Boiler Systems

Course No: M04-007

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HVAC

BOILER SYSTEMS

Contents

1 Introduction

The boiler is a closed vessel used to generate steam and hot water for heat or power. Within this vessel, water is contained and steam is produced and collected or hot water is produced. Heat is needed to change the water to the required medium. The most commonly used fuel sources for producing large volumes of steam or hot water are fuel oil, coal, or gas. Boilers come in many types and varieties. The following sections will describe in brief these various types of boilers, and the components they are composed of.

Boiler Types

Steam Boilers

A high-pressure steam boiler operates at pressures greater than 15 psig. One advantage of the high-pressure boiler is the reduced size of the boiler and steam piping. A low-pressure steam boiler operates at pressures less than 15 psig. An advantage of the low-pressure boiler is the simpler design and operation; no pressure reducing valves are required, and the water chemical treatment is less costly and complex.

Hot Water Boilers

A high-temperature hot water (HTHW) boiler furnishes water at a temperature greater than 250 °F or at a pressure higher than 160 psig. HTHW systems can carry greater heat to end locations than the lower temperature systems. A low-temperature hot water boiler furnishes water at a temperature less than 250 °F and a pressure less than 160 psig.

Hot water boilers usually require pumps to circulate the hot water and require power for pumping. Steam boilers do not require the pumps, but they do need larger piping. High-pressure steam systems will also require pressure reducing valves.

The efficiency of a boiler increases as the heating surface of the boiler increases. Figures B-1 and B-2 show that, with a larger heating surface, more heat is transferred to the water, and the amount of steam produced increases while using the same amount of fuel.

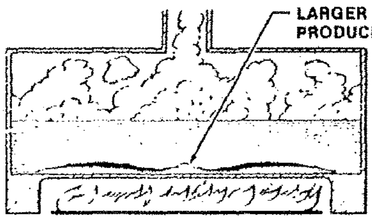

Figure B-1

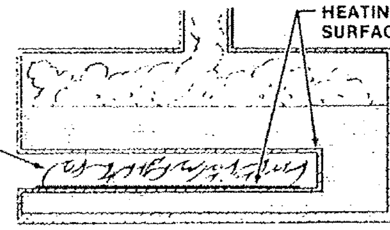

Figure B-2

Source: Steingrass 1986. Used with permission of American Technical Publishers, Inc.

Boilers are classified based on their physical arrangement of the working fluid, the combustion gases, and the type of working fluid or heat carrier used.

Firetube Boilers

The largest percentage of small to medium-sized industrial boilers are firetube boilers (Figure B-3). The name comes from the tubes through which the flue gases flow. As the flue gases flow through the tubes, heat from the flue gases transfers to the water surrounding the tubes. Steam or hot water is generated in the process.

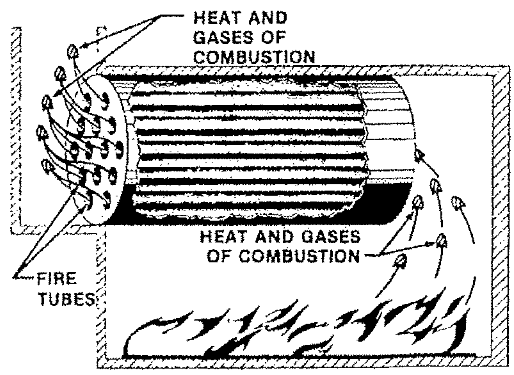

Figure B-3. Firetube Boiler.

Source: Steingrass 1986. Used with permission of American Technical Publishers, Inc.

The most common firetube boilers used today are the Wetback and Dryback boilers. Both are variations of the Scotch boiler. Their names refer to the design of the rear of the combustion chamber, which is water-lined (Wetback) or lined with a high-temperature insulating material (Dryback).

The Wetback boiler (Figure B-4) has more heating surface, but is more difficult to service because of limited access.

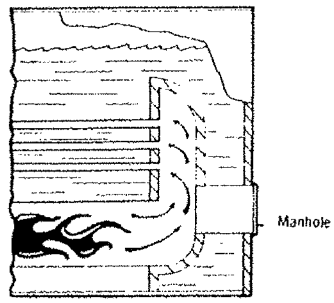

Figure B-4. Wetback Boiler.

Source: Dukelow 1983. Used with permission of Kansas State University, Manhattan.

The Dryback boiler (Figure B-5) is easier to service, but its insulation may deteriorate over a period of time, and its efficiency may be reduced if the insulation is not properly maintained.

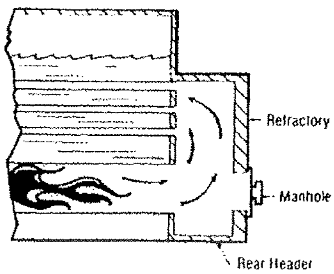

Figure B-5. Dryback Boiler.

Source: Dukelow 1983. Used with permission of Kansas State University, Manhattan.

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 Figure B-6.

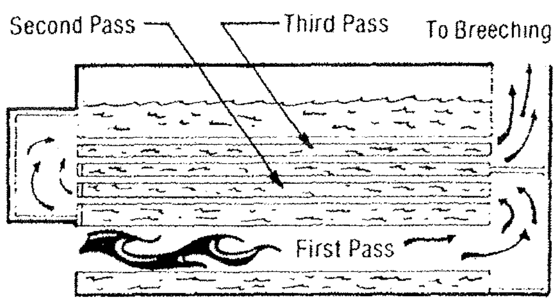

Figure B-6. Boiler Passes.

Source: Dukelow 1983. Used with permission of Kansas State University, Manhattan.

Note that the number of passes does not determine the efficiency of a firetube boiler. Generally, increased passes increase consumption of air blower power due to increased resistance to flow.

Watertube Boilers

The watertube boiler gets its name from the circulation of water through the boiler tubes. The tubes generally connect two cylindrical drums. The higher drum—the steam drum—is half filled with water. The lower drum—the mud drum—is filled completely with water. The lower drum collects any sludge that may develop. The heating of the riser tubes causes a release of steam in the steam drum. A packaged watertube boiler is shown in Figure B-7. Hot water can be generated using the same principle.

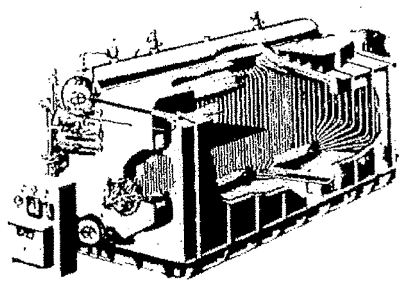

Figure B-7. Watertube Boiler.

Source: Dukelow 1983. Used with permission of Kansas State University, Manhattan.

Watertube boilers are applicable for a wide range of sizes and pressures. Pressures range from 50 to 5,000 psig. Sizes range from 20,000 to 1,000,000 lb/h of steam for industrial watertube boilers. Watertube boilers using solid fuels require greater spacing between the boiler tubes than boilers using liquid and gaseous fuels. This requirement is due to the buildup of ash residue and other particulates on pipes, which reduces air circulation around the pipes. This makes converting a gas- or oil-fired boiler to a coal-firing boiler difficult. Conversion from a coal boiler to a gas or oil boiler is more easily accomplished.

Cast Iron Sectional Boilers

Cast iron sectional boilers are also called watertube cast iron boilers, even though there are no tubes in them. These boilers can be expanded by adding sections. As shown in Figure B-8, the combustion gases flow around the sections that contain water.

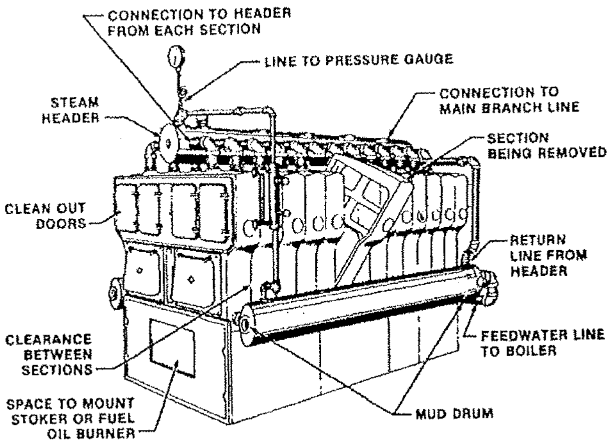

Figure B-8. Cast Iron Sectional Boiler.

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Forced Draft Boilers

A forced draft boiler (Figure B-9) consists of a burner and a blower. Air is pushed through the burner wind box.

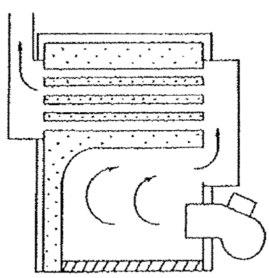

Figure B-9. Forced Draft Boiler.

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Natural Draft Boilers

The draft in the natural draft boiler is caused by the difference in weight of the column of flue gases within the stack, and a corresponding column of equal dimensions outside. The intensity of the draft is negative and is expressed in inches of water.

Induced Draft Boilers

A fan is used to pull the air and combustion products through the boiler. The fan is located in an area of the boiler that will allow it to suck particles through the boiler, not permitting ash, etc., to settle and clog the air passage. If this is not done, the boiler will become dirty inside and inefficient.

Boiler Components

The main components of a boiler are:

- Feedwater system—supplies the water to the boiler.
- Fuel and combustion system—supplies fuel for making heat and provides air for combustion.
- Steam/water system—collects and controls the steam or water.

Each of these components can be further broken down into more specific components. Figure B-10 illustrates the location of various boiler components for a steam boiler. Descriptions of these components and their functions are provided in the pages following the figure.

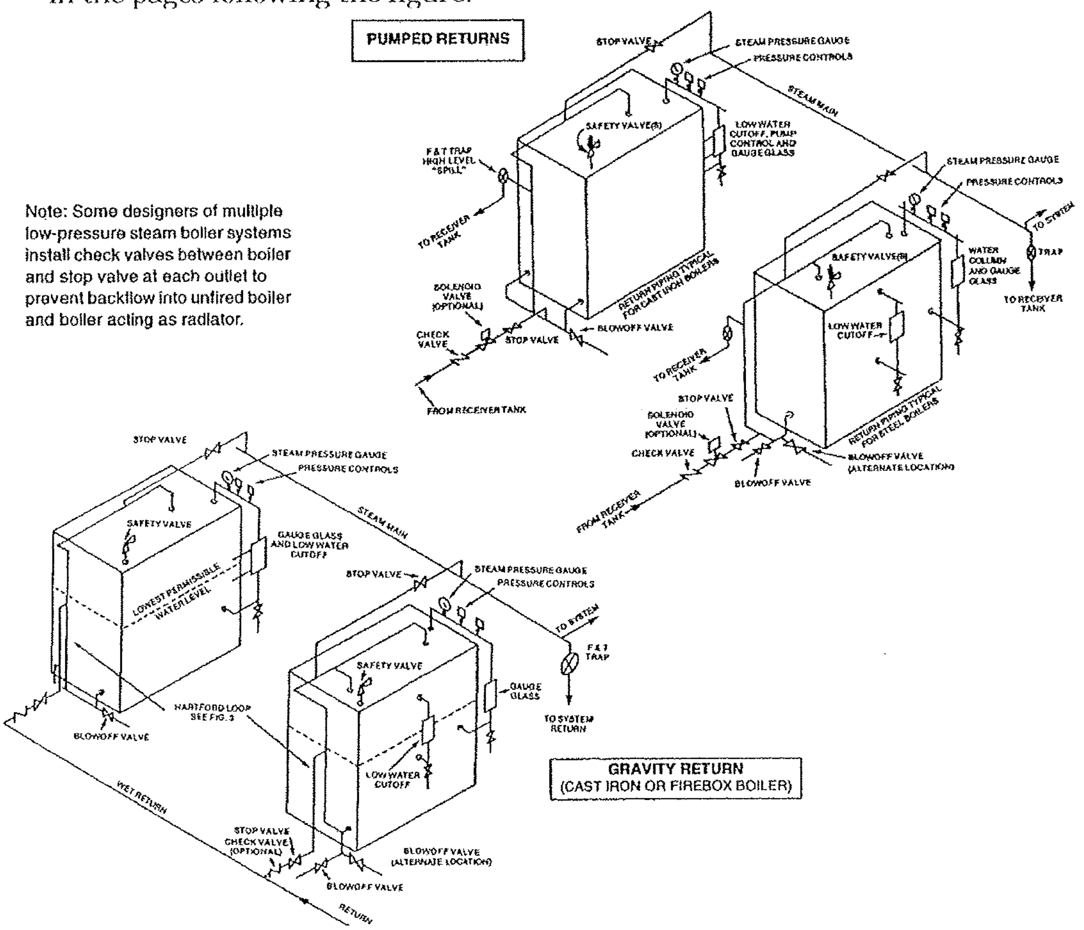

Figure B-10. Steam Boiler.

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Components at the Boiler

Safety valve. Considered by many as the most important valve on a boiler, the safety valve will pop open when boiler pressure exceeds the maximum allowable working pressure. The valve is located at the highest part of the steam side of the boiler. No other valves should be located between the safety valve and the boiler. According to the American Society of Mechanical Engineers (ASME), safety valves should be tested every 30 days.

Safety relief valve. Used primarily on water boilers. As with the safety valve, the safety relief valve is an automatic pressure relieving device.

Steam/water pressure gauge. Shows the amount of pressure in the boiler in pounds per square inch (psi). The steam pressure gauge must be viewed easily, and connected to the highest part of the steam side of the boiler.

Water column. Indicates the water level in the boiler. Although the ASME code does not require a water column for all boilers, most steam boilers are equipped with one (Figure B-11).

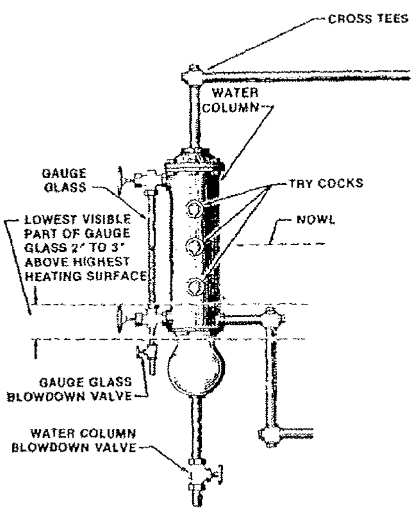

Figure B-11. Water Column and Components.
Source: Steingrass 1986. Used with permission of American Technical Publishers, Inc.

The water level may be determined using one of two methods. Checking the water level through the gauge glass is the easiest. The gauge glass blowdown valve allows the operator to "blow down" the lines to remove sludge and sediment to check the water level. This valve needs to be checked every day. The second method involves the use of try cocks. Try cocks are valves that are operated manually. With the try cocks opened and the boiler water level at its normal level, water will spill from the bottom try cock. A steam and water mixture will be discharged from the middle try cock, and the top try cock will disperse steam.

The water column blowdown valve is used to keep the water column and its lines free from sludge and sediment. This valve needs to be checked every day. Bottom blowdown valves are located at the lowest point of the water side of a boiler. Two valves may be used, one a quick-opening, the other a screw type.

Surface blowdown line. Located at the normal operating water level, the surface blowdown line removes the surface impurities, which prevent steam bubbles from breaking through the surface of the water.

Fusible plug. The ASME code requires the fusible plug only on coal-fired boilers; however, they may still be found on gas- and fuel-oil-fired burners. The fusible plug is the boiler's last warning of a low water level. When the water level is low, the tin in the plug melts and allows steam to escape causing a whistling noise to alert the operator.

Boiler vent. A 1/2 or 3/4 in. line with a valve on it coming off the highest part of the steam side of the boiler. The boiler vent must be kept open when filling the boiler with water to prevent the build up of pressure within the boiler. The boiler vent must be kept open when warming up the boiler to allow the air from the steam side to vent. The boiler vent must also be kept open when taking the boiler off-line to prevent a vacuum from forming. Try cocks may be used in the absence of a boiler vent. Safety valves should never be used to vent a boiler.

Pressure control. Located at the highest part of the steam side of the boiler, the pressure control is a switch that turns the burner on or off based on steam pressure.

Feedwater System Components

The feedwater system (Figure B-12) supplies the boiler with water at a certain temperature and pressure.

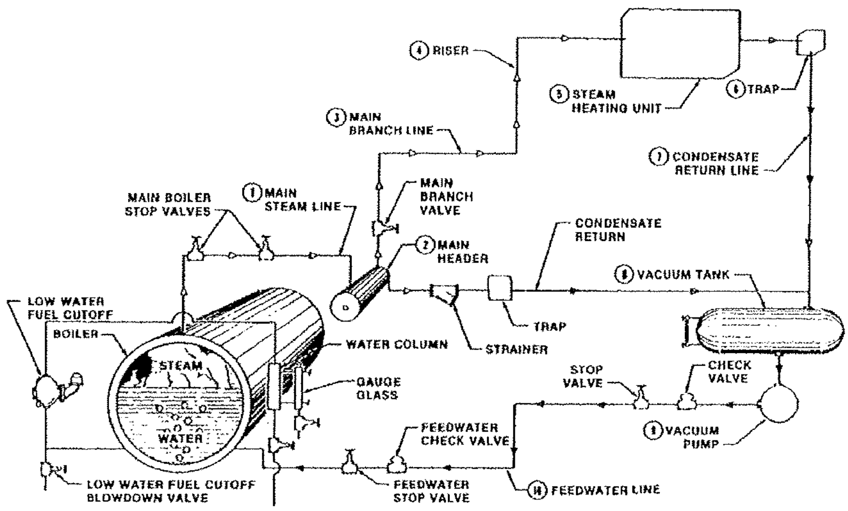

Figure B-12. Feedwater System.

Source: Steingrass 1986. Used with permission of American Technical Publishers, Inc.

Feedwater stop valve. Permits the flow of water to the boiler when opened. This valve should be located as close to the boiler as possible and is operated manually.

Feedwater check valve. Located between the stop valve and the feedwater pump, this valve allows the water to flow in one direction and prevents water from flowing out of the boiler into the feedwater line. This valve operates automatically.

Vacuum pump. The vacuum pump moves water from the vacuum tank to the boiler. During this process, the vacuum pump creates a vacuum on the return lines, which draws condensate back to the vacuum tank. The pump removes and discharges all air in the water to the atmosphere, and it discharges all the water back to the boiler.

City water makeup. Additional water needed in the system is called makeup water. This water replaces water lost due to leaks or blowing down the boiler. This additional water is added through the city makeup system, shown in Figure B-13. The system can be automatic or manual.

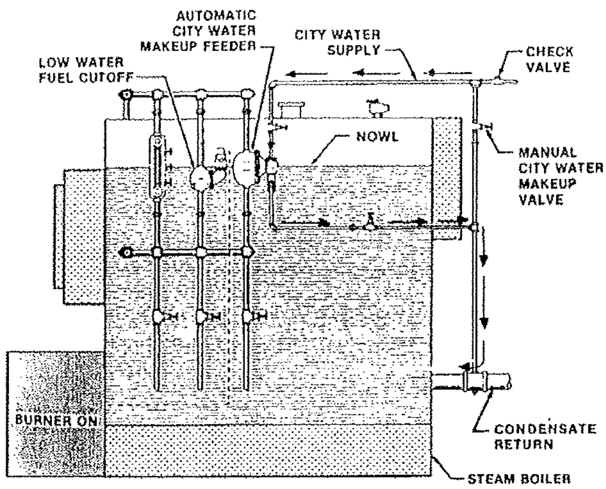

Figure B-13. Makeup System.

Source: Steingrass 1986. Used with permission of American Technical Publishers, Inc.

Low water fuel cutoff. The ASME code requires low pressure boilers to have a low water fuel cutoff. Located slightly below the normal operating water level, the low water fuel cutoff shuts off the burner when water level is low. This component should be checked daily.

Feedwater regulator. Located at the normal operating water level, the feedwater regulator maintains a constant water level in the boiler by starting and stopping the feedwater pump.

Fuel and Combustion System Components

In the combustion process, fuel is mixed with air, and is burned to produce heat necessary to operate the boiler. The types of fuel commonly used in low pressure boilers are fuel oil, gas, and coal. The factors determining the selection of fuel include the price and availability of the fuel, local pollution codes and regulations, and the boiler design. The combustion components will be discussed according to the different fuel systems.

Fuel oil system.

Fuel oil heaters: Used to heat some grades of oil for ease in pumping and used to heat other oils to allow for burning. There are many separate components necessary for the proper performance of the fuel oil heater.

Fuel oil strainers: The purpose of a strainer in the fuel oil system is to remove foreign matter. It will be necessary to clean these strainers more often when using heavier grades of fuel oil.

Fuel oil pump: The fuel oil pump draws the fuel oil from the fuel oil tank and delivers it to the burner at a controlled pressure.

Fuel oil burner: The fuel oil is delivered to the furnace in a fine spray via the fuel oil burner, providing efficient combustion. There are different types of fuel oil burners.

Gas system. In a gas system, gas burners supply the proper mixture of air and gas to the furnace so complete combustion is achieved. As with the fuel oil system, there are many components necessary to maintain safety and efficiency. Figure B-14 shows the various components of a gas burner system.

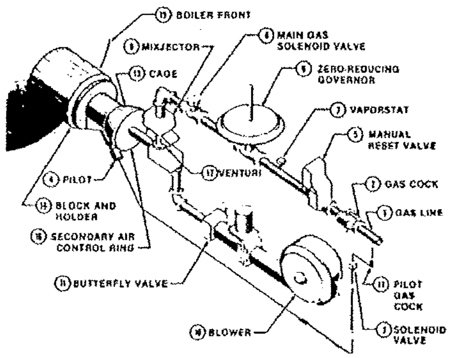

Figure B-14. Gas Burner System.
Source: Steingrass 1986. Used with permission of American Technical Publishers, Inc.

Gas train: A gas train consists of all components required to provide gas supply to the burner. Each regulator on the gas train must have a separate vent to the outside. Figure B-15 shows the different components of a gas train.

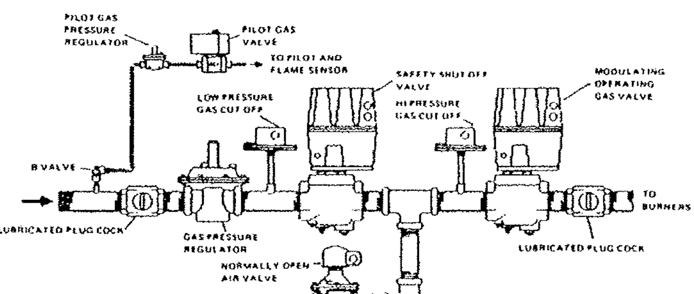

Figure B-15. Gas Train.
Source: Cleaver Brooks. Used with permission.

Coal systems. Coal can be fed using pulverizers, stokers, or by hand firing, which is rarely used anymore.

Stokers: A mechanical coal-feeding device that feeds the coal to the furnace consistently. Use of a stoker also increases efficiency because automatic feeding eliminates the need to open the fire door. The most common type of stoker used in the Army, Air Force, and Navy is the spreader (Figure B-16).

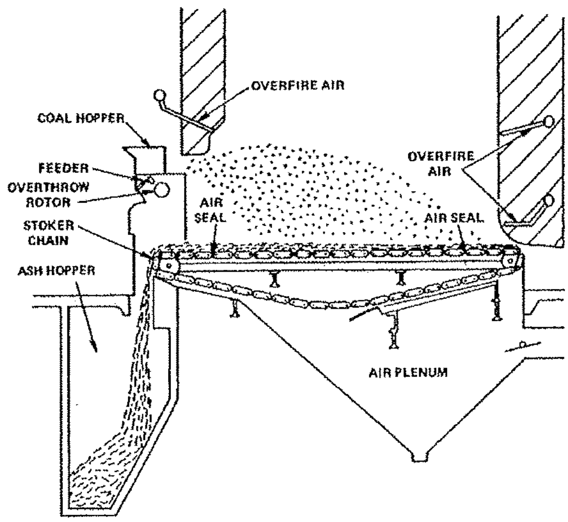

Figure B-16. Spreader Stoker.

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Automatic combustion controls. Safety and operational efficiency in combustion is maintained with the proper air to fuel mixture, and by controlling the firing rate of the fuel. Combustion controls regulate the fuel in proportion to steam/water demand, the air supply, and the ratio of air to the fuel supplies. The "ON/OFF" is the most common combustion control, which regulates the burner by the amount of steam pressure/water temperature in the boiler.

Steam/Hot Water Components

Steam is generated within the boiler. It is then piped to areas needing either heat or energy for other industrial applications.

Main steam/water stop valve (Figure B-17). Located on the main steam/water line, the purpose of this valve is to allow for cutting the boiler in on the line and for taking the boiler off-line. This valve should be an outside screw and yoke (OS&Y) valve (Figure B-18). A globe valve should never be used for a main steam/water stop valve. When an OS&Y valve is used, it is visually possible to tell when the valve is completely open or closed. The valve is open when the stem is up. A globe valve should not be used because it is difficult to know when the valve is completely open or closed. If it is partially open when steam shoots through, the valve will quickly erode, reducing its effectiveness as a stop.

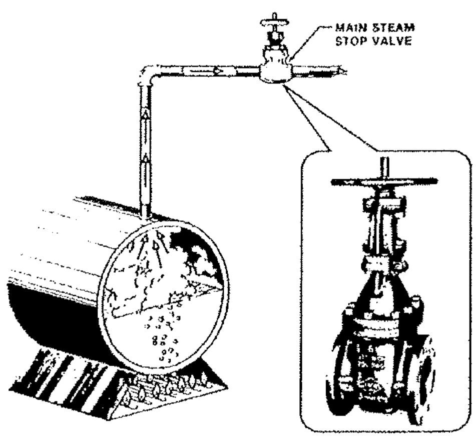

Figure B-17. Main Steam/Water Stop Valve.

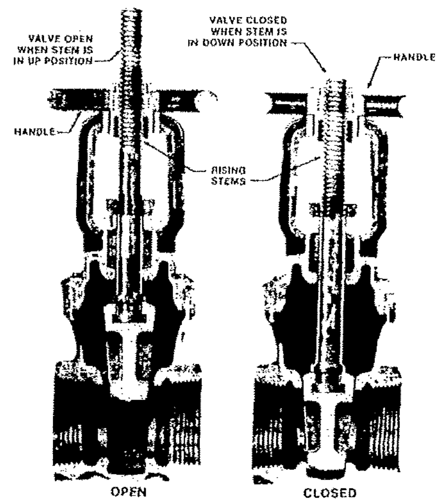

Figure B-18. OS&Y Valve.

Source: Steingrass 1986. Used with permission of American Technical Publishers, Inc.

Steam traps. The purpose of a steam trap is to remove the condensate that forms in a steam line during temperature drops. If the condensate is not removed from the steam line, water hammer will occur. Water hammer can cause pipes to rupture in some cases and disturbing noises in others. Steam traps should be located wherever condensate buildup can occur. These areas are the ends of the main steam branch header, the ends of the main steam branch line, and on each radiator or heat exchanger where steam gives up its heat. Steam strainers should be located in the steam line in front of the steam trap.

Return steam traps are no longer used, but may still be found in older systems. The return steam trap returns the condensate directly to the boiler.

Nonreturn steam traps are used on all low pressure steam systems. The nonreturn steam trap sends the condensate through a vacuum pump to a condensate return tank, which in turn pumps the steam to the boiler. There are three types of nonreturn steam traps. They are the inverted bucket steam trap, the thermostatic steam trap, and the float thermostatic steam trap.

Fuel Burners

Gas and oil are the primary types of fuel burners for packaged boilers. Burners must be able to perform five functions:

1. Deliver fuel to the combustion chamber
2. Deliver air to the combustion chamber
3. Mix the fuel and air
4. Ignite and burn the mixture
5. Remove the products of combustion.

Gas-fired burners. Gas burners are classified according to the pressure available at the gas inlet valve. They can be low pressure (2 to 8 oz per square inch), intermediate (8 oz to 2 psig), or high (2 to 50 psig).

A pilot burner usually is used to ignite gas burners. These pilots can either be continuous or lit each time the burner is started up and shut down after each use.

The gas burner can be modulated to provide satisfactory combustion. This is commonly done by adjusting the air and gas flow simultaneously by:

- using a gas valve and air damper in parallel
- varying gas pressure
- varying air pressure.

Oil-fired burners. The major difference between oil and gas burners is the fact that oil is pumped to the burner by a fuel oil pump. Also, in oil burners the fuel needs to be prepared so that it will burn properly. This preparation is done by atomization and vaporization. Atomization changes the oil into tiny droplets, and vaporization turns these tiny droplets to gas by the heat of the furnace. Oil burners are classified by the means in which the oil is atomized. These are:

- pressure
- steam or compressed air
- rotary.

Oil burners are typically ignited by a high electric voltage spark, or by a high temperature electric heating element.

2 Chemistry of Combustion

Chemical reactions are an important part of the combustion process in delivering energy in the form of heat to boiler surfaces. In fact, the chemical internal energy, which is the energy associated with the destruction and formation of chemical bonds between atoms, will either provide the necessary heat input or will not.

Fuels

Any material that can be burned to release energy is called a fuel. Most familiar fuels consist primarily of hydrogen and carbon, commonly known as hydrocarbon fuels, and they exist in all phases (i.e., coal, gasoline, and natural gas).

The major component of coal is carbon. Coal also contains varying amounts of oxygen, hydrogen, nitrogen, sulfur, moisture, and ash. The difficulty of analyzing coal's mass lies in the variety of its composition from one geographic location to another.

Most liquid hydrocarbon fuels are a mix of numerous hydrocarbons and are distilled from crude oil. The more volatile hydrocarbons vaporize first, forming gasoline. The less volatile fuels obtained during distillation are kerosene, diesel fuel, and fuel oil. The composition of a particular fuel depends on the source of the crude oil as well as on the refinery. Although liquid hydrocarbon fuels are mixtures of many different hydrocarbons, they are usually considered to be a single hydrocarbon for convenience in analysis. For example, gasoline is treated as octane (C_8H_{18}) and diesel fuel as dodecane ($C_{12}H_{26}$). Another common liquid hydrocarbon fuel is methyl alcohol (CH_3OH), also called methanol, which is used in some gasoline blends. The gaseous hydrocarbon fuel natural gas, which is a mixture of methane and smaller amounts of other gases, is sometimes treated as methane (CH_4) for simplicity.

Many types of fuel oils are available for heating and are broadly classified as distillate fuel oils (lighter oils) or residual fuel oils (heavier oils). ASTM has established specifications for fuel oil properties that subdivide the oils into various grades. Grades number 1 and 2 are distillate fuel oils. Grades 4 and 5 (light), 5 (heavy), and 6 are residual oils. Specifications for the grades are based on required characteristics of fuel oils for use in different type burners. Characteristics that determine grade classification and suitability for a given application are flash point, viscosity, pour point, water and sediment content, carbon residue, ash, distillation qualities, specific gravity, sulfur, carbon hydrogen content, and heating value. Not all of these are included in the ASTM standards.

Combustion

A chemical reaction during which a fuel is oxidized and a large quantity of energy is released is called combustion. Combustion can also be described as the rapid burning of fuel and oxygen that results in the release of heat. Approximately 14 to 15 lb of air is needed to burn a pound of fuel.

Types of Combustion

The three types of combustion are perfect, complete, and incomplete. *Perfect combustion* occurs when all the fuel is burned using only the theoretical amount of air. The theoretical amount of air is the amount of air used to achieve perfect combustion in a laboratory; this would include use of the primary and secondary air, and no excess air. These classifications of air will be explained in the section on efficient combustion. Perfect combustion is seldom, if ever, achieved in a boiler. *Complete combustion* occurs when all the fuel is burned using the minimum amount of air above the theoretical amount of air needed to burn the fuel. Complete combustion is the boiler operator's goal. When complete combustion is achieved, the fuel is burned at the highest combustion efficiency with minimum pollution. *Incomplete combustion* occurs when all the fuel is not burned, resulting in the formation of soot and smoke.

Combustibles

Air is necessary for combustion of fuel. On a mole or volume basis, dry air consists of 20.9 percent oxygen, 78.1 percent nitrogen, 0.9 percent argon, and small amounts of carbon dioxide, helium, neon, and hydrogen. In the analysis of combustion processes, the argon is treated as nitrogen, and the other trace amounts of gases are disregarded. So the oxygen is approximately 21 percent, and nitrogen approximately 79 percent by mole numbers. Pure oxygen O_2 is used as an oxidizer only in some specialized applications where air cannot be used. Oxygen will support combustion, but it is not a combustible.

A combustible is a material or element that will catch fire and burn when subjected to fire. A combustible will not burn without the introduction of other elements. Oxygen is not easily kindled or excited without the presence of other elements. Nitrogen is not a combustible and will not support the combustion process.

Efficient Combustion

Air used in the combustion process is classified into three types: primary air, secondary air, and excess air. *Primary air* controls the rate of combustion, which determines the amount of fuel that can be burned. *Secondary air* controls combustion efficiency by controlling how completely the fuel is burned. *Excess air* is air supplied to the boiler that is more than the theoretical amount needed to burn the fuel.

When firing a boiler, the operator's goal is to achieve complete combustion. This means burning all fuel using the minimum amount of air. Obtaining complete combustion requires the proper mixture of fuel and air, atomization, and fuel temperature, and enough time to finish the combustion process. Atomization is the breaking of fuel into smaller particles so it will be better exposed to air, which will improve combustion. High firing rates burn the maximum amount of fuel and require more air than low firing rates.

The boiler operator must maintain efficient combustion to minimize the amount of smoke produced. Efficient combustion reduces fuel costs and air pollution. If combustion is not completed before gases come in contact with the cooler surfaces, as the gases cool, they will produce soot and smoke. These will build up and act as an insulator, reducing the amount of heat transfer to the water.

The Combustion Process

Obviously, bringing oxygen into intimate contact with fuel will not start a combustion process. If it did, the whole world would be on fire. The fuel must be brought above its ignition temperature to start the combustion. The ignition temperatures and upper and lower flammability limits of various substances in atmospheric air are listed in Table B-1.

Substance	Molecular symbol	Lower flammability limit[a] %	Upper flammability limit[a] %	Ignition temperature[a] °F	References
Carbon (activated coke)	C			1220	Hartman (1958)
Carbon Monoxide	CO	12.5	74	1128	Scott *et al.* (1948)
Hydrogen	H_2	4.0	75.0	968	Zabetakis (1956)
Methane	CH_4	5.0	15.0	1301	*Gas Engineers Handbook (1965)*
Ethane	C_2H_6	3.0	12.5	968-1166	Trinks (1947)
Propane	C_3H_8	2.1	10.1	871	NFPA (1962)
Butane, n	C_4H_{10}	1.86	8.41	761	NFPA (1962)
Ethylene	C_2H_4	2.75	28.6	914	Scott *et al.* (1948)
Propylene	C_3H_6	2.00	11.1	856	Scott *et al.* (1948)
Acetylene	C_2H_2	2.50	81	763-824	Trinks (1947)
Sulfur	S			374	Hartman (1958)
Hydrogen Sulfide	H_2S	4.3	45.50	558	Scott *et al.* (1948)

Flammability limits adapted from Coward and Jones (1952)

[a] All values corrected to 60 °F, 30 in. Hg, dry

Table B-1. Ignition Temperatures and Flammability Limits

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Upper and lower flammability limits are simply the range within which an element or material has the capacity for combustion. In Table B-1, at 60 °F and at 30 in. of mercury (Hg), using methane (CH_4) for an example, combustion is most likely between 5 and 15 percent capacity for combustion. As the percentage of flammability for a given material goes up, the rate of combustion becomes greater.

Many questions about combustion processes can be answered quantitatively. Stoichiometry is the branch of chemistry that deals with the quantitative relationships between elements and compounds in chemical reactions. The atomic theory of matter is basic to stoichiometry. Table B-2 lists oxygen and air requirements for stoichiometric combustion of some pure combustible materials (or components) found in common fuels. For many combustion calculations, only approximate values for theoretical air are necessary. If complete information on the fuel is not available, values from Table B-3 can be used.

Constituent	Molecular Symbol	Combustion Reactions	Stoichiometric Oxygen and Air Requirements: lb/lb Fuel[a] O_2	lb/lb Fuel[a] Air	ft³/ft³ Fuel O_2	ft³/ft³ Fuel Air
Carbon (to CO)	C	$C + 0.5\alpha_2 \rightarrow CO$	1.33	5.75	--	--
Carbon (to CO_2)	C	$C + O_2 \rightarrow CO_2$	2.66	11.51	--	--
Carbon Monoxide	CO	$CO + 0.5\alpha_2 \rightarrow CO_2$	0.57	2.47	0.50	2.39
Hydrogen	H_2	$H2 + 0.5\alpha_2 \rightarrow H_2O$	7.94	34.28	0.50	2.39
Methane	CH_4	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	3.99	17.24	2.00	9.57
Ethane	C_2H_6	$C_2H_6 + 3.5O_2 \rightarrow 2CO_2 + 3H_2O$	3.72	16.09	3.50	16.75
Propane	C_3H_8	$C_3H_8 + 5O_2 = 3CO_2 + 4H_2O$	3.63	15.68	5.00	23.95
Butane	C_4H_{10}	$C_4H_{10} + 6.5O_2 = 4CO_2 + 5H_2O$	3.58	15.47	6.50	31.14
--	C_nH_{2n+2}	$C_nH_{2n+2} + (1.5n + 0.5)O_2 \rightarrow nCO_2 + (n+1)H_2O$	--	--	$1.5n + 0.5$	$7.18n + 2.39$
Ethylene	C_2H_4	$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$	3.42	14.78	3.00	14.38
Propylene	C_3H_6	$C_3H_6 + 4.5O_2 \rightarrow 3CO_2 + 3H_2O$	3.42	14.78	4.50	21.53
--	C_nH_{2n}	$C_nH_{2n} + 1.5nO_2 \rightarrow nCO_2 + nH_2O$	3.42	14.78	$1.50n$	$7.18n$
Acetylene	C_2H_2	$C_2H_2 + 2.5\alpha_2 \rightarrow 2CO_2 + H_2O$	3.07	13.27	2.50	11.96
--	C_nH_{2m}	$C_nH_{2m} + (n + 0.5m)O_2 \rightarrow nCO_2 + mH_2O$	--	--	$n + 0.5m$	$4.78n + 2.39m$
Sulfur (to SO_2)	S	$S + O_2 \rightarrow SO_2$	1.00	4.31	--	--
Sulfur (to SO_3)	S	$S + 1.5O_2 \rightarrow SO_3$	1.50	6.47	--	--
Hydrogen Sulfide	H_2S	$H_2S + 1.5O_2 \rightarrow SO_2 + H_2O$	1.41	6.08	1.50	7.18

[a] Atomic masses: H = 1.008; C = 12.01; O = 16.00; S = 32.06

Table B-2. Stoichiometric Oxygen and Air Requirements for Combustible Materials.

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Not having enough air to combine with the components of fuel stoichiometrically will prevent 100 percent oxidation of all the fuel components, and a lower efficiency will result. Figures B-19 and B-20 and Tables B-3 through B-5 show how to determine the right amount of excess air and CO_2 for highest combustion efficiency. From Table B-3, natural gas requires a minimum amount of air (theoretical air = 9.6 lb/lb of fuel) for complete combustion. This amount of air is based on the amount of oxygen molecules needed to combine with the fuel (its stoichiometric equation is found in Table B-2 under methane). The approximate theoretical CO_2 values for stoichiometric combustion of other common types of fuel, as well as CO_2 values for differing amounts of excess air, are given in Table B-4. Desirable amounts of CO_2 depend on the excess air, fuel, firing method, and other considerations. CO_2 is important because it is an indication that carbon has oxidized. When carbon is oxidized, combustion has taken place; the greater the combustion of carbon, the greater the efficiency of the combustion system.

Type of Fuel	Theoretical Air Required for Combustion
Solid fuels	lb/lb fuel
Anthracite	9.6
Semibituminous	11.2
Bituminous	10.3
Lignite	6.2
Coke	11.2
Liquid fuels	lb/gal fuel
No. 1 fuel oil	12.34 (103)
No. 2 fuel oil	12.70 (106)
No. 5 fuel oil	13.42 (112)
No. 6 fuel oil	13.66 (114)
Gaseous fuels	ft^3/ft^3 fuel
Natural gas	9.6
Butane	31.1
Propane	24.0

Table B-3. Theoretical Amounts of Air Required for Combustion.
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	Theoretical or Maximum	Percent CO_2 at Given Excess Air Values		
Type of Fuel	CO_2, %	20%	40%	60%
Gaseous Fuels				
Natural Gas	12.1	9.9	8.4	7.3
Propane Gas (Commercial)	13.9	11.4	9.6	8.4
Butane Gas (Commercial)	14.1	11.6	9.8	8.5
Mixed Gas (Natural and Carbureted Water Gas)	11.2	12.5	10.5	9.1
Carbureted Water Gas	17.2	14.2	12.1	10.6
Coke Oven Gas	11.2	9.2	7.8	6.8
Liquid Fuels				
No. 1 and 2 Fuel Oil	15.0	12.3	10.5	9.1
No. 6 Fuel Oil	16.5	13.6	11.6	10.1
Solid Fuels				
Bituminous Coal	18.2	15.1	12.9	11.3
Anthracite	20.2	16.8	14.4	12.6
Coke	21.0	17.5	15.0	13.0

Table B-4. Theoretical CO_2 Values for Stoichiometric Combustion.
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Now that the exact amount of air needed under perfect conditions for complete combustion (which conditions will probably never exist) have been theoretically established, refer to an example analysis to gain a better understanding of Table B-4. Figure B-19 illustrates an actual flue gas analysis performed on a battalion headquarters building, using an electronic combustion analyzer. A low efficiency of 78.7 percent on the initial test is shown. Then the excess air was reduced by 29 percent, raising the efficiency by 2 percent with a final efficiency of 80.7 percent. Using the values for natural gas from Table B-4:

	Theoretical or Maximum CO_2 %	**Percent CO_2 at given excess air values**		
		20%	**40%**	**60%**
Natural Gas	12.1	9.9	8.4	7.3

In the second test, excess air induced is 39 percent at 8.48 CO_2 (8.48 is found from Table B-5 by interpolation). The amount of theoretical air required for combustion of natural gas is found in Table B-3 to be 9.6. If the actual amount used for combustion in the "after adjustment" data of Figure B-19 is used, a value of 6.4 is found. Subtracting 6.4 from 9.6 gives a percent difference of 3.2 between theoretical and actual air used for combustion. The data in Table B-5 is close enough in value to actual testing data that may be used to determine the excess air needed based on percent CO_2 found in flue gases. Note what happens on Table B-5 if excess air goes up; efficiency goes down. If the CO_2 content goes down in the flue gas, less carbon is oxidized, and the efficiency goes down. The two example tests are plotted on Figure B-20.

Figure B-20 appears to give exact values of excess air as correlated to the tests. The example shows that boiler efficiency is a function of temperature as well as O_2, CO_2, and excess air content. This combustion efficiency for gas relates all these elements and presents the total combustion efficiency.

BACHARACH MODEL 300
****
COMBUSTION ANALYZER

ID: 7846

DATE: 26 Jun 90

TIME: 0945 AM/PM

FUEL: NATURAL GAS

PRIMRY TEMP(F): 88
STACK TEMP(F): 416

% OXYGEN: 9.1
% EXCESS AIR: 68.8

% CARBON - DIOXIDE: 6.7
PPM CARBON - MONOXIDE: 9

% EFFICIENCY: 78.7
% STACK LOSS: 21.3

TEST PERFORMED BY:

COMMENTS before adjustment

BACHARACH MODEL 300
****
COMBUSTION ANALYZER

ID: 7846

DATE: 26 Jun

TIME: ________ AM/PM

FUEL: NATURAL GAS

PRIMRY TEMP(F): 89
STACK TEMP(F): 409

% OXYGEN: 6.4
% EXCESS AIR: 39.0

% CARBON - DIOXIDE: 8.2
PPM CARBON - MONOXIDE: 44

% EFFICIENCY: 80.7
% STACK LOSS: 19.3

TEST PERFORMED BY:

COMMENTS after adjustment

Figure B-19. Flue Gas Analysis; initial test and after 29 percent reduction in excess air.

CO_2		12.1	11.5	11.0	10.4	9.8	9.2	8.7	8.1	7.5	6.9	6.4	5.8
Excess Air		0	4.5	9.5	15.1	21.3	28.3	36.2	45.0	55.6	67.8	82.2	99.3
Oxygen		0	1	2	3	4	5	6	7	8	9	10	11
	°F												
	300	85.6	85.4	85.2	85.0	84.7	84.5	84.2	83.9	83.5	83.0	82.4	81.7
	350	84.6	84.3	84.1	83.8	83.5	83.2	82.8	82.4	81.9	81.3	80.6	79.8
	400	83.5	83.2	82.9	82.6	82.2	81.8	81.4	80.9	80.3	79.6	78.8	77.8
	450	82.5	82.1	81.8	81.4	81.0	80.5	80.0	79.4	78.7	78.9	77.0	75.9
	500	81.4	81.0	80.6	80.2	79.7	79.1	78.6	77.9	77.1	76.2	75.2	73.9
	550	80.3	79.9	79.4	79.0	78.4	77.8	77.2	76.4	75.5	74.5	73.4	71.9
	600	79.2	78.7	78.2	77.7	77.1	76.4	75.7	74.9	73.9	72.8	71.5	69.9
	650	78.1	77.6	77.1	76.5	75.8	75.1	74.3	73.4	72.3	71.1	69.7	67.9
	700	77.0	76.5	75.9	75.3	74.5	73.7	72.9	71.9	70.7	69.4	67.8	65.9
	750	75.9	75.4	74.7	74.1	73.2	72.4	71.5	70.4	69.1	67.7	66.0	63.9
	800	74.8	74.2	73.5	72.8	71.9	71.0	70.0	68.8	67.5	65.9	64.1	61.9
	850	73.7	73.1	72.3	71.6	70.6	69.7	68.6	67.3	65.9	64.2	62.3	59.9
	LOSS PER PERCENT COMBUSTIBLES												
		2.8	3.0	3.2	3.4	3.7	4.0	4.3	4.6	5.0	5.5	6.1	6.8

Table B-5. Combustion Efficiency Chart for Gas.

Source: *Improving Boiler Efficiency,* Dukelow 1983. Used with permission of Kansas State University, Manhattan.

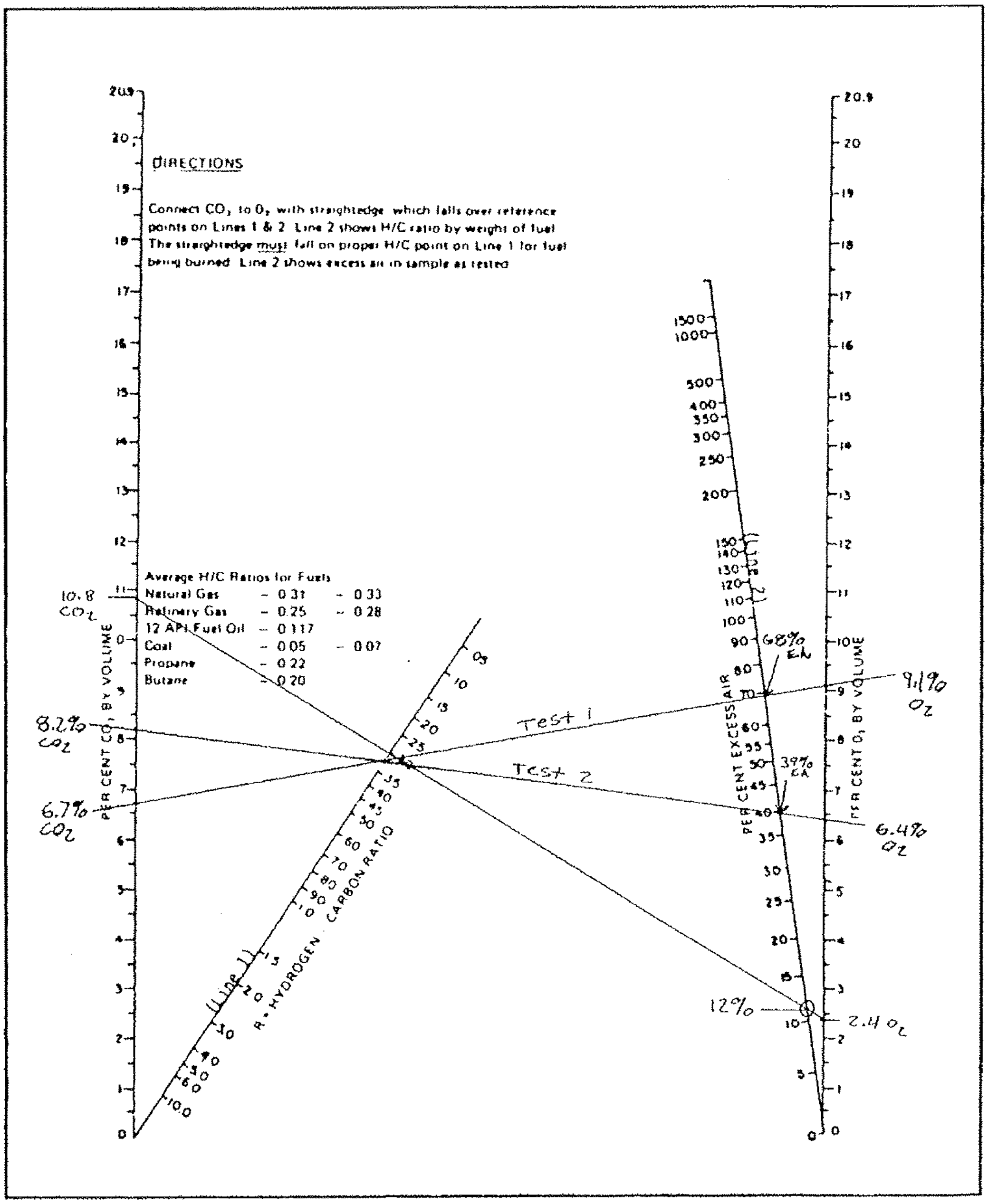

Figure B-20. Properties of Products of Combustion.

Source: *Improving Boiler Efficiency,* Dukelow 1983. Used with permission of Kansas State University, Manhattan.

In calculating the efficiency of boilers, all factors involved must be considered. One problem that makes calculating efficiency difficult is the leaks in the system. If hot water leaks out in the condensate return pipes, it will have to be replaced by makeup water at a much cooler temperature. Also, the makeup air for combustion may have a high moisture content. This means the H_2O is not permitting as much oxidation of H_2 from the fuel, causing incomplete combustion.

Because the needs of the combustion process vary, it is necessary to fluctuate the amount of excess air fed into the combustion process. Mixing of air with fuel may not be sufficiently accomplished to combine or oxidize all fuel components perfectly.

Having considered the obstacles to perfect efficiency in boiler operation, it is apparent we find 100 percent efficiency almost impossible. It is desirable to have all elements of the fuel oxidized by the end of the combustion stage. The theoretical CO_2, ultimate CO_2 or maximum CO_2 concentration attainable in the combustion products of a hydrocarbon fuel with air is the CO_2 concentration obtained when the fuel is completely burned with the theoretical air, or zero excess air. As the carbon-hydrogen ratio of fuel varies, so does the theoretical CO_2 content.

Air Pollution

One of the main constituents of air pollution is that caused by combustion processes. Pollutants may be grouped into four categories:

1. Products of incomplete fuel combustion
   a. Combustible aerosols (solid and liquid), including smoke, soot and organics, and excluding ash
   b. Carbon monoxide (CO)
   c. Gaseous hydrocarbons (HC)
2. Oxides of nitrogen (generally grouped and referred to as NO_x)
   a. Nitric oxide (NO)
   b. Nitrogen dioxide (NO_2)
3. Emissions resulting from fuel contaminants
   a. Sulfur oxides, primarily sulfur dioxide (SO_2) and small amounts of sulfur trioxide (SO_3)
   b. Ash
   c. Trace metals
4. Emissions resulting from additives
   a. Combustion-controlling additives
   b. Other additives.

Emissions of nitrogen oxides and incomplete combustion are directly related to the combustion process and may be minimized by altering the process. During the combustion process, nitrogen oxides form by either thermal fixation (reaction of nitrogen and oxygen at high combustion temperatures) or from fuel nitrogen (oxidation of organic nitrogen in fuel molecules). High excess air and flame temperature techniques for ensuring complete fuel combustion, and therefore low emissions of incomplete combustion products, tend to promote increased NO_x formation. Emissions of fuel contaminants are related to fuel selection and are slightly affected by the combustion process.

The emission levels of incomplete fuel combustion can be reduced by making sure of adequate excess air, improving mixing of air and fuel (increasing turbulence, improving distribution, and improving liquid fuel atomization), increasing residence time in the hot combustion zone (possibly by decreasing firing rate), increasing combustion zone temperatures (to speed reactions), and avoiding quenching the flame before reactions are completed.

3 Boiler Design

Boiler Sizing

When specifying a boiler, the engineer must determine the pressure rating and the generating capacity or size of the boiler. The boiler horsepower is determined by the following formula:

$$hp = \frac{W(hg - hf)}{34.5\, hfg}$$

where:

	hp	=	boiler horsepower
	W	=	quantity of dry saturated steam at desired pressure (lb/h)
	hg	=	enthalpy of dry saturated water at feedwater temperature
	hf	=	enthalpy of saturated water at feedwater temperature
	hfg	=	enthalpy of evaporation at 212 °F = 970.3

Note: All enthalpies are in units of Btu/lb.

The actual output that can be expected from a boiler can be determined from the following formula:

$$W = \frac{34.5\,(hp)\, hfg}{hg - hf}$$

Figure B-21 was taken from a manufacturer's catalog. Equations for hp and W are used to determine the operating steam pressure of the boiler. In these equations, the enthalpy may be determined from steam tables. This chart can be used to determine either steam quantity or boiler horsepower when one of these is known (as well as the operating conditions).

Boiler Sizing Example 1

Find the size of a boiler required to generate 4,500 lb of dry saturated steam per hour at 100 psig from 180 °F feedwater. Using Figure B-21:

1. Locate the point of intersection of the psig line and 180°F.
2. Read from left hand scale a value of 32.13 pounds of steam per hour per boiler horsepower.
3. Divide: $$\frac{4{,}500\,lb/h}{32.13\,lb/h\,/\,hp} = 140.05\,hp$$
4. Round off to next standard rating of 150 hp.

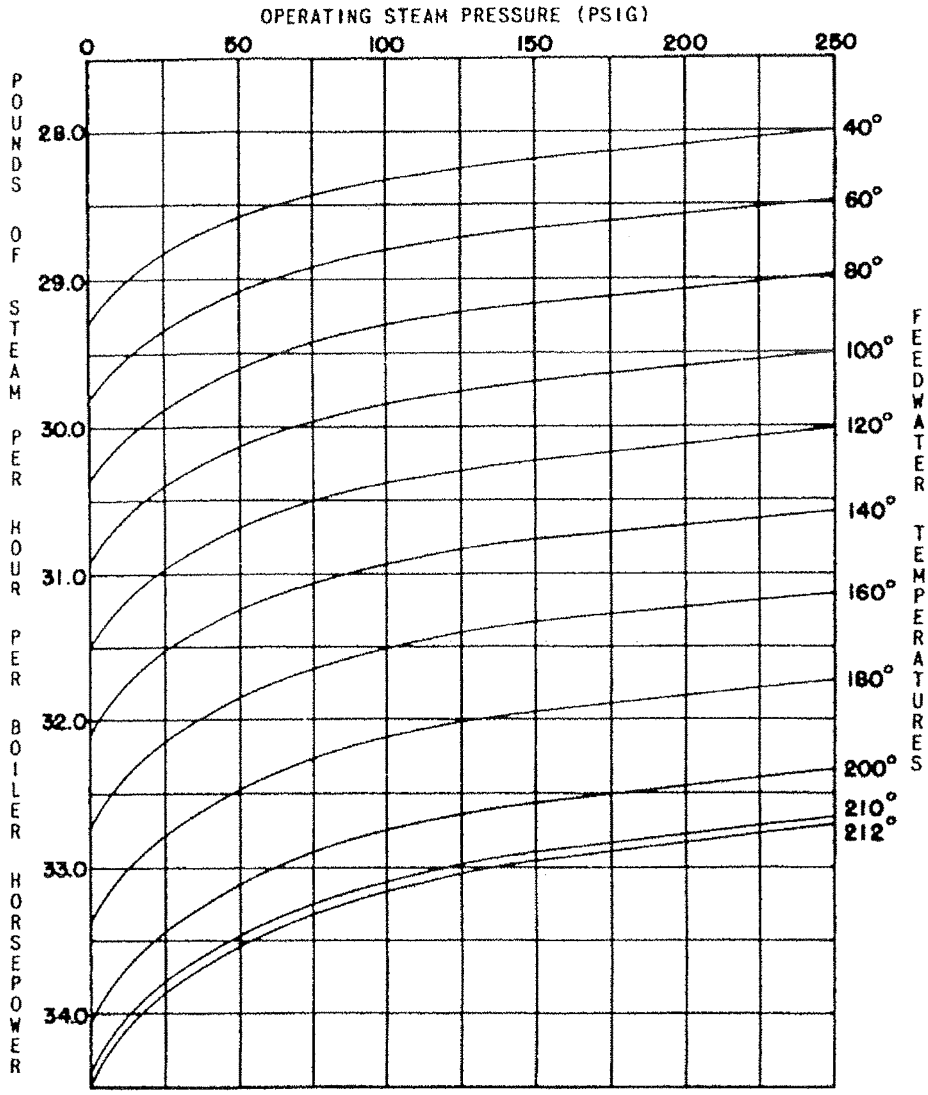

Figure B-21. Pounds of Steam/Hour per Boiler Horsepower vs. Feedwater Temperature and Steam Pressure.

Boilers may also be selected by determining the total MBH output required for the boiler and checking the manufacturer's specifications.

Boiler Sizing Example 2

The total output required for a building is 1,300 MBH. Checking specifications for a cast-iron sectional boiler (see Table B-6), an LGB-14 boiler is selected with a capacity of 1,368.9 MBH.*

Boiler Number*	A.G.A. Input MBH +	A.G.A. Gross Output MBH +	Net I=B=R Ratings**			Net Sq. Ft. Water ***	Boiler HP	Boiler Water Content – Gallons		Approx. Shipping Wt. (Lbs.)	Chimney/ Breeching Size (I.D.) ▲
			Sq. Ft. Steam	Steam MBH +	Water MBH +			Steam (to Waterline)	Water		
LGB-6	650	526.5	1,645	395.0	457.0	3,050	15.7	34.6	54.7	1,725	12'
LGB-7	780	631.8	1,975	474.0	550.0	3,670	18.9	40.3	63.9	2,005	12'
LGB-8	910	737.1	2,305	554.0	642.0	4,280	22.0	46.0	73.0	2,290	14'
LGB-9	1,040	842.4	2,630	632.0	732.0	4,880	25.2	51.9	82.1	2,560	14'
LGB-10	1,170	947.7	2,965	711.0	824.0	5,495	28.3	57.6	91.2	2,800	16'
LGB-11	1,300	1,053.0	3,295	791.0	917.0	6,115	31.4	63.4	100.4	3,105	16'
LGB-12	1,430	1,158.3	3,620	869.0	1,007.0	6,715	34.6	69.1	109.5	3,365	16'
LGB-13	1,560	1,263.6	3,955	949.0	1,099.0	7,325	37.8	74.9	118.6	3,785	16'
LGB-14	1,690	1,368.9	4,310	1,035.0	1,190.0	7,935	40.9	80.7	127.7	4,085	16'
LGB-15	1,820	1,474.2	4,680	1,124.0	1,282.0	8,545	44.0	86.4	136.9	4,355	16'
LGB-16	1,950	1,579.5	5,050	1,212.0	1,374.0	9,160	47.2	92.2	146.0	4,725	17'
LGB-17	2,080	1,684.8	5,410	1,298.0	1,464.0	9,760	50.3	98.0	155.1	4,975	17'
LGB-18	2,210	1,790.1	5,760	1,387.0	1,558.0	10,385	53.3	103.6	164.2	5,270	18'
LGB-19	2,340	1,895.4	6,130	1,471.0	1,649.0	10,995	56.6	109.5	173.4	5,540	18'
LGB-20	2,470	2,000.7	6,470	1,553.0	1,739.0	11,595	59.7	115.3	182.5	5,820	19'
LGB-21	2,600	2,106.0	6,820	1,637.0	1,833.0	12,220	62.9	121.0	191.6	6,080	19'
LGB-22	2,730	2,211.3	7,155	1,717.0	1,924.0	12,825	66.0	126.8	201.2	6,365	19'

Table B-6. Cast Iron Sectional Boiler Specifications.

Boiler Design Checklist

The following items must be considered in the initial design stages to ensure maintenance accessibility and greater operating efficiency.

1. All equipment must be readily accessible. Provide ample room for parts replacement, cleaning, and dismantling.
2. Arrange equipment to take advantage of the most direct runs of pipe.
3. Check and adhere to all local and state codes and regulations.
4. Provide a minimum clearance of 3 ft on all sides and 4 ft above the boiler.
5. Install boiler on a level concrete floor of sufficient strength to support the operating weight of the unit.
6. Install floor drains next to or behind the unit to facilitate flushing the foundation.

* The specific model LGB-14 was selected from Table B-6, which is from a manufacturer's catalog. Different models from other manufacturers may be just as appropriate.

7. Provide ample ventilation. According to one manufacturer, two ventilation openings to the exterior of the building will provide a positive movement of air. These openings should be louvered and filtered to protect against the weather.
8. Provide isolation pads to prevent vibration.

4 Acceptance Testing

Boiler Clearances

Many code books used in engineering have been published for the safety of human life, property, and public welfare. Some of the codes available for limitations on boiler clearances are: Life Safety Code (National Fire Protection Association); Uniform Building Code (International Conference of Building Officials); and Uniform Mechanical Code (International Association of Plumbing and Mechanical Officials). For a thorough breakdown of the limitations on boiler clearances, the Uniform Mechanical Code (UMC) is used. As set forth in the 1985 edition of the UMC, safety requirements are as follows: "All boilers and pressure vessels, and the installation thereof, shall conform to minimum requirements for safety from structural and mechanical failure and excessive pressures, established by the building official in accordance with nationally recognized standards."

The safety requirements include such items as controls, gages, and stack dampers, and integrateable welding by approved welders in conformity with nationally recognized standards. The controls must be approved by an approved testing agency, and provide electrical controls that are suitable for installation in their environment. Gages aid in regulating the safety of boilers by providing pressure measurements and a water level glass for steam boilers. A pressure gage with a temperature indicator on water boilers is necessary.

Section 2114 of the UMC states with regard to clearance for access: "when boilers are installed or replaced, clearance shall be provided to allow access for inspection, maintenance, and repair, and passageways shall have an unobstructed width of no less than 18 in. Clearance for repair and cleaning may be provided through a door or access panel into another area, provided the opening is of sufficient size. Power boilers having a steam generating capacity in excess of 5,000 lb per hour or having a heating surface in excess of 1,000 sq ft or input in excess of 5,000,000 Btu/h shall have a minimum clearance of 7 ft from the top of the boiler to the ceiling."

There are other important safety considerations when installing a boiler. Floors must be constructed of a noncombustible material unless the boilers are listed for mounting on combustible flooring. Boilers must be anchored securely to the structure and be mounted on a level base capable of supporting and distributing the weight contained thereon.

As with all engineering and design problems, each problem has its own solution unique to its own environment and circumstance. The codes found in most books will suffice for safety requirements and maintenance. It is still possible, however, to find that all code requirements are met and, yet, something is lacking. Innovative thinking should be used cautiously so as to comply with all safety standards and still accomplish the task at hand.

Boiler Flue Gas Venting

In venting gases produced in the combustion processes of the various types of boilers (oil burning, gas fired, and multi-fuel), it is important to understand the many ways in which codes effect the design and specifications of flue gas venting systems. A few definitions will be helpful in the following discussion on flue gas vents and vent connectors:

Vent: A listed factory-made vent pipe and vent fitting for conveying flue gases to the outside atmosphere.

Type B Gas Vent: A factory-made gas vent listed by a nationally recognized testing agency for venting listed or approved appliances equipped to burn only gas.

Type L Vent: A venting system consisting of listed vent piping and fittings for use of oil-burning appliances listed for use with Type L or with listed gas appliances.

Vent Connector, Gas: That portion of a gas-venting system that connects a listed gas appliance to a gas vent.

Boilers of all kinds must be connected properly to a chimney or vent. A boiler may make direct use of the flue gas vent only if one boiler is in the system. If multiple boilers are used then a multiple appliance venting system may be used. If two or more oil- or gas-burning appliances are connected to one common venting system as shown in Figure B-22, they may be vented into the same system serving liquid-fuel-fired appliances, provided: (1) the gas appliances are each equipped with a safety shut off device and (2) each oil appliance is equipped with a primary safety control. The rule of thumb, however, is that gas vents shall be insulated in accordance with the terms of their listings and the manufacturer's instructions.

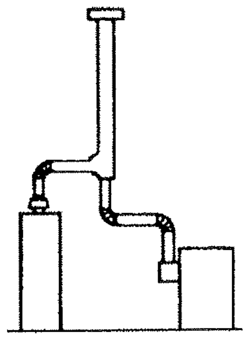

Figure B-22. Boiler Venting.

Table B-7 shows some of the vent types available for various boilers. Venting systems must comply with the following requirements from NFPA 54 and 31:

A single or common gas vent shall be allowed in multi-story installation to vent gas-fueled Category I equipment that is located on more than one floor, under the condition that it is designed and installed under approved methods.

Two or more connectors cannot enter a common venting system unless the inlets are offset in such a way that no portion of any inlet is opposite the other inlets. The smaller connector shall enter at the highest level consistent with the available head room or clearance to combustible material.

When two or more appliances are connected to one venting system, the venting system area must not be less than the area of the largest vent connector plus 50 percent of the areas of the additional vent connectors (NFPA 54, Appendix G).

Each vent connector of a multiple venting system must have the greatest possible rise between the headroom available from the draft hood outlet, the barometric damper or the flue collar, or the point of interconnection to a manifold, to the common vent.

COLUMN I TYPE B, GAS Round or Oval	COLUMN II TYPE BW GAS	COLUMN III TYPE L	COLUMN IV PLASTIC PIPE
All listed gas appliances with draft hoods such as: 1. Central furnaces 2. Floor furnaces 3. Heating boilers 4. Ranges and ovens 5. Recessed wall furnaces (above wall section) 6. Room and unit heaters 7. Water heaters	1. Gas-burning wall heaters listed for use with Type BW vents	1. Oil burning appliances listed for use with Type L vents 2. Gas appliances as shown in first column	1. Condensing appliances listed for use with a specific plastic pipe recommended and identified in the manufacturer's installation instructions

Table B-7. Vent Types.

Based on *Fire Protection Handbook*, 18th Ed., 1997.

It is also important to make sure the venting system is constructed in a way that a positive flow, adequate to convey all combustion products to the outside atmosphere, is produced. It may be tempting to put a vent in a plenum or through an air duct to utilize the heat, but this must not be done. Dangerous gas could seep through and endanger persons in the occupied space.

Some additional codes on connectors are:

- Connectors serving gravity-vent-type appliances shall not be connected to a vent system served by a power exhaust unless the connection is made on the negative side. A gravity vent is operated by the push or upward force on hot air (see Figure B-22). This force is caused by the downward convections of colder, more dense air pulled down by gravity. The hot air continues its acceleration up and out of the vents. If a fan is placed before the outlet of the connection into the common vent, the positive pressure may overcome the force of gravity, and push the exhaust gases back into the occupied space, which is extremely dangerous.
- All connectors shall be as short and straight as possible.
- An appliance shall be located as close as practical to the venting system.
- Connectors shall not be concealed by building construction; however, Type B and L materials may be enclosed following inspection if they meet provisions of section 915 b 2H of the Uniform Mechanical Code.
- Vent connectors shall not pass through any ceiling, floor, fire wall, or partition. A single wall metal pipe connector shall not pass through any interior wall.

- Connectors shall be securely supported, and joints fastened with sheet metal screws, rivets, or other approved means.

Boiler Piping

Boiler or steam piping differs from other systems because it usually carries three fluids: steam, water, and air. Steam systems are classified according to piping arrangement, pressure conditions, and method of returning condensate to boiler. All applicable codes and regulations should be checked to determine acceptable piping practice for the particular application. Codes may dictate piping design, limit the steam pressure, or qualify the selection of equipment.

Two piping arrangements are generally used to suit their own purposes. One of these is the one-pipe system, which uses a single pipe to supply steam and return condensate. Ordinarily, there is one connection at the heating unit for both supply and return. A two-pipe steam system is more commonly used in air-conditioning, heating, and ventilating applications.

Piping arrangements are further classified with respect to condensate return connections to the boiler and direction of flow in the risers:

1. Condensate return to boiler (see Figure B-25)
   a. Dry-return: condensate enters boiler above water line
   b. Wet-return: condensate enters boiler below water line
2. Steam flow in riser
   a. Up-feed: steam flows up riser
   b. Down-feed: steam flows down riser.

Steam piping systems are normally divided into five classifications: high pressure, medium pressure, low pressure, vapor, and vacuum systems. The following are pressure ranges for the five systems:

High Pressure:	100 psig and above
Medium Pressure:	15 to 100 psig
Low Pressure:	0 to 15 psig
Vapor:	Vacuum to 15 psig
Vacuum:	Vacuum to 15 psig

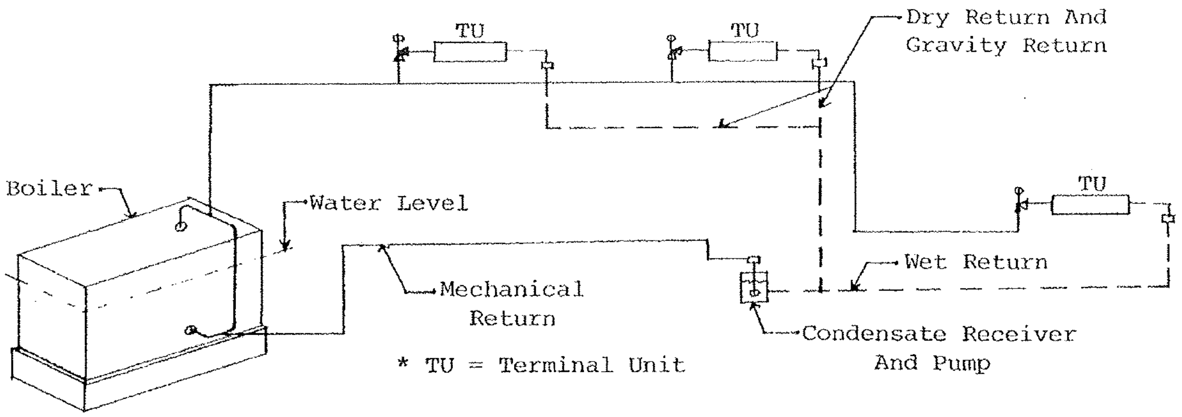

Figure B-23. Dry Return, Wet Return, Gravity Return, Mechanical Return.

Vapor and vacuum systems are identical except the vapor system does not have a vacuum pump as a vacuum system does.

Piping systems are further identified by the type of condensate return piping from the terminal units to the boiler. In common use are two arrangements, gravity and mechanical return. When all the units are located above the boiler or condensate receiver water line, the system is described as a gravity return since the condensate returns to the boiler by gravity (see Figure B-23). If traps or pumps are used to aid the return of condensate to the boiler, the system is classified as a mechanical return system (see Figure B-23).

Water Treatment

A wide range of treatment procedures can be used for boiler waters. In any particular case, the method selected must depend on the composition of the makeup water, the operating pressure of the boiler, the makeup rate, and many other considerations. All makeup water or steam systems should be treated. In acceptance testing, treatment should be done only if available. Refer to Corps of Engineers Guide Specifications for appropriate water treatment provisions.

Efficiency Performance Methods

The performance of a boiler relates directly to its ability to transfer heat from the fuel to the water while meeting operational specifications. A boiler's performance will include all aspects of its operation. Boiler efficiency and operating capacity are basic elements of boiler performance.

Performance specifications include the operating capacity and the factors for adjusting that capacity, steam pressure, boiler water quality, boiler temperatures, boiler pressures, boiler drafts and draft losses, flue gas analysis, fuel analysis, and fuel burned. Other performance specifications indicate the fan power requirements (boiler flue gas temperatures and draft losses) and the fuel supply assumptions. Fuels will vary in their energy content per cubic foot. Higher octane gases will have a greater energy content than those with a lower energy content. Coal varies significantly in energy content and in its capacity to combust. The fuel supply assumptions will take these factors into account.

From the performance specifications, a calculated efficiency may be obtained. Boiler efficiency is a percentage of the ratio of heat supplied to the boiler and the heat absorbed by the boiler water. Two methods of calculating the efficiency of a boiler are acceptable. They are known as the *input/output method* and *heat loss method*. These methods are very detailed and not necessary as an acceptance testing criteria. The primary test required for acceptance testing is the flue gas temperature.

Boiler System Acceptance Testing Checklist

Before an individual or acceptance testing team begins work, an inspection of the entire system should be made to confirm that all components of the system are ready to function. The following is a checklist to follow during acceptance testing.

BOILER SYSTEM ACCEPTANCE TESTING CHECKLIST

PROJECT:____

LOCATION:____

NAME:____

A. Gas-Firing	Correct yes	Correct no	Date Checked
1. Condition and cleanliness of gas injection orifices			
2. Cleanliness and operation of filter and moisture traps			
3. Condition of burner refractory (loose or cracked)			
4. Condition and operation of air dampers (operable)			
5. Flame scanner operational			
6. Pilot ignition set			
7. Ignition time main flame			
8. Pilot flame out time. Main flame out			
9. Operating temperature a. Inlet b. Outlet			
10. Operating pressure			
11. Combustion air adequate			
12. Gas piping leak tested			
13. Gas train components vented			
14. Gas meter reading			
15. Confirm start-up sequence			

B. Oil-Firing	Correct yes	Correct no	Date Checked
1. Cleanliness of oil strainer			
2. Condition of burner throat refractory (loose or cracked)			

C. Combustion Controls	Correct yes	Correct no	Date Checked
1. Cleanliness and proper movement of fuel valves			
2. Excessive "play" in control linkages or air dampers			
3. Adequate pressure to all pressure regulators			
4. Unnecessary cycling of firing			
5. Proper operation of all safety interlocks and boiler trip circuits, i.e. low pressure, high pressure and low gas pressure			

D. Flame Appearance	Correct yes	no	Date Checked
1. Oil & pulverized flames - short, bright, crisp and highly turbulent			
2. Gas flames--blue, slightly streaked or nearly invisible			

E. Flue Material Type and Connection	Correct yes	no	Date Checked
1. Gas flue - type B or IC (replaces type L)			
2. Oil flue - type IC (replaces type L)			
3. Gas-oil - type IC (replaces type L)			
4. Flue installed per listing			
5. Location and size of makeup air			
6. Do exhaust fans affect flue performance?			
7. Does stack have cap?			
8. Is single wall breeching installed?			

F. Boiler	Correct yes	no	Date Checked
1. Combustible floor - boiler approved for combustible floor			
2. 18 in. unobstructed clearance around all sides of boiler			
3. Boiler > 5,000 BtuH - minimum clearance of 7 ft from the top of boiler to ceiling			
4. Make-up water system installed			
5. Make-up water controls set			
6. Feed water auxiliaries operational			
7. Feed water treatment in place			
8. Treatment system discussed with user			
9. Boiler flushed and clean			
10. Pressure relief operational			
11. Operating pressure			
12. Water level control tested			
13. Installation checked and approved by manufacturer			
14. Combustion test complete and results submitted			
15. Pressure relief valve matches boiler capacity			

G. Flue Gas Temperature	Correct yes	no	Date Checked
1. Temperature - actual vs. recommended			

Glossary

ANODE: The positively charged electrode toward which current flows.

ASTM: American Society for Testing and Materials.

ASME: American Society of Mechanical Engineers.

BLOW DOWN: Removal of a portion of boiler water for the purpose of reducing concentration, or to discharge sludge.

BOILER PASSES: The number of passes for a boiler refers to the number of horizontal runs the flue gases take between the furnace and the flue gas outlet.

BURNER WINDBOX: A plenum chamber around a burner in which an air pressure is maintained to ensure proper distribution and