CHAPTER 31

BOILERS

BOILERS are pressure vessels designed to transfer heat (produced by combustion) to a fluid. The definition has been expanded to include transfer of heat from electrical resistance elements to the fluid or by direct action of electrodes on the fluid. In most boilers, the fluid is usually water in the form of liquid or steam. If the fluid being heated is air, the heat exchange device is called a furnace, not a boiler. The firebox, or combustion chamber, of some boilers is also called a furnace.

Excluding special and unusual fluids, materials, and methods, a boiler is a cast-iron, carbon or stainless steel, aluminum, or copper pressure vessel heat exchanger designed to (1) burn fossil fuels (or use electric current) and (2) transfer the released heat to water (in water boilers) or to water and steam (in steam boilers). Boiler heating surface is the area of fluid-backed surface exposed to the products of combustion, or the fire-side surface. Various manufacturers define allowable heat transfer rates in terms of heating surface based on their specific boiler design and material limitations. Boiler designs provide for connections to a piping system, which delivers heated fluid to the point of use and returns the cooled fluid to the boiler.

Chapters 6, 10, 11, 12, and 14 cover applications of heating boilers. Chapter 7 discusses cogeneration, which may require boilers.

CLASSIFICATIONS

Boilers may be grouped into classes based on working pressure and temperature, fuel used, material of construction, type of draft (natural or mechanical), and whether they are condensing or noncondensing. They may also be classified according to shape and size, application (such as heating or process), and the state of the output medium (steam or water). Boiler classifications are important to the specifying engineer because they affect performance, first cost, and space requirements. Excluding designed-to-order boilers, significant class descriptions are given in boiler catalogs or are available from the boiler manufacturer. The following basic classifications may be helpful.

Working Pressure and Temperature

With few exceptions, boilers are constructed to meet ASME *Boiler and Pressure Vessel Code*, Section IV (SCIV), Rules for Construction of Heating Boilers (low-pressure boilers), or Section I (SCI), Rules for Construction of Power Boilers (high-pressure boilers).

Low-pressure boilers are constructed for maximum working pressures of 15 psig steam and up to 160 psig hot water. Hot water boilers are limited to 250°F operating temperature. Operating and safety controls and relief valves, which limit temperature and pressure, are ancillary devices required to protect the boiler and prevent operation beyond design limits.

High-pressure boilers are designed to operate above 15 psig steam, or above 160 psig and/or 250°F for water boilers. Similarly, operating and safety controls and relief valves are required.

Steam boilers are generally available in standard sizes up to and above 100,000 lb steam/h (60,000 to over 100,000,000 Btu/h), many of which are used for space heating applications in both new and existing systems. On larger installations, they may also provide steam for auxiliary uses, such as hot water heat exchangers, absorption cooling, laundry, and sterilizers. In addition, many steam boilers provide steam at various temperatures and pressures for a wide variety of industrial processes.

Water boilers are generally available in standard sizes from 35,000 to over 100,000,000 Btu/h, many of which are in the low-pressure class and are used primarily for space heating applications in both new and existing systems. Some water boilers may be equipped with either internal or external heat exchangers for domestic water service.

Traditionally, boilers were rated by boiler horsepower, a unit of measurement with one boiler horsepower being equal to 33,475 Btu/h or the evaporation of 34.5 lb of water per hour at standard atmospheric pressure (14.7 psia) and 212°F.

Every steam or water boiler is rated for a maximum working pressure that is determined by the applicable boiler code under which it is constructed and tested. When installed, it also must be equipped at a minimum with operation and safety controls and pressure/temperature-relief devices mandated by such codes.

Fuel Used

Boilers may be designed to burn coal, wood, various grades of fuel oil, waste oil, various types of fuel gas, or to operate as electric boilers. A boiler designed for one specific fuel type may not be convertible to another type of fuel. Some boilers can be adapted to burn coal, oil, or gas. Several designs accommodate firing oil or gas, and other designs permit firing dual-fuel burning equipment. Accommodating various fuel burning equipment is a fundamental concern of boiler manufacturers, who can furnish details to a specifying engineer. The manufacturer is responsible for performance and rating according to the code or standard for the fuel used (see section on Performance Codes and Standards).

Construction Materials

Most noncondensing boilers are made with cast iron sections or steel. Some small boilers are made of copper or copper-clad steel. Condensing boilers are typically made of stainless steel or aluminum because copper, cast iron, and carbon steel will corrode because of acidic condensate.

Cast-iron sectional boilers generally are designed according to ASME SCIV requirements and range in size from 35,000 to 13,975,000 Btu/h gross output. They are constructed of individually cast sections, assembled into blocks (assemblies) of sections. Push or screw nipples, gaskets, and/or an external header join the

The preparation of this chapter is assigned to TC 6.1, Hydronic and Steam Equipment and Systems.

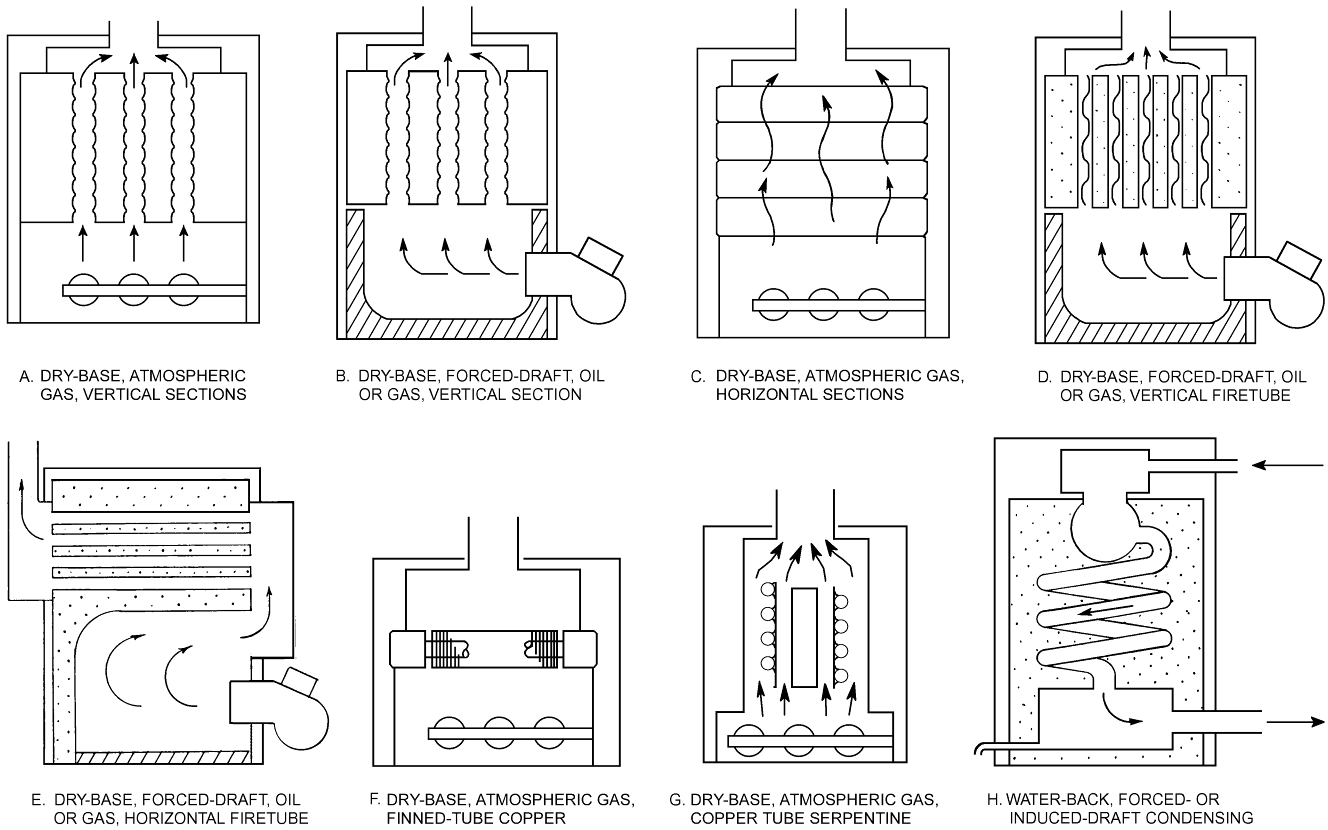

Fig. 1 Residential Boilers

sections pressure-tight and provide passages for the water, steam, and products of combustion. The number of sections assembled determines the boiler size and energy rating. Sections may be vertical or horizontal, the vertical design being more common (Figures 1A and 1C).

The boiler may be **dry-base** (the combustion chamber is beneath the fluid-backed sections), as in Figure 1B; **wet-base** (the combustion chamber is surrounded by fluid-backed sections, except for necessary openings), as in Figure 2A; or **wet-leg** (the combustion chamber top and sides are enclosed by fluid-backed sections), as in Figure 2B.

The three types of boilers can be designed to be equally efficient. Testing and rating standards apply equally to all three types. The wet-base design is easiest to adapt for combustible floor installations. Applicable codes usually demand a floor temperature under the boiler no higher than 90°F above room temperature. A steam boiler at 215°F or a water boiler at 240°F may not meet this requirement without appropriate floor insulation. Large cast-iron boilers are also made as water-tube units with external headers (Figure 2C).

Steel boilers generally range in size from 50,000 Btu/h to the largest boilers made. Designs are constructed to either ASME SCI or SCIV (or other applicable code) requirements. They are fabricated into one assembly of a given size and rating, usually by welding. The heat exchange surface past the combustion chamber is usually an assembly of vertical, horizontal, or slanted tubes. Boilers of the fire-tube design contain flue gases in tubes completely submerged in fluid (Figures 1D and 1E show residential units, and Figures 3A through 3D and Figure 4A show commercial units). Water-tube boilers contain fluid inside tubes with tube pattern arrangement providing for the combustion chamber (Figures 4C and 4D). The internal configuration may accommodate one or more flue gas passes. As with cast-iron sectional boilers, dry-base,

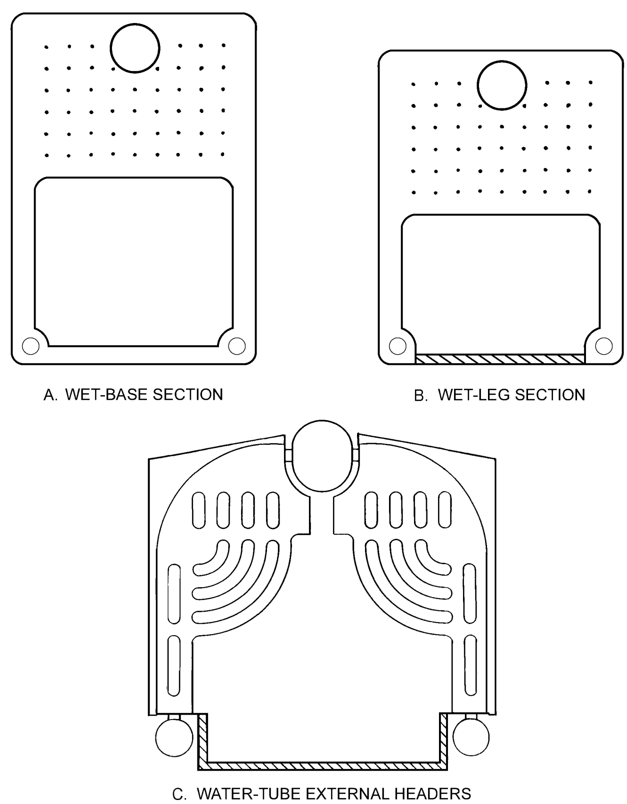

Fig. 2 Cast-Iron Commercial Boilers

wet-leg, or wet-base designs may be used. Most small steel boilers are of the dry-base, vertical fire-tube type (Figure 1D).

Larger boilers usually incorporate horizontal or slanted tubes; both fire-tube and water-tube designs are used. A popular horizontal fire-tube design for medium and large steel boilers is the **scotch marine**, which is characterized by a central fluid-backed cylindrical combustion chamber, surrounded by fire-tubes accommodating two or more flue gas passes, all within an outer shell (Figures 3A through 3D). In another horizontal fire-tube design, the combustion chamber has a similar central fluid-backed combustion chamber surrounded by fire tubes accommodating two or more flue gas passes, all within an outer shell. However, this design uses a dry base and wet-leg (or mud leg) (Figure 4A).

Copper boilers are usually some variation of the water-tube boiler. Parallel finned copper tube coils with headers, and serpentine copper tube units are most common (Figures 1F and 1G). Some are offered as wall-hung residential boilers. The commercial bent water-tube design is shown in Figure 4B. Natural gas is the usual fuel for copper boilers.

Stainless steel boilers usually are designed to operate with condensing flue gases. Most are single-pass, firetube design and are generally resistant to thermal shock. ASME limits operating temperatures to 210°F and 160 psig working pressure.

Aluminum boilers are also usually designed to operate with condensing flue gases. Typical designs incorporate either cast aluminum boiler sections or integrally finned aluminum tubing. ASME limits operating temperatures to 200°F and working pressure to 50 psig.

Type of Draft

Draft is the pressure difference that causes air and/or fuel to flow through a boiler or chimney. A **natural draft boiler** is designed to operate with a negative pressure in the combustion chamber and in the flue connection. The pressure difference is created by the tendency of hot gases to rise up a chimney or by the height of the boiler up to the draft control device. In a **mechanical draft boiler**, a fan or blower or other machinery creates the required pressure difference. These boilers may be either forced draft or induced draft. In a **forced-draft boiler**, air is forced into the combustion chamber to maintain a positive pressure in the combustion chamber and/or the space between the tubing and the jacket (breaching). In an **induced-draft boiler**, air is drawn into the combustion chamber to maintain a negative pressure in the combustion chamber.

Condensing or Noncondensing

Traditionally designed boilers must operate without condensing the flue gas in the boiler. This precaution was necessary to prevent corrosion of cast-iron, steel, or copper parts. Hot-water units were operated at 140°F minimum water temperature to prevent this corrosion and to reduce the likelihood of thermal shock.

Because a higher boiler efficiency can be achieved with a lower water temperature, the condensing boiler allows the flue gas water vapor to condense and drain. Full condensing boilers are now available from a large number of manufacturers. These boilers are specifically designed for operation with the low return water temperatures found in hot-water reset, water-source heat pump, two-pipe fan-coil, and reheat systems. Two types of commercial condensing boilers are shown in Figure 5. Figure 6 shows a typical relationship of overall condensing boiler efficiency to return water temperature. The dew point of 130°F shown in the figure varies with the percentage of hydrogen in the fuel and oxygen-carbon dioxide ratio, or excess air, in the flue gases. A condensing boiler is shown in Figure 1H. Condensing boilers can be of the fire-tube, water-tube, cast-iron, and cast-aluminum sectional design.

Condensing boilers are generally provided with high-turndown modulating burners and are more efficient than noncondensing boilers at any return water temperature (RWT), including noncondensing-temperature applications. Efficiencies of noncondensing boilers must be limited to avoid potential condensing and corrosion. Further efficiencies can be gained by using lower RWT or higher Δt as

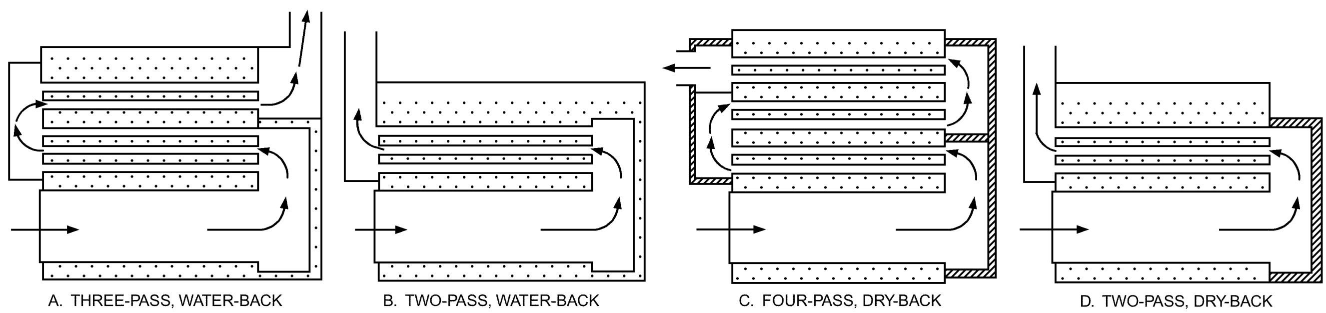

Fig. 3 Scotch Marine Commercial Boilers

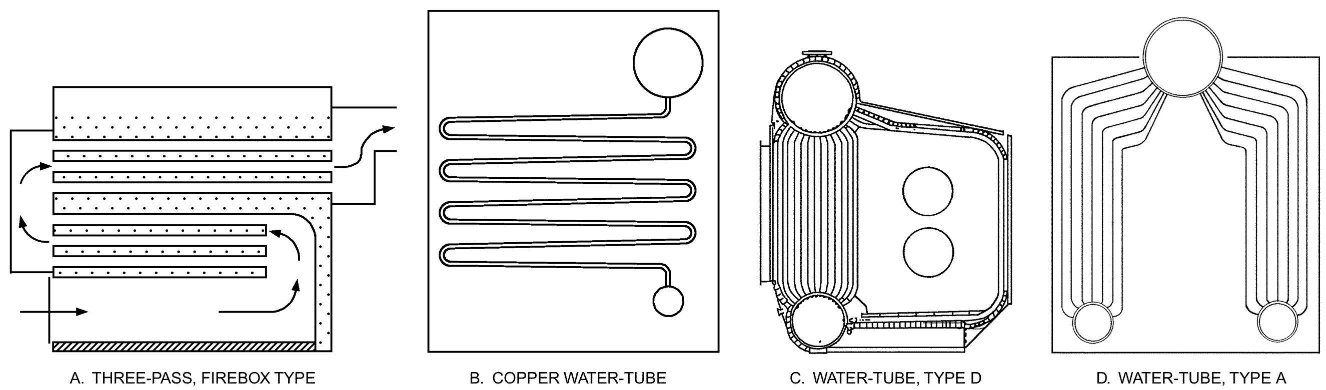

Fig. 4 Commercial Fire-Tube and Water-Tube Boilers

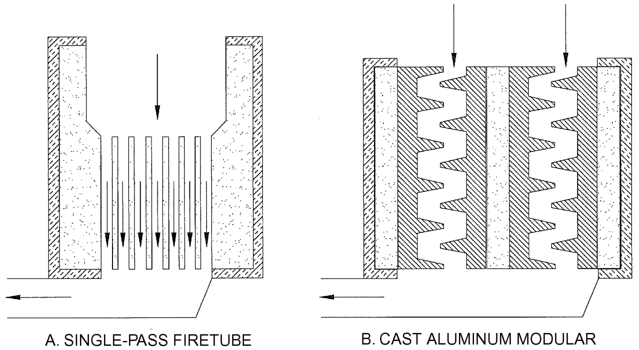

Fig. 5 Commercial Condensing Boilers

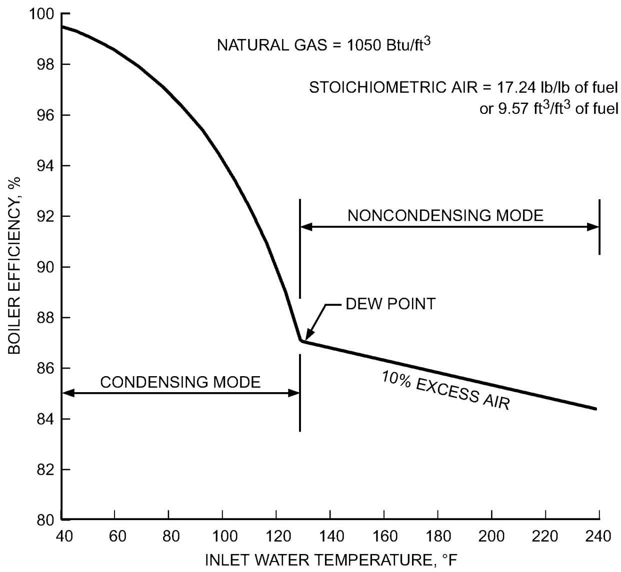

Fig. 6 Effect of Inlet Water Temperature on Efficiency of Condensing Boilers

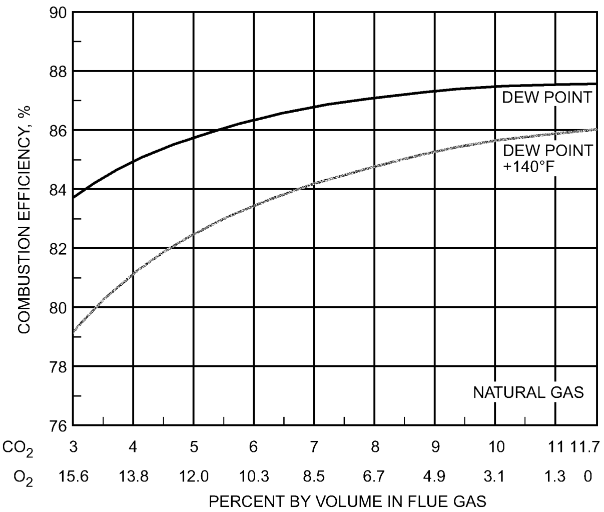

Fig. 7 Relationship of Dew Point, Carbon Dioxide, and Combustion Efficiency for Natural Gas

recommended by ASHRAE. For example, a natural gas condensing boiler operating with 60°F RWT in a water-source heat pump application has potential boiler efficiency in excess of 98% (Figure 6).

For maximum reliability and durability over extended product life, condensing boilers should be constructed from corrosion-resistant materials throughout the fireside combustion chamber and heat exchanger. These materials include certain grades of stainless steel and aluminum.

Noncondensing heat plant efficiency may in some cases be improved with the use of external flue gas-to-water economizers. The condensing medium may include domestic hot-water (DHW) preheat, steam condensate or hot-water return, fresh-water makeup, or other fluid sources in the 70 to 130°F range. The medium can also be used as a source of heat recovery in the HVAC system. Care must be taken to protect the noncondensing boiler from the low-temperature water return in the event of economizer service or control failure.

Figure 7 shows how dew point varies with a change in the percentages of oxygen/carbon dioxide for natural gas. Boilers that operate with a combustion efficiency and oxygen and carbon dioxide concentrations in the flue gas such that the flue gas temperature falls between the dew point and the dew point plus 140°F should be avoided, unless the venting is designed for condensation. This temperature typically occurs with boilers operating between 83 and 87% efficiency and the flue gas has an oxygen concentration of 7 to 10% and the carbon dioxide is 6 to 8%. Chapter 30 gives further details on chimneys.

The condensing portion of these boilers requires special material to resist the corrosive effects of the condensing flue gases. Cast iron, carbon steel, and copper are not suitable materials for the condensing section of a boiler. Certain stainless steels and aluminum alloys, however, are suitable. Commercial boiler installations can be adapted to condensing operation by adding a condensing heat exchanger in the flue gas vent.

Heat exchangers in the flue gas venting require a condensing medium such as (1) low pressure steam condensate or hot water return, (2) domestic water service, (3) fresh water makeup, or (4) other fluid sources in the 70 to 130°F range. The medium can also be a source of heat recovery in HVAC systems.

Wall Hung Boilers

Wall hung boilers are a type of small residential gas fired boiler developed to conserve space in buildings such as apartments and condominiums. These boilers are popular in Europe. The most common designs are mounted on outside walls. Combustion air enters through a pipe from the outdoors, and flue products are vented directly through another pipe to the outdoors. In some cases, the air intake pipe and vent pipe are concentric. Other designs mount adjacent to a chimney for venting and use indoor air for combustion. These units may be condensing or noncondensing. As these boilers are typically installed in the living space, provisions for proper venting and combustion air supply are very important.

Integrated (Combination) Boilers

Integrated boilers are relatively small, residential boilers that combine space heating and water heating in one appliance. They are usually wall mounted but may also be floor standing. They operate primarily on natural gas and are practical to install and operate. The most common designs have an additional heat exchanger and a storage tank to provide domestic hot water. Some designs (particularly European) do not have a storage tank. Instead they use a larger heat exchanger and the appropriate burner input to provide instantaneous domestic hot water.

Electric Boilers

Electric boilers are a separate class of boiler. Because no combustion occurs, a boiler heating surface and flue gas venting are unnecessary. The heating surface is the surface of the electric elements or electrodes immersed in the boiler water. The design of electric boilers is largely determined by the shape and heat release rate of the electric elements used. Electric boiler manufacturers' literature describes available size, shapes, voltages, ratings, and methods of control.

SELECTION PARAMETERS

Boiler selection should be based on a competent review of the following parameters:

All Boilers

- Application of terminal unit selection
- Applicable code under which the boiler is constructed and tested
- Gross boiler heat output
- Part- versus full-load efficiency (life-cycle cost)
- Total heat transfer surface area
- Water content weight or volume
- Auxiliary power requirement
- Cleaning and service access provisions for fireside and waterside heat transfer surfaces
- Space requirement and piping arrangement
- Water treatment requirement
- Operating personnel capabilities and maintenance/operation requirements
- Regulatory requirements for emissions, fuel usage/storage

Fuel-Fired Boilers

- Combustion chamber (furnace volume)
- Internal flow pattern of combustion products
- Combustion air and venting requirements
- Fuel availability/capability

Steam Boilers

- Steam quality

The codes and standards outlined in the section on Performance Codes and Standards include requirements for minimum efficiency, maximum temperature, burner operating characteristics, and safety control. Test agency certification and labeling, which are published in boiler manufacturers' catalogs and shown on boiler rating plates, are generally sufficient for determining boiler steady-state operating characteristics. However, for noncondensing commercial and industrial boilers, these ratings typically do not consider part-load or seasonal efficiency, which is less than steady-state efficiency. Condensing boilers, generally provided with modulating burners, provide higher part- and full-load efficiency. Some boilers are not tested and rated by a recognized agency, and, therefore, do not bear the label of an agency. Nonrated boilers (rated and warranted only by the manufacturer) are used when jurisdictional codes or standards do not require a rating agency label. As previously indicated, almost without exception, both rated and nonrated boilers are of ASME Code construction and are marked accordingly.

EFFICIENCY: INPUT AND OUTPUT RATINGS

The efficiency of fuel-burning boilers is defined in the following ways: combustion, overall, and seasonal. However, manufacturers are not required to test or publish efficiencies that coincide with these industry definitions. Further explanation of boiler test requirements is found in the section on Performance Codes and Standards.

Combustion efficiency is input minus stack (flue gas outlet) loss, divided by input, and generally ranges from 75 to 86% for most noncondensing boilers. Condensing boilers generally operate in the range of 88 to 95% combustion efficiency.

Overall (or **thermal**) **efficiency** is gross energy output divided by energy input. Gross output is measured in the steam or water leaving the boiler and depends on the characteristics of the individual installation. Overall efficiency of electric boilers is generally

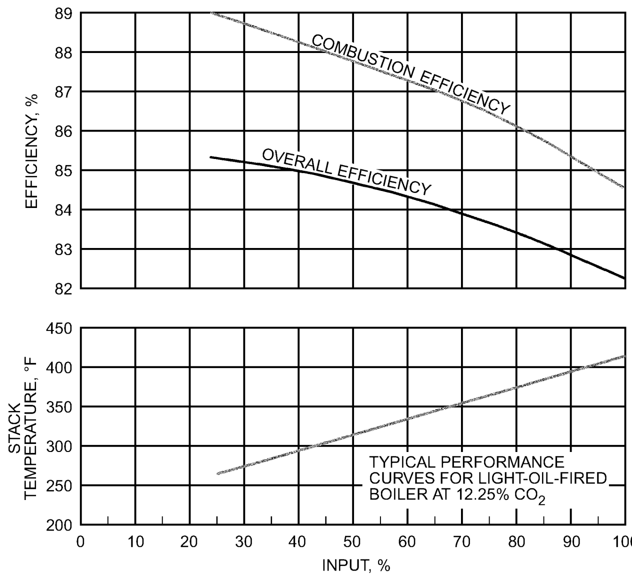

Fig. 8 Boiler Efficiency as Function of Fuel and Air Input

92 to 96%. Overall efficiency is lower than combustion efficiency by the percentage of heat lost from the outside surface of the boiler (radiation loss or jacket loss) and by off-cycle energy losses (for applications where the boiler cycles on and off). Overall efficiency can be precisely determined only under controlled laboratory test conditions, directly measuring the fuel input and the heat absorbed by the water or steam of the boiler. Precise efficiency measurements are generally not performed under field conditions because of the inability to control the required parameters and the high cost involved in performing such an analysis. An approximate combustion efficiency for noncondensing boilers can be determined under any operating condition by measuring flue gas temperature and percentage of CO_2 or O_2 in the flue gas and by consulting a chart or table for the fuel being used. The approximate combustion efficiency of a condensing boiler must include the energy transferred by condensation in the flue gas.

Seasonal efficiency is the actual operating efficiency that the boiler will achieve during the heating season at various loads. Because most heating boilers operate at part load, the part-load efficiency, including heat losses when the boiler is off, has a great effect on the seasonal efficiency. The difference in seasonal efficiency between a boiler with an on/off firing rate and one with modulating firing rate can be appreciable if the airflow through the boiler is modulated along with the fuel input. Figure 8 shows how efficiency increases at part load for a typical boiler equipped with a burner that can fire at reduced inputs while modulating both fuel and air. This increase in efficiency is due to the increase in the ratio of heat exchanger surface area to heat input as the firing rate is reduced.

PERFORMANCE CODES AND STANDARDS

Commercial heating boilers (i.e., boilers with inputs of 300,000 Btu/h and larger) at present are only tested for full-load steady-state efficiency according to standards developed by either (1) the Hydronics Institute Division of the Gas Appliance Manufacturers Association (GAMA) [formerly the Institute of Boiler and Radiator Manufacturers (I-B-R) and the Steel Boiler Institute (SBI)], (2) the American Gas Association (AGA), or (3) Underwriters Laboratories (UL).

The Hydronics Institute (1990) standard for rating cast-iron sectional, steel, and copper boilers bases performance on controlled test conditions for fuel inputs of 300,000 Btu/h and larger. The gross output obtained by the test is limited by such factors as flue gas temperature, draft, CO_2 in the flue gas, and minimum overall efficiency. This standard applies primarily to oil-fired equipment; however, it is also applied to forced draft gas fired or dual-fueled units.

Gas boilers are generally design-certified by an accredited testing laboratory based on tests conducted in accordance with ANSI *Standard* Z21.13 or UL *Standard* 795. Note that the Z21.13 test procedure may be applied to both condensing and noncondensing boilers. This test uses 80°F RWT, 100°F Δt, steady-state, full-load operation, and allows the presence of condensate to be ignored. Efficiencies published under this test procedure are generally not achieved in actual operation.

Instead of the HI-GAMA, AGA, and UL standards, test procedures for commercial-industrial and packaged fire-tube boilers are often performed based on ASME *Performance Test Code* 4.1 (1991). Units are tested for performance under controlled test conditions with minimum required levels of efficiency. Further, the American Boiler Manufacturers Association (ABMA) publishes several guidelines for the care and operation of commercial and industrial boilers and for control parameters.

Residential heating boilers (i.e., all gas- and oil-fired boilers with inputs less than 300,000 Btu/h in the United States) are rated according to standards developed by the U.S. Department of Energy (DOE). The procedure determines both on-cycle and off-cycle losses based on a laboratory test. The test results are applied to a computer program, which simulates an installation and predicts an annual fuel utilization efficiency (AFUE). The steady-state efficiency developed during the test is similar to combustion efficiency and is the basis for determining DOE **heating capacity**, a term similar to gross output. The AFUE represents the part-load efficiency at the average outdoor temperature and load for a typical boiler installed in the United States. Although this value is useful for comparing different boiler models, it is not meant to represent actual efficiency for a specific installation.

SIZING

Boiler sizing is the selection of boiler output capacity to meet connected load. The boiler gross output is the rate of heat delivered by the boiler to the system under continuous firing at rated input. Net rating (I-B-R rating) is gross output minus a fixed percentage (called the piping and pickup factor) to allow for an estimated average piping heat loss, plus an added load for initially heating up the water in a system (sometimes called **pickup**). This I-B-R piping and pickup factor is 1.15 for water boilers and ranges from 1.27 to 1.33 for steam boilers, with the smaller number applying as the boilers get larger. The net rating is calculated by dividing the gross output by the appropriate piping and pickup factor.

Piping loss is variable. If all piping is in the space defined as load, loss is zero. If piping runs through unheated spaces, heat loss from the piping may be much higher than accounted for by the fixed net rating factor. Pickup is also variable. When the actual connected load is less than design load, the pickup factor may be unnecessary.

On the coldest day, extra output (boiler and radiation) is needed to pickup the load from a shutdown or low night setback. If night setback is not used, or if no extended shutdown occurs, no pickup load exists. Standby capacity for pickup, if needed, can be in the form of excess capacity in baseload boilers or in a standby boiler.

If piping and pickup losses are negligible, the boiler gross output can be considered the design load. If piping loss and pickup load are large or variable, those loads should be calculated and equivalent gross boiler capacity added. Boiler capacity must be matched to the terminal unit and system delivery capacity. That is, if the boiler output is greater than the terminal output, the water temperature will rise and the boiler will cycle on the high-limit control, delivering an average input that is much lower than the boiler gross output. Significant oversizing of the boiler may result in a much lower overall boiler efficiency.

BURNER TYPES

Burners for installation on boilers are grouped generally by fuel used and pressure type. Fuel groupings include fuel oil, natural gas, propane, wood, or coal. A **dual-fuel burner** may use two or more fuels (e.g., No. 2 fuel oil and natural gas). The pressure type refers to whether the burner is atmospheric or a fan is used for pressurization. In **atmospheric burners**, firing generally natural gas or propane, the fuel is introduced across a drilled orifice manifold where it contacts combustion air and is ignited. The chimney or flue produces a natural draft to remove the products of combustion. In **power burners**, a fan pushes combustion air into a burner or combustion chamber under positive pressure where it mixes with the fuel and is ignited. The products of combustion are pushed through the combustion chamber and boiler by the fan, then flow through the chimney by natural draft, or induced draft caused by a chimney fan.

Burners may also be classified by method of fuel atomization. In **air atomization**, fuel oil at 80 to 300 psig is pumped through a nozzle orifice to create a fine mist. The fuel-rich mist is mixed with combustion air provided by a fan and is ignited at the burner. In **steam atomization**, generally used on heavy grades of fuel oil, high-pressure steam is mixed with pressurized fuel oil through a nozzle orifice to heat the oil and reduce the oil's viscosity to create a fine mist. The mist is mixed with combustion air provided by a fan and is ignited at the burner.

BOILER CONTROLS

Boiler controls provide automatic regulation of burner and boiler performance to ensure safe and efficient operation. Operating and combustion controls regulate the rate of fuel input in response to a signal representing load change (demand), so that the average boiler output equals the load within some accepted tolerance. Water level and flame safety controls cut off fuel flow when unsafe conditions develop. The National Fire Protection Association (NFPA) Code 85, *Boiler and Combustion Systems Hazard Code* (NFPA 2007), is generally accepted as the governing code for boiler control systems. Other requirements from insurance companies or local governing agencies may also be applicable. Often, the governing agency having jurisdiction may specify specific requirements that the heating system designer or specifying engineer must comply with in the design. It is essential that the designer or engineer determine the applicable codes, and specify the controls and skills needed to complete the control system.

Operating Controls

Steam boilers are operated by boiler-mounted, pressure-actuated controls, which vary fuel input to the boiler. Traditional examples of burner controls were on/off, high/low/off, and modulating. Modulating controls infinitely vary fuel input from 100% down to a selected minimum set point. The ratio of maximum to minimum is the turndown ratio. The minimum input is usually between 5 and 33% (i.e., 20 to 1 down to 3 to 1 ratios); input depends on the size and type of fuel-burning equipment and system. High turndown ratios in noncondensing boilers must be considered carefully to prevent condensation at lower firing rates.

Hot-water boilers are operated by temperature-actuated controls that are usually mounted on the boiler. Traditionally, burner controls were the same as for steam boilers (i.e., on/off, high/low/off, and modulating). Modulating controls typically offer more precise water temperature control and higher efficiency than on/off or high/low controls, if airflow through the boiler is modulated along with fuel input.

Boiler reset controls can enhance the efficiency of hot-water boilers. These controls may operate with any of the burner controls mentioned previously. They automatically change the high-limit set point of the boiler to match the variable building load demands caused by changing outdoor temperatures. By keeping boiler water temperature as low as possible, efficiency is enhanced and standby losses are reduced.

Microprocessor-Based Control Systems. The introduction of microprocessor-based control systems has changed traditional operating controls on boilers. In the past, smaller boilers were equipped with on/off or high/low/off electromagnetic-relay-based burner operating controls with mercury switches, with larger boilers provided with modulating controls. The low cost and greater efficiency of microprocessor-based control systems has resulted in the availability of such controls on small factory-packaged boilers, and nearly all medium and larger boiler installations. The recent introduction of integrated combustion and burner safeguard microprocessor controllers has accelerated this availability.

Traditionally, most burner installations used a single actuator to drive the combustion air damper and fuel ratio valves through common linkages. Such installations were called **single-jackshaft** controls. The fuel ratio valves often used set screw cams to produce efficient combustion throughout the firing range of the burner. Tuning the burner involved positioning the set screws to adjust the cam, which in turn regulated the fuel ratio at various firing rates. Tuning was often cumbersome, and easily lost when set screws loosened. Single-jackshaft control also invariably meant compromises were made in tuning, generally resulting in inefficient combustion with high excess air ratios at low firing rates. Current technology eliminates the single-jackshaft, using "linkless" burners with individual actuators controlling the combustion air damper and each fuel valve. With the high-speed processing ability of the microprocessors, individual actuators can quickly and accurately respond to changes in load, ensuring efficient combustion throughout the full firing range. When oxygen analyzers are installed to measure the oxygen content of the flue gas, microprocessor combustion controllers can modulate the combustion air damper and fuel valve actuators to ensure optimal combustion efficiency.

Water Level Controls

Maintaining proper water level in a boiler is of paramount concern. Should water level drop below a preset limit, damage may occur from overheating of boiler surfaces, resulting in cracking of cast-iron sections, or plastic deformation of steel tubes and tubesheets. Such a condition is known as **dry-firing** of the boiler. The installation of a low-water cutoff switch to stop fuel flow to the burner is necessary to prevent damage from dry firing.

To maintain proper water levels, different methods may be used. Smaller boilers generally use a boiler feedwater controller to cause a feedwater pump to pump water directly to the boiler to maintain proper water level. In larger installations, a feedwater piping loop may serve several boilers in parallel. In such an installation, each boiler has a feedwater valve controlled by a feedwater controller mounted on the boiler. The controller modulates the feedwater valve to maintain proper water level in the boiler. Simple feedwater control systems use water level as the control parameter to modulate the feedwater valve. Such systems are considered **single-element** feedwater systems. In larger boiler installations where steam is generated, the steam flow rate or rate of change of steam pressure may also be monitored with a signal sent to the feedwater controller. If the controller is programmed to modulate the feedwater valve based on both water level and steam flow rate or rate of change of pressure, the feedwater control system is referred to a **two-element** system. A **three-element** system uses water level, steam flow rate, and rate of pressure change to modulate the feedwater valve.

FLAME SAFEGUARD CONTROLS

Flame safeguard controls monitor flame condition and shut fuel flow to the burner in the event of an unsafe condition. The safety circuit of a flame safeguard control system typically includes switch contacts for low-water cutoff, high limits, air proving switches, redundant safety and operating controls, and flame monitors. Flame monitors typically sue either infrared or ultraviolet scanners to monitor flame condition and deactivate the burner in the event of nonignition or other unsafe flame condition. Flame safeguard controllers usually use preprogrammed algorithms to operate a burner and cycle it through stages of operation. The first stage is a purge cycle wherein the boiler's combustion chamber is flushed with combustion air to remove any unspent fuel and products of combustion that remain from the previous cycle. After purging, the pilot flame is ignited and the main fuel introduced into the burner and ignited. In the absence of a pilot fuel, such as with direct electronic spark ignition, the main fuel is introduced and ignited. In either case, the flame monitor determines whether ignition has occurred and whether the resulting flame is proper. If ignition has failed, or flame is not indicated, the flame monitor cuts off fuel flow, causing a postpurge cycle to rid the combustion chamber of unspent fuel and products of combustion. On restart, the burner again starts with a purge cycle and repeats the steps to ignition. When proper flame is established, the flame safeguard control system allows the operating control or combustion control system to control or modulate the burner firing rate.

Traditionally, flame safeguard systems were separate controllers from operating or combustion control systems. With the advent of microprocessor-based control systems, separate microprocessors control the individual functions of flame safeguard and combustion control. Recently introduced burner controllers provide an integrated control with algorithms for both flame safeguard and combustion control.

REFERENCES

ANSI. 2004. Gas-fired low-pressure steam and hot water boilers. *Standard* Z21.13-2004/CSA 4.9-2004. CSA International, Mississauga, Ontario.

ASME. 2007. Rules for construction of power boilers. *Boiler and Pressure Vessel Code*, Section I-2007. American Society of Mechanical Engineers, New York.

ASME. 2007. Rules for construction of heating boilers. *Boiler and Pressure Vessel Code*, Section IV-2007. American Society of Mechanical Engineers, New York.

ASME. 2007. Recommended rules for the care and operation of heating boilers. *Boiler and Pressure Vessel Code*, Section VI-2007. American Society of Mechanical Engineers, New York.

ASME. 2007. Recommended rules for the care of power of boilers. *Boiler and Pressure Vessel Code*, Section VII-2007. American Society of Mechanical Engineers, New York.

Hydronics Institute. 1990. *Testing and rating standard for heating boilers*, 6th ed. Hydronics Institute, Berkeley Heights, NJ.

BIBLIOGRAPHY

ABMA. 1999. *Packaged boiler engineering manual*. American Boiler Manufacturers Association, Arlington, VA.

ASME. 1998. Steam generating units. *Performance Test Code* 4. American Society of Mechanical Engineers, New York.

ASME. 2006. Controls and safety devices for automatically fired boilers, *Standard* CSD-1-2006. American Society of Mechanical Engineers, New York.

NFPA. 2007. Boiler and combustion systems hazard code. NFPA *Code* 85-2007. National Fire Protection Association, Quincy, MA.

Strehlow, R.A. 1984. *Combustion fundamentals.* McGraw-Hill, New York.

Woodruff, E.B., H.B. Lammers, and T.F. Lammers. 1984. *Steam-plant operation*, 5th ed. McGraw-Hill, New York.

UL. 2006. Commercial-industrial gas heating equipment. *Standard* 795. Underwriters Laboratories, Northbrook, IL.