. Principles of Boiler Safety Systems
- Short Course Program BBC #780, "Basic Principles of Boiler Control"
- "Basic Principles of Boiler Control" Instructional Resource Package, which includes student workbooks, an instructor's manual, audiovisual materials and other teaching aids.

Mr. Dukelow served as an advisor for the film series and is the author of the Short Course Program and the Instructional Resource Package.

For further information, please address inquiries to:

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Chapter 1

Introduction

This text includes information for saving boiler plant fuel. It is intended for use by plant managers, owners, engineers as well as boiler operators and persons directly responsible for operating and maintaining boiler plants. Although most of the information applies to boilers of all kinds and sizes, the basic orientation of the text is toward the users of commercial, institutional and light industrial boilers.

Chapters 2 through 4 cover general information about energy, boilers, and the concepts of boiler performance and efficiency.

Chapters 5 through 6 cover the various fuels and their characteristics, their combustion and how the various features affect performance and efficiency.

Chapters 7 through 15 discuss various aspects of boiler operation, the equipment involved, and the relationship of the equipment design to boiler efficiency.

Chapters 16 through 18 cover design and operational considerations relating to boiler efficiency.

Chapters 19 and 20 are "how to" chapters that provide procedures and analytical methods for determining boiler plant performance.

Chapter 21 discusses methods for identifying energy-use standards, setting reduction goals, and tracking performance in meeting these goals.

Simple, straightforward approaches for evaluating capital expense to save energy are covered in Chapter 22.

An appendix and bibliography also are included.

The most compelling motivation for investing time and money to save energy is a healthy financial return. Throughout the text, the economic benefits are explained. The reader should examine each of the suggestions relevant to his present operating practice to identify potential economic benefits. The text then should be used for taking the action indicated to realize the potential benefit.

There are no "short cuts" and only thorough analysis based on sound technology can achieve results. Little of this technology is recent, and the principles involved have been used on large industrial and utility boilers for many years.

Users who do not have the necessary technical expertise should particularly beware of "quack" solutions now being promoted and use the text as a guide to sound, proven approaches.

The text is primarily for use in improving existing installations or procedures to save fuel.

Chapter 2

Energy Overview

2.1 Energy vs. Capital—Environment

For many years higher boiler efficiency could be obtained with higher capital investment for more fuel-efficient design. From the 1940s to the 1970s when fuel was cheap and plentiful, good technical and financial decisions favored less efficient equipment design. This is illustrated in Fig. 1 which shows the relationship between the cost of sophisticated boiler controls related to the average price of No. 6 Fuel Oil. From 1950 to 1974 using more sophisticated control equipment to save fuel could only be justified for larger boilers. As fuel costs skyrocket relative to the capital costs of fuel-using or fuel-saving equipment, many of the known fuel-saving equipment and procedures can be justified on smaller boilers.

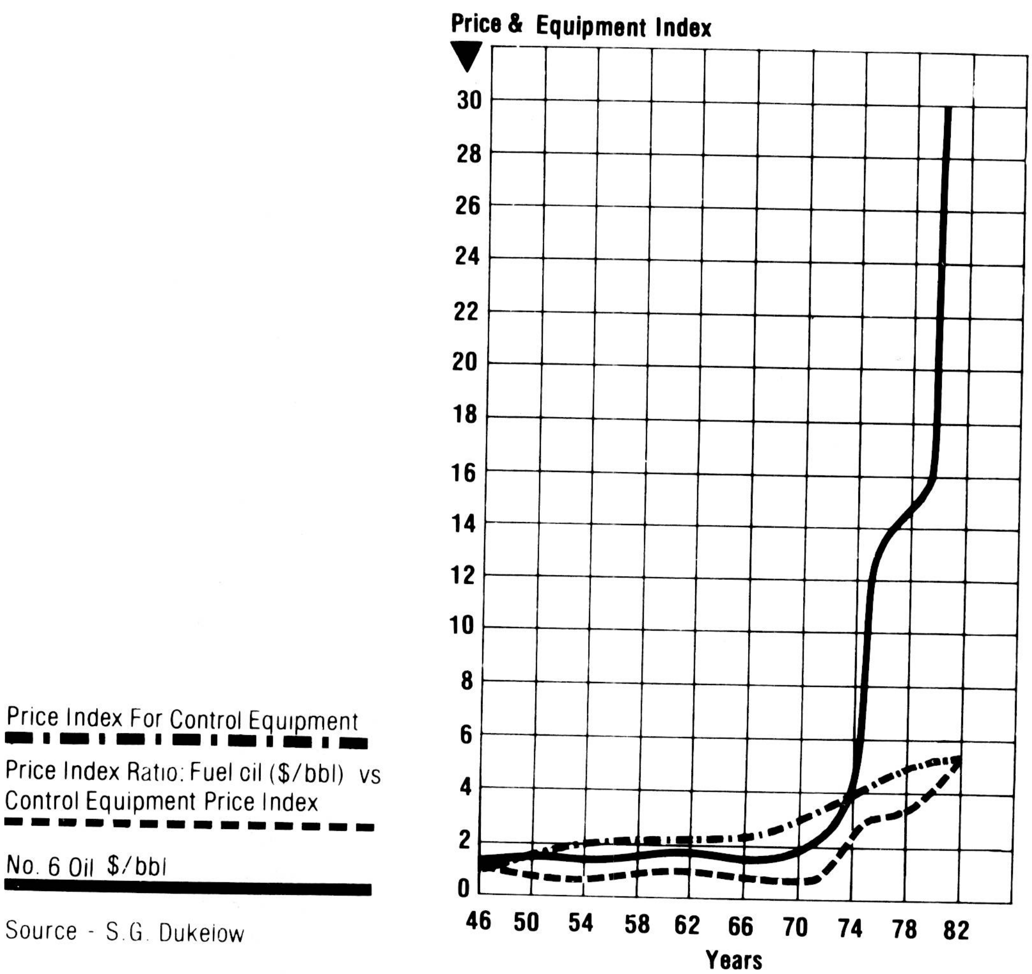


Fig. 1 Capital/Energy Cost

2.2 Future Fuel Prices

The price of all fuels has risen rapidly in the past few years. Oil now costs 10 times what it did in 1973; gas costs five to six times more; and coal, three to four times more. These increases are due to the rising price of imported crude oil and the relaxed regulation of natural gas prices.

Fuels compete in various ways. For a fuel user, natural gas is the easiest to use and requires the least handling. Oil is the next desirable fuel, and coal—due to its handling problems and capital requirements—the least desirable.

The price of fuel oil acts as a price umbrella for all fuels. With the potential for oil or gas users to switch to coal, the price of coal based on supply and demand tends to follow oil price increases. Gas prices also tend to follow oil price increases because users will pay increased prices for the most desirable fuel.

A barrel of fuel oil is generally in the same price range as the OPEC selling price for a barrel of crude oil. The price of other fuels can be expected to keep pace with the rising cost of fuel oil.

Current predictions are that fuel prices in the next few years will rise 10 percent/year plus inflation.

2.3 Fossil Fuel and Electrical Consumption

Individuals and institutions use both fossil fuel and electricity. Although the focus of the text is on boiler efficiency as it relates to fossil fuel, the reader should keep in mind that a boiler plant also uses electric power in driving the various motors for fans and pumps.

The relative prices of fossil fuel and electrical energy also should be kept in mind because there are situations where energy in one form can be economically substituted for another. The average amount of fossil fuel energy used to produce a kilowatt-hour of electrical energy is 10,500 BTU. The heat content of a kilowatt-hour is 3,413 BTU. Burning the 10,500 BTU of fossil fuel with a boiler efficiency of 80 percent will produce 8,400 BTU. A cursory comparison, ignoring capital or operating cost comparison, indicates that electricity uses approximately 2.5 times as much fossil fuel as boiler steam or hot water to heat the same space.

The equivalent for 5¢/Kwh electricity would be fuel oil at $1.70/gallon. The electrical cost equivalent of fuel oil at 80¢/gallon is 2.4¢/Kwh.

Substituting heat from an electric heat pump with a Coefficient of Performance (COP) of 2.0 for steam or hot water makes fuel oil costs for heating with steam or hot water roughly equivalent to the cost of heat pump electrical energy.

These calculations are based on 80¢/gallon for fuel oil. (5.60/MBTU), and 5¢ per Kwh for electrical power. Other fuel and electrical energy costs can be adjusted to develop the required COP for equivalent energy costs.

2.4 The Energy Users

The two major energy-using devices in the commercial, institutional, light industry sectors are the boilers for converting fossil fuel into steam or hot water heat and the air conditioning systems which normally use electric power or heat to pump heat from circulating water or air.

The end uses of energy in this sector are space heating and cooling. Overall, approximately 50 percent of total energy used in this sector is for space heating, and approximately 15 percent is for space cooling. Although this is an overall breakdown, these figures are not necessarily correct for any specific location. The balance for a specific location can be determined more correctly using Degree-Day tables in the appendix.

Because fuel for boilers provides most of the space heating energy requirement, improving boiler efficiency will reduce fuel costs by some percentage of the approximate 50 percent used for space heating. Reductions in the end use of the steam or hot water can lead to an additional percentage of the approximate 50 percent used for space heating.

If absorption cooling based on steam is used, improving boiler efficiency results in a percentage of the approximate 15 percent used for space cooling.

Chapter 3

Boiler Types

and Classifications

A basic diagram of a boiler is shown in Fig. 2. The fuel shown can be any substance that gives off heat when burned. The air is required to support the combustion of the fuel. The products of the combustion are the hot flue gases, which carry the heat through the boiler in contact with the heat transfer surface, and ash (ash is only present when the fuel contains ash).

In a steam boiler the output of useful heat is carried by the steam. (Blowdown is a necessary non-useful output which will be discussed later.) In a hot water boiler the useful heat output is carried in a stream of hot water. The boiler steam or hot water output should be considered only as carriers of heat because that is their only useful function. In both types of boilers the heat is transferred to these heat carriers from the flue gas via the heat transfer surface between the hot flue gas and the heat carrier or working fluid.

Boilers here are classified according to the physical arrangement of the working fluid, the combustion gases, and the type of working fluid or heat carrier used.

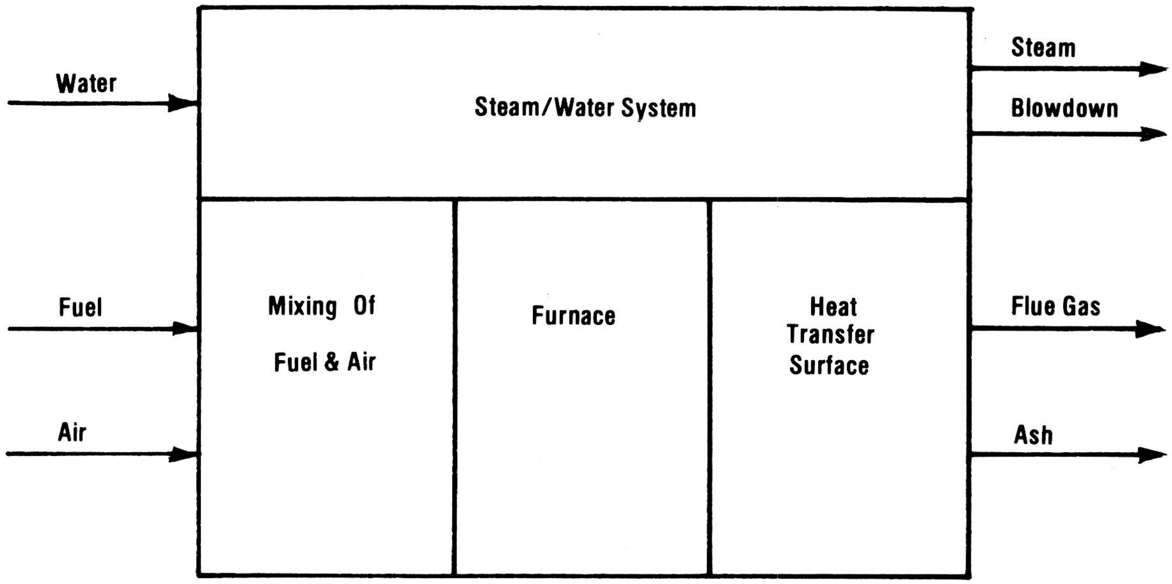


Fig. 2 Basic Diagram of a Boiler Source: S.G. Dukelow

3.1 Firetube Boilers

Firetube boilers constitute the largest share of small- to medium-sized industrial units. In firetube boilers the flue gas products of combustion flow through boiler tubes surrounded by water. Steam is generated by the heat transferred through the walls of the tubes to the surrounding water. The flue gases are cooled as they flow through the tubes, transferring their heat to the water—therefore the cooler the flue gas, the greater the amount of heat transferred. Cooling of the flue gas is a function of the heat conductivity of the tube surfaces, the temperature difference between the flue gases and the water in the boiler, the heat transfer area, the time of contact between the flue gases and the boiler tube surfaces, and other factors.

Firetube boilers used today evolved from the earliest designs of a spherical or cylindrical pressure vessel mounted over the fire with the flame and hot gases around the boiler shell. This obsolete approach has been improved by installing longitudinal tubes in the pressure vessel and passing the flue gases through the tubes. This increased the heat transfer area. The results are the two variations of the Horizontal Return Tubular (HRT) boiler shown in Fig. 3 and Fig. 4. A variation of the HRT boiler in Fig. 3 is the package-shop-assembled Firebox boiler shown in Fig. 5.

A parallel evolution of the firetube boiler was the locomotive boiler, designed with the furnace surrounded by a heat transfer area and a heat transfer surface added by using horizontal tubes. This type is shown in Fig. 6.

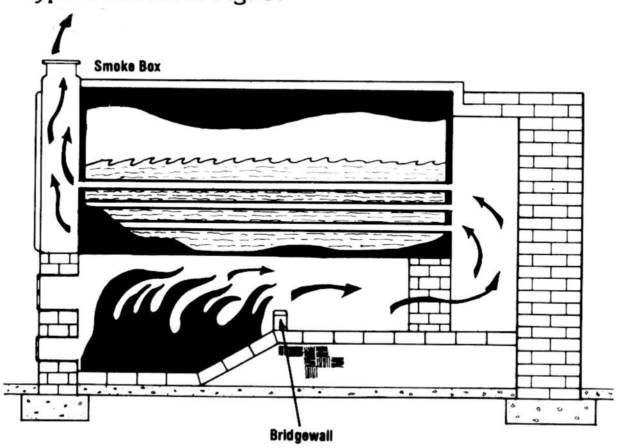


Fig. 3 Horizontal-Return Tube Boiler

The Scotch Marine boiler design, as shown in Fig. 7, with the furnace a large metal tube combined that feature of the English Cornish boiler of the 1800s and the smaller horizontal tubes of the HRT boiler. This boiler originally was developed to fit the need for compact shipboard boilers. Because

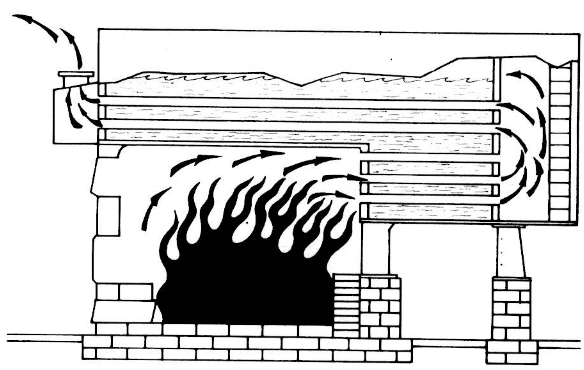


Fig. 4 Two-Pass Boiler

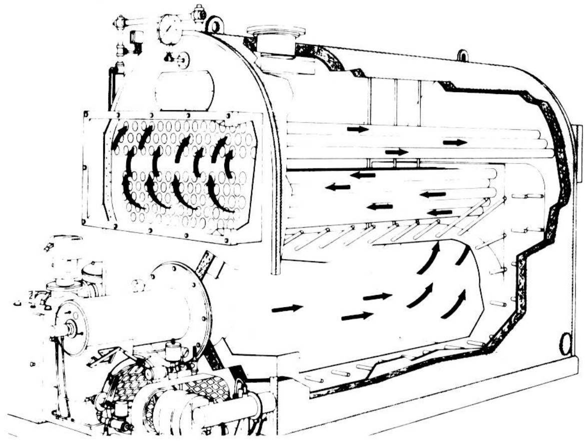


Fig. 5 Firebox Boiler

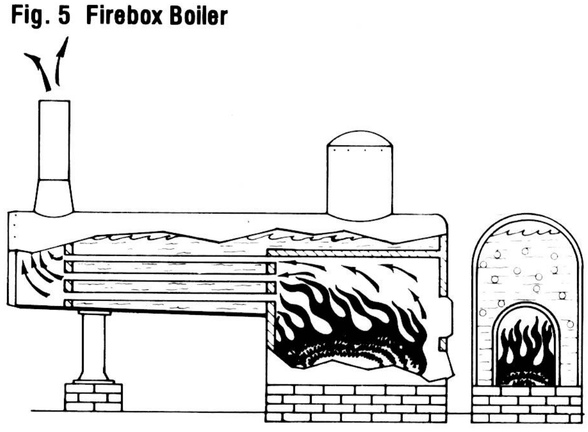


Fig. 6 Locomotive Type Boiler

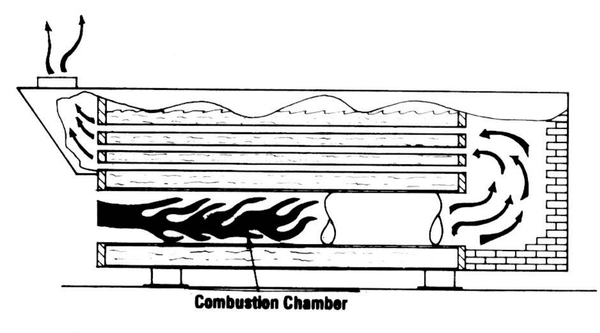


Fig. 7 Scotch Marine Boiler

the furnace is cooled completely by water, no refractory furnace is required. The radiant heat from the combustion is transferred directly through the metal wall of the furnace chamber to the water. This allows the furnace walls to become a heat transfer surface—a surface particularly effective because of the high temperature differential between the flame and the boiler water.

A modified Scotch boiler design as used in the standard firetube package boiler is the most common firetube boiler used today. There are two variations of the Scotch boiler design. These are called Wetback and Dryback as shown in Fig. 8 and Fig 9. These names refer to the design of the rear of the combustion chamber which must be either water-jacketed or lined with high-temperature insulating material, such as refractory, to protect it from the heat of combustion.

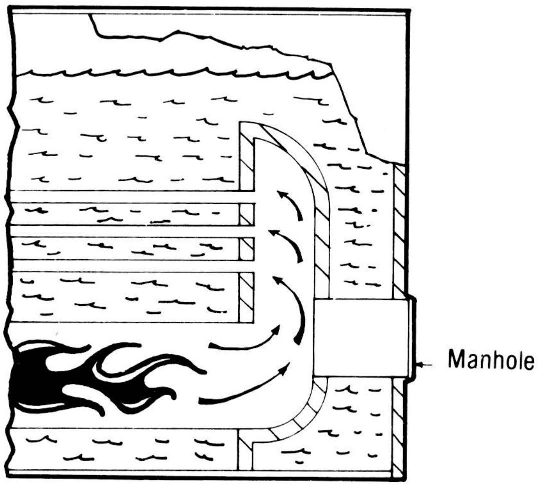


Fig. 8 Wetback

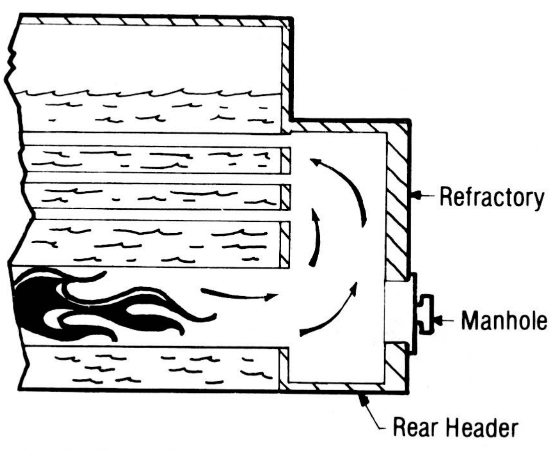


Fig. 9 Dryback

The Wetback boiler gains some additional heating surface; however, it is more difficult to service because access to the back end of the boiler tubes is limited. The only such access normally provided is a 16-inch manhole in the rear water header or through the furnace tube.

The Dryback boiler is easier to service because the rear doors can be opened or removed for access to the insulating or refractory material. The refractory or insulation lining may deteriorate over a period of time. If this lining is not properly maintained, efficiency may be reduced because the flue gases will bypass the heating surface on three- and four-pass designs, the radiation loss through the rear doors will increase, and the metal doors will be damaged.

The number of boiler passes for a firetube boiler refers to the number of horizontal runs the flue gases take between the furnace and the flue gas outlet. The combustion chamber or furnace is considered the first pass; each separate set of firetubes provides additional passes as shown in Fig. 10..

The number of gas passes in a firetube boiler does not determine its efficiency. For the same total number and size of tubes (same tube heating surface), increasing the number of passes increases the length the flue gas must travel because the gases must pass through tubes in series rather than parallel. This increases the flue gas velocity within the tubes but does little to change the total time for the hot gases to flow from furnace to outlet in contact with tube heating surface.

The increased gas velocity in some cases may improve heat transfer by increasing turbulence to the gases as they travel through the tubes. Generally, however, increasing the number of passes and resultant velocity of the gases increases the resistance to flow and forces the combustion air blower to consume more power.

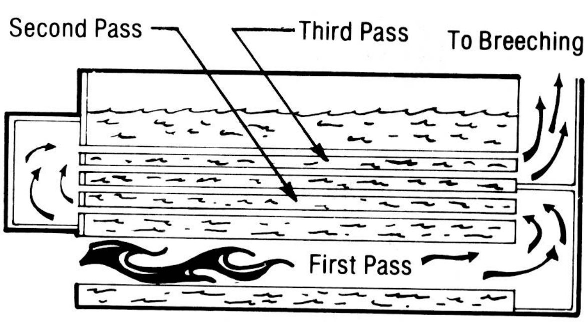


Fig. 10 Boiler Passes

One additional firetube boiler generally only used where space is limited and steam requirements are small is the Vertical Firetube Boiler as shown in Fig. 11. This is a variation of the firebox boiler with the water-jacketed furnace and vertical tubes.

Characteristics of the various types of firetube boilers relative to operational limitations are approximate in Table 1.

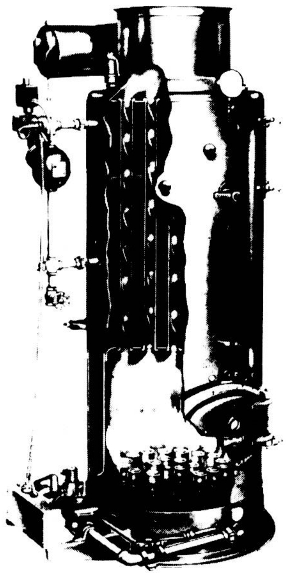


Fig. 11 Vertical Firetube Boiler

Boiler Type	Max. Pressure	Max BoHP Range	Max BTU Input Range
HRT	150 psig	30-300	1.25 to 12.5 Million
Firebox	200 psig	10-600	420,000 to 25 Million
Package "Scotch"	300 psig	10-1000	420,000 to 42 Million
Vertical Firetube	200 psig	2-300	80,000 to 12.5 Million

Table 1

3.2 Watertube Boilers

As the name implies, water circulates within the tubes of a watertube boiler. These tubes usually are connected between two or more cylindrical drums. The higher drum is called the steam drum and is maintained approximately half full of water. The lower drum is filled completely with water and is the low point of the boiler. Sludge that may develop in the boiler gravitates to the low point and can be drawn off the bottom of this lower drum, commonly called the mud drum.

A cross-sectional view of a typical small field-erected watertube boiler is shown in Fig. 12. Heating the "riser" tubes with hot flue gas causes circulation and releases steam in the steam drum. This principle is shown in Fig. 13.

Because watertube boilers can be easily designed for greater or lesser furnace volume using the same boiler convection heating surface, watertube boilers are particularly applicable to solid fuel firing. They are also applicable for a full range of sizes and for pressures from 50 psig to 5,000 psig. The present readily available minimum size of industrial watertube boilers is approximately 20,000 to 25,000 lbs/hr.—equivalent to 600 to 750 BoHP (boiler horsepower). Many watertube boilers operating today are in the 250- to 300-BoHP size range.

The maximum size of watertube boilers now handle approximately 10,000,000 lbs/hr. In industrial use, the largest are approximately 1,000,000 lbs/hr.

A typical current industrial watertube boiler for gas and oil firing is the packaged (shop-assembled) boiler shown in Fig. 14. Such packaged watertube boilers generally have a single burner up to approximately 125,000 lbs/hr. (approximately 4,000 BoHP) and are furnished in sizes up to approximately 250,000 lbs/hr.

Fig. 15 shows the baffles for directing flue gas flow. All watertube boilers have such gas baffles to assure contact between the hot gases and a maximum amount of the tube heating surface. The baffle design determines the number of gas passes and which tubes act as "risers" and "downcomers" as shown in Fig. 13. Leakage in the baffles causes hot flue gas to bypass a portion of the heating surface—decreasing the heat being transferred and lowering the boiler's efficiency.

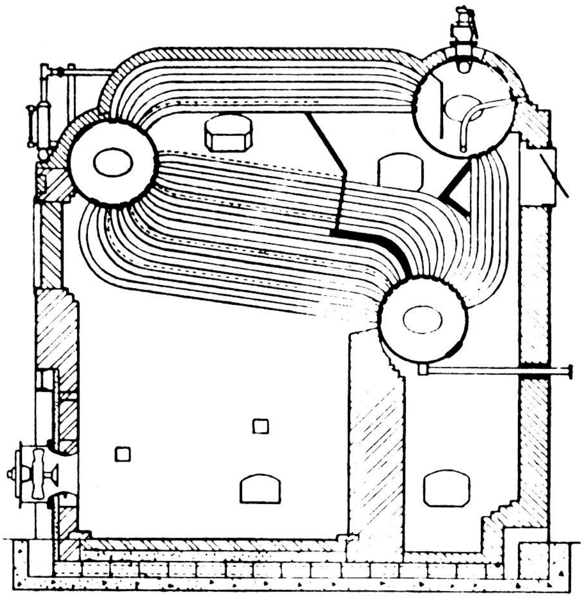


Fig. 12 Small Field-erected Watertube Boiler

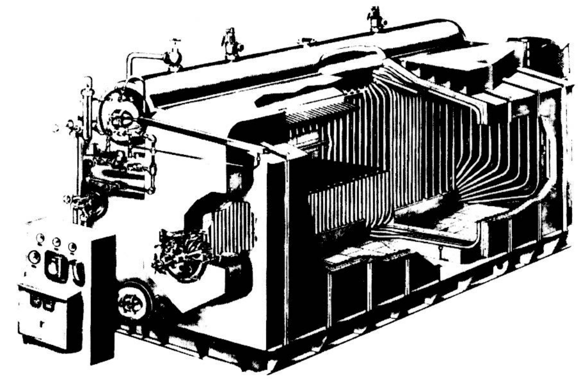
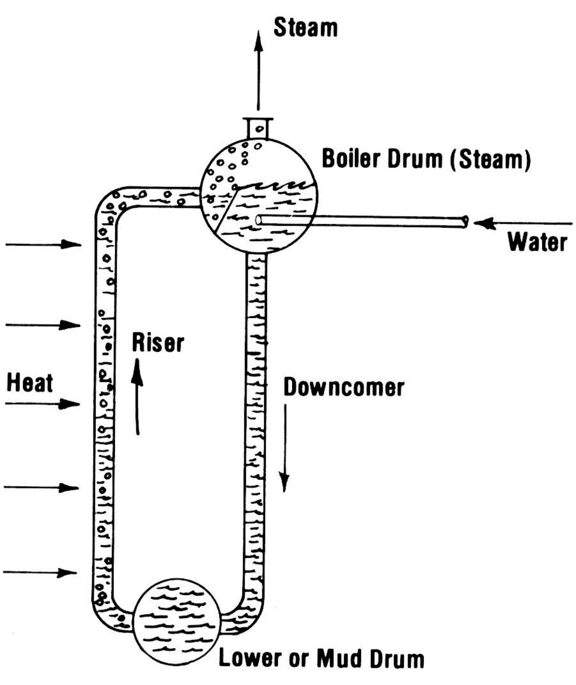


Fig. 14 Packaged Watertube Boiler

3.3 Steam Boilers—High and Low Pressure

Increasing the number of passes in a watertube boiler generally improves the efficiency because the gas flow is lengthened with relatively lower increase in gas velocity. The hot flue gas remains in contact with the tubes longer, and the flue gas flows over a greater portion of the tube surface. Improved heat transfer and greater cooling of the flue gas result. Just as in firetube boilers, however, increasing the number of passes causes the combustion air blower to use more power, and this should be balanced against the improvement in efficiency.



Source - S.G. Dukelow similar to a number of others

Fig. 13 Circulation of Watertube Boiler

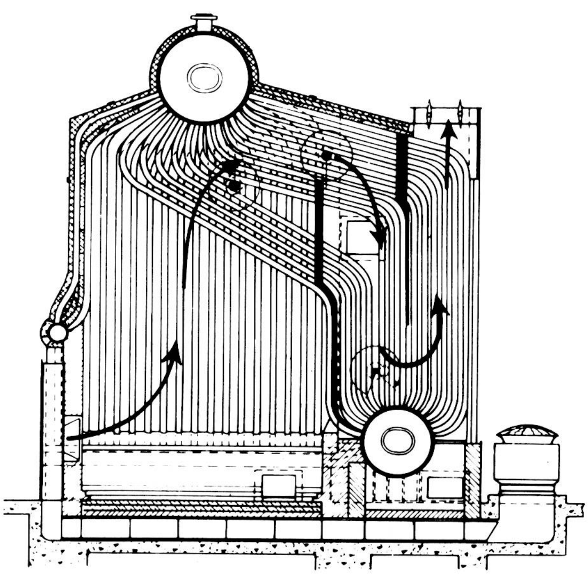


Fig. 15 Flue Gas Flow and Watertube Boiler