

HIGH PRESSURE BOILERS

Fifth Edition



AMERICAN TECHNICAL PUBLISHERS
ORLAND PARK, ILLINOIS 60467-5756

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High Pressure Boilers contains procedures commonly practiced in industry and the trade. Specific procedures vary with each task and must be performed by a qualified person. For maximum safety, always refer to specific manufacturer recommendations, insurance regulations, specific job site and plant procedures, applicable federal, state, and local regulations, and any authority having jurisdiction. The material contained is intended to be an educational resource for the user. American Technical Publishers, Inc. assumes no responsibility or liability in connection with this material or its use by any individual or organization.

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5 6 7 8 9 – 12 – 9 8 7 6 5 4 3 2 1

Printed in the United States of America

ISBN 978-0-8269-4322-4



This book is printed on recycled paper.



ACKNOWLEDGMENTS

The authors and publisher are grateful for the technical information and assistance provided by the following companies, organizations, and testing agencies:

ABB Inc., Drives & Power Electronics	Lab Safety Supply, Inc.
ASI Robicon	McDonnell & Miller
Aurora Pump	The Permutit Co., Inc.
Babcock and Wilcox Co.	Port of Seattle
CH2O	Quad/Graphics, Inc.
Cleaver-Brooks	Rosemount Analytical
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Eastern Illinois University Renewable Energy Center	Sarco Co., Inc.
Fireye, Inc.	Sterling
Fluke Corporation	Teledyne Farris Engineering
Fred Hutchinson Cancer Research Center	TSI Incorporated
Hach Company, USA	Worthington Pump
Jenkins Bros.	

Technical review assistance:

Stephen F. Connor
Cleaver-Brooks

Selected sample questions from actual licensing examinations included in Chapter 13, "Licensing," were provided by the following agencies, municipalities, provinces, and states:

Alaska Department of Labor and Workforce Development, Mechanical Inspection Section	National Institute for the Uniform Licensing of Power Engineers (NIULPE), Inc.
Province of Alberta, Municipal Affairs, Safety Services, Boilers and Pressure Vessels	Ohio Department of Commerce, Division of Industrial Compliance, Bureau of Operations and Maintenance
Arkansas Department of Labor, Boiler Inspection Division	City of Philadelphia, Department of Licenses and Inspections
Block and Associates	Salt Lake City Corporation, Department of Building and Housing Services
City of Dearborn, Department of Public Works, Building and Safety Division	City of Sioux City, Board of Examiners of Mechanical Stationary Engineers, Inspection Services Division
City of Elgin	City of Terre Haute, Office of the Board of Examining Engineers
The Commonwealth of Massachusetts, Department of Public Safety, Engineering Section, Division of Inspection	
City of Milwaukee, Building Inspection and Safety Engineering	

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INTRODUCTION

High Pressure Boilers provides information on the safe and efficient operation of high pressure boilers and related equipment. The content and the format of the book are specifically designed for use in preparation for obtaining a boiler operator's license. The extensive illustrations depict equipment details and sequential operating procedures for common boiler operator duties. Numerous photographs from leading equipment manufacturers are included to illustrate what a boiler operator may see on the job.

This new edition has been thoroughly updated to take a systems approach to boiler operations. Steam system topics include fittings, accessories, and condensate return. Feedwater system topics include feedwater fittings, accessories, and water treatment. Combustion system topics include combustion equipment, fuels and combustion, and combustion and boiler controls. Draft system topics include different types of draft systems and emissions requirements. Instrumentation and control system topics include measuring instruments and boiler control systems.

Topics with new coverage include power generation and distribution, steam turbines, instrumentation and control systems, and testing of combustion safety systems. Topics with expanded coverage include steam traps, superheated steam, shrink and swell, feedwater heaters and economizers, burner management systems, low NO_x burners, renewable energy fuels, combustion control systems, single-point and parallel positioning, variable-speed drives, and emissions requirements.

Key terms defined in the chapter are listed at the end of each chapter for review. Tech tips and case studies are located throughout the book to enhance the text content. Sample examinations following each chapter are used to test for understanding of information presented in the chapter. Also, an appendix, glossary, and index are provided for easy reference.

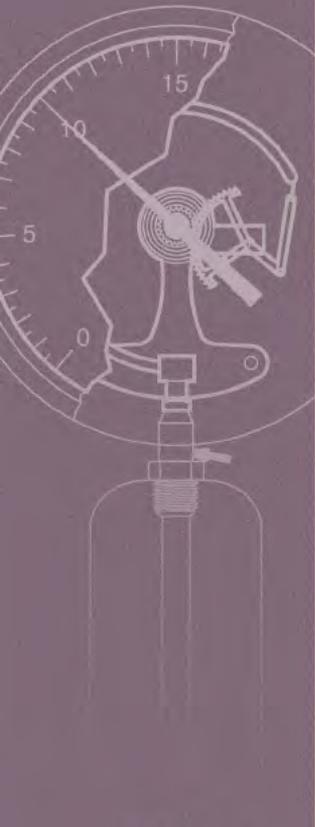
Media Clip icons on selected illustrations indicate that a video or animation is available that relates to the concepts presented in the illustration. The "Additional Activities" section at the end of each chapter references related CD-ROM content and other learning material included in the available *High Pressure Boilers Study Guide*. To obtain information on related training products, visit the American Technical Publishers website at www.go2atp.com.

The Publisher

INTERACTIVE CD-ROM FEATURES

The *High Pressure Boilers* Interactive CD-ROM provided in the back of the book is designed as a self-study aid to enhance and supplement the book content. Instructions for using the CD-ROM can be found on the last page of this book.

- Quick Quizzes® reinforce fundamental concepts with 10 interactive questions per chapter.
- An Illustrated Glossary provides a reference to commonly used terms and includes links to selected illustrations and media clips.
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- Boiler Operator Resources provide the learner with printable tables of supplemental information.
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ARROW SYMBOLS



Air



Water



Fuel Oil



Air to
Atmosphere



Gas



Steam



Condensate



Gases of
Combustion

CHAPTER

1

STEAM BOILERS

OBJECTIVES

- Describe symbol stamps and boiler classifications used in the ASME Code.
- Describe the operation of firetube boilers and list the common types.
- Describe the operation of watertube boilers and list the common types.
- List and describe boilers that use other fuels or use waste heat.
- Describe stress and explain design strategies used with boilers to minimize the effects of stress.
- Describe strategies used to improve boiler efficiency.
- Describe the construction of boilers, tubes, and tube sheets.

INTRODUCTION

Modern society depends on steam for many uses. Steam generated by boilers is used to supply electricity, water, and gas. Steam is also used for various industrial and commercial processes and to heat water and buildings.

A steam boiler is a closed vessel containing water. Water in a steam boiler is pressurized and turned into steam when heat is added. When a fuel is burned, the chemical energy (ability of the chemical to do work) in the fuel is transformed into heat. This heat, which is a form of energy, is contained in the steam. The total heat in steam from a specific point (usually 32°F) is called enthalpy.

STEAM BOILER TYPES

In the ASME Code, steam boilers are generally classified as either low pressure steam boilers or high pressure steam boilers. A *boiler* is a closed vessel used for heating water for generating steam by direct application of heat from combustion fuels or electricity. Steam boilers, however, can be further classified as firetube steam boilers or watertube steam boilers, as well as other ways. The type of steam boiler used in a particular application depends on the pressure, temperature, and amount of steam required.

ASME Code

Most states have adopted the *ASME Boiler and Pressure Vessel Code* (ASME Code). The *ASME Code* is a code written by ASME International (formerly the American Society of Mechanical Engineers) that governs and controls the types of material, methods of construction, and procedures used in the installation of boilers. The local pressure vessel code can be consulted to determine whether there are any differences from the ASME definitions. ASME symbol stamps indicate that parts within the boiler system conform to ASME standards. See **Figure 1-1**.

Boiler Classifications. Steam and hot water boilers may be further classified by the ASME Code, state codes, local codes, and ordinances. See **Appendix**. For example, boilers are classified by the ASME Code and many local jurisdictions as follows:

- Hot water supply boiler—low pressure hot water heating boiler having a volume exceeding 120 gal., a heat input exceeding 200,000 Btu/hr, or an operating temperature exceeding 200°F that provides hot water to be used externally to itself
- Low pressure hot water heating boiler—boiler in which water is heated for the purpose of supplying heated water at pressures not exceeding 160 psi (pounds per square inch) and temperatures not exceeding 250°F
- Low pressure steam heating boiler—boiler operated at pressures not exceeding 15 psi for steam
- Power hot water boiler (high temperature water boiler)—boiler used for heating water or liquid to a pressure exceeding 160 psi or to a temperature exceeding 250°F
- Power steam boiler—boiler in which steam or other vapor is generated at pressures exceeding 15 psi
- Small power boiler—a boiler with pressures exceeding 15 psi but not exceeding 100 psi and having less than 440,000 Btu/hr heat input

ASME SYMBOL STAMPS		
Symbol	Before 2013	2013 and After
Power Boiler		
Boiler Assembly		
Electric Boiler		
Miniature Boiler		
Pressure Piping		
Safety Valve		
Heating Boiler		

Figure 1-1. Both the older ASME symbol stamps and the 2013 designs indicate that boiler components conform to ASME standards.

Low Pressure Steam Boilers

A *low pressure steam boiler* is a boiler that operates at a steam pressure of not more than 15 psi. Low pressure steam boilers are used primarily for heating buildings, such as schools, apartments, warehouses, and factories, and for heating domestic water. These boilers can be firetube, watertube, or cast iron sectional designs.

Boiler size will vary based on the quantity of steam required. A low pressure steam boiler has a maximum allowable working pressure (MAWP) of 15 psi. This may vary in some jurisdictions.

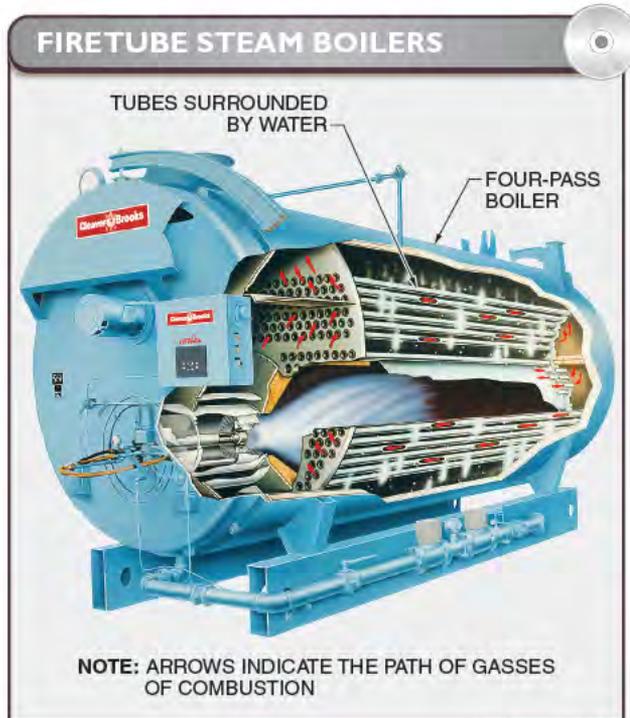
High Pressure Steam Boilers

A *high pressure steam boiler* is a boiler that operates at a steam pressure over 15 psi. High pressure boilers are also known as power boilers. *Boiler horsepower (BHP)* is the amount of energy equal to the evaporation of 34.5 lb of water/hr from and at a feedwater temperature of 212°F.

High pressure steam boilers are used in generating electricity and in industrial and commercial locations where steam is used for processes other than heating. Paper mills use steam for dryers. Breweries use steam in equipment such as brew kettles and mash tubs. Pasteurizing and sterilizing facilities use steam generated by high pressure boilers in their processes.

Firetube Steam Boilers

A *firetube steam boiler* is a boiler in which hot gases of combustion pass through tubes that are surrounded by water. See **Figure 1-2**. Firetube steam boilers may be either high pressure or low pressure boilers. Three common types of firetube steam boilers are the horizontal return tubular boiler, scotch marine boiler, and vertical firetube boiler.



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Figure 1-2. In firetube steam boilers, heat and gases of combustion pass through tubes surrounded by water.

All firetube boilers have the same basic operating principles. The heat produced by gases of combustion passes through the tubes while water surrounds the tubes. However, firetube boilers have different designs, based on application and installation considerations. Firetube boiler tubes are always measured by their outside diameter (OD).

Advantages and Disadvantages of Firetube Boilers. Firetube boilers are designed for pressure up to a maximum of 350 psi and approximately 750 BHP. The advantages of a firetube boiler are as follows:

- can be factory assembled, thus giving better quality control
- initial cost is less than a watertube boiler
- requires little or no setting (brickwork)
- contains larger volume of water for a given size compared to a watertube boiler
- requires less headroom

Some of these advantages can be disadvantages. Because of the large volume of water these boilers contain, serious damage may occur. See **Figure 1-3**. Knowledge of the following basic principles of boiler operation can prevent serious accidents:

- Water will boil and turn to steam when it reaches 212°F at atmospheric pressure at sea level.
- The higher the steam pressure, the higher the boiling point of water in the boiler.
- As steam pressure in a boiler increases, there is a corresponding increase in temperature.



Figure 1-3. A boiler explosion can cause property damage and loss of life.

4 HIGH PRESSURE BOILERS

When a steam boiler is operating at 100 pounds per square inch gauge pressure (psig), the temperature of the water and steam will be approximately 338°F. See **Figure 1-4**. If there is a sudden drop in pressure from 100 psig to 0 psig without a corresponding drop in water temperature, the water at 338°F immediately flashes into steam. The volume increases by a factor of 1600 when water flashes into steam. This can result in a disastrous explosion. At this temperature and pressure, approximately 13% of the water flashes into steam. The remaining water cools to 212°F at the corresponding atmospheric pressure. Specific steam pressure and temperature relationships are identified in the Properties of Saturated Steam tables. See **Appendix**.

STEAM PRESSURE AND TEMPERATURE RELATIONSHIP	
Gauge Pressure*	Temperature†
20	259
30	274
40	287
50	298
60	307
70	316
80	324
90	331
100	338
150	366
200	388
250	406
300	422

* in psi
† in °F

NOTE: gauge pressure + atmospheric pressure (14.7) = absolute pressure
100 psig + 14.7 = 114.7 psia

Figure 1-4. The boiling point of water increases as steam pressure increases.

Principles of Firetube Boiler Operation. When water is heated, it increases in volume and becomes less dense. This warmer water, now less dense, rises and the cooler water drops to take its place. See **Figure 1-5**. As steam bubbles begin to form, this steam/water mixture becomes less dense, which greatly increases the natural circulation in the boiler. The steam bubbles break through the surface and enter the steam space.

Adding tubes inside the shell increases the heating surface. Tube sheets at each end support the tubes. The

heating surface is the part of a boiler with water on one side and heat and gases of combustion on the other. See **Figure 1-6**. By increasing the heating surface, more heat is transferred from the gases of combustion. This results in more rapid water circulation and faster formation of steam bubbles.

When larger quantities of steam are generated, the thermal efficiency of the boiler increases. *Thermal efficiency* is the ratio of the heat absorbed by the boiler (output) to the heat available in the fuel (input). Modern firetube boilers with improved design and heat transfer rates have achieved thermal efficiency rates as high as 90% to 95%.



Firetube boilers are typically available as package boilers.

A *furnace* is the location where the combustion process takes place. A furnace is also known as a firebox or combustion chamber. Placing an internal furnace within the boiler shell greatly increases the heating surface. This also increases heat absorption through radiant heat transfer. See **Figure 1-7**. Also, the boiler creates steam more quickly.

Firetube boilers are designed as dry-back or wet-back boilers. A *dry-back boiler* is a firetube boiler with a refractory-lined rear door that directs the gases of combustion from the furnace to the second-pass tubes and then through succeeding passes if so designed. A *wet-back boiler* is a firetube boiler with three tubesheets and a turnaround chamber, with a water leg formed between the rear tubesheet and the chamber. This water leg directs the gases of combustion from the furnace to the second pass tubes and then through succeeding passes.

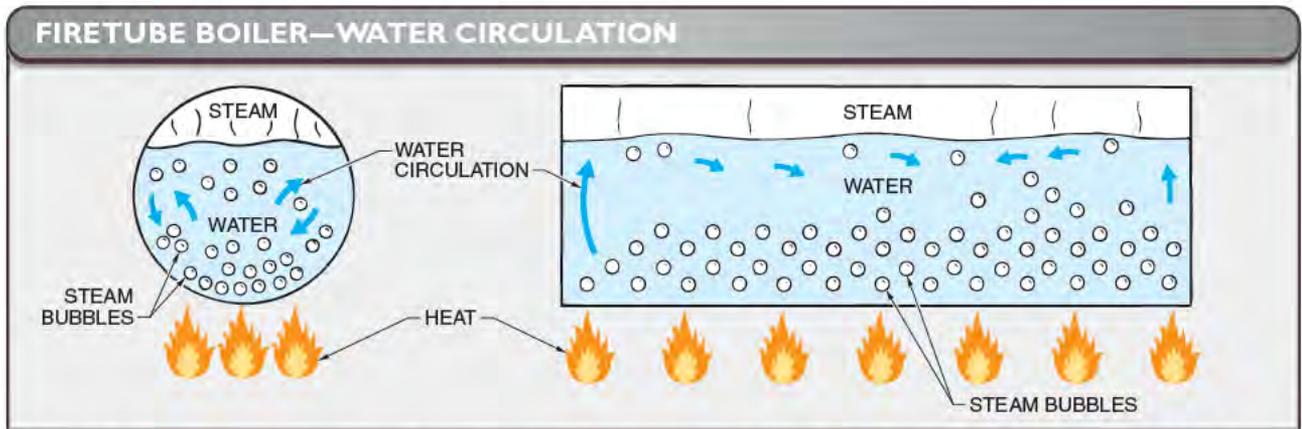


Figure 1-5. Water becomes less dense when heated. This warmer water rises, releasing steam bubbles, as cooler, denser water drops.

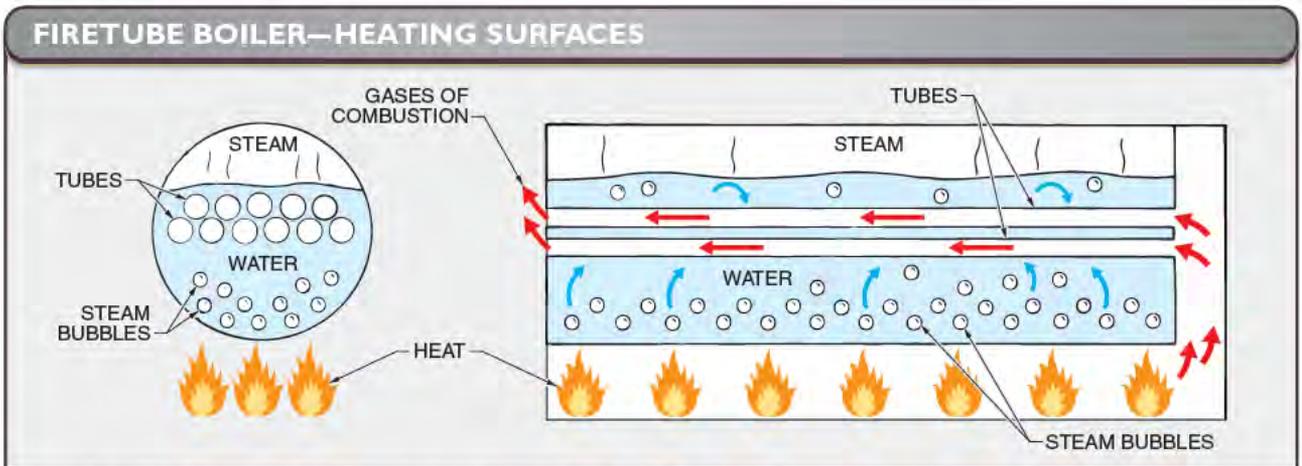


Figure 1-6. Boiler efficiency increases as the number of tubes in a boiler increases.

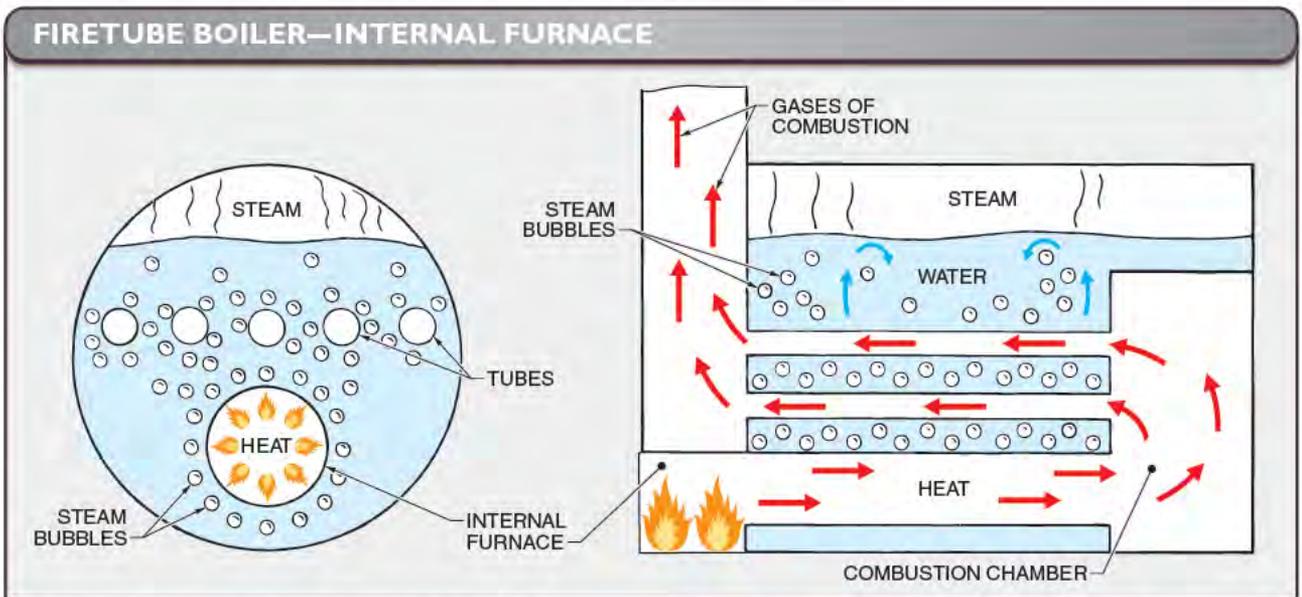


Figure 1-7. Adding an internal furnace to a boiler increases the heating surface, increasing boiler efficiency.

6 HIGH PRESSURE BOILERS

Horizontal Return Tubular Boilers. A *horizontal return tubular (HRT) boiler* is a firetube boiler consisting of a shell suspended over a firebox. See **Figure 1-8**. For many years, the HRT boiler was the workhorse in industry, however HRT boilers are less common now. HRT boilers are fired with fuel oil, gas, wood, or coal. The two methods used to support the drum are columns with a suspension sling and supporting brackets resting on metal plates in a brick setting.

The tube sheets of an HRT boiler are supported with through stays (braces) and diagonal stays. The feedwater pipe extends approximately three-fifths of the length of the drum. It enters through the front tube sheet. This helps to heat the feedwater and direct it to a cooler location in the boiler, which increases water circulation in the boiler.

Some HRT boilers are also equipped with a dry pipe to ensure a higher quality of steam. All connections to HRT boilers, such as steam nozzles and safety valve connections, must be manufactured according to the ASME Code.

The drum is riveted on older HRT boilers. Since the bottom of the drum is in the firebox, leaks often develop around the rivets. The bottom blowdown line also must pass through the firebox. The blowdown line is protected

by a sleeve and refractory or by a wrapping of protective insulation. Modern boiler drums are welded.

Scotch Marine Boilers. A *scotch marine boiler* is a firetube boiler with an internal furnace. See **Figure 1-9**. Scotch marine boilers were used on ships for many years and have a corrugated or plain furnace, combustion chamber, and tubes passing through the boiler to the front tube sheet. Scotch marine boilers used in industry today have been modified to meet the demands of stationary plants. The furnace is completely surrounded by water. This increases the boiler heating surface, which in turn increases boiler efficiency. By inserting baffles on the fire side, the boiler can be made into a two-, three-, or four-pass boiler. By increasing the number of passes, more heat can be absorbed by the water. This increases thermal efficiency.

Scotch marine boilers are designed as dry-back or wet-back boilers. The dry-back design has a refractory-lined chamber at the rear or top of the boiler that directs the gases of combustion from the furnace to the first pass of tubes or from one section of tubes to another. The wet-back design has a water-cooled chamber at the rear or top of the boiler that directs the gases of combustion from the furnace to the first pass of tubes or from one section of tubes to another.

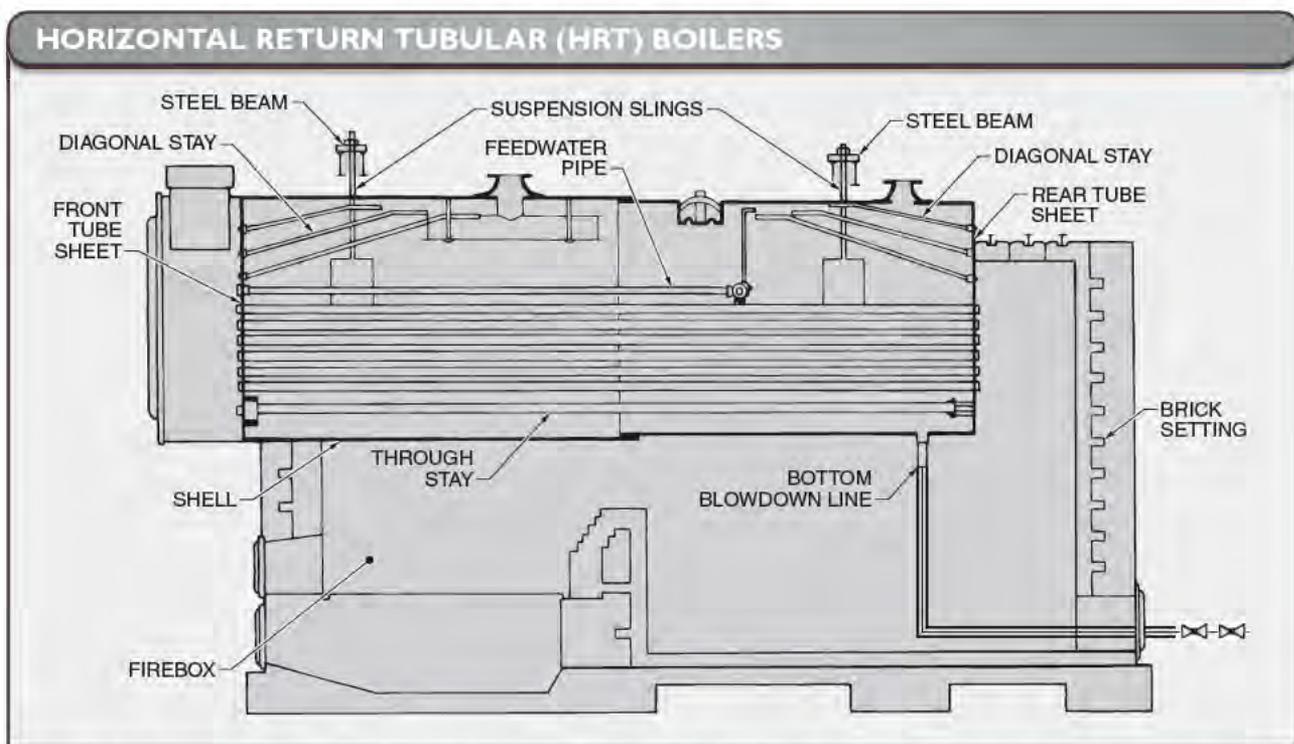


Figure 1-8. On an HRT boiler, the drum is suspended over the firebox. Stays are used to support the flat surfaces.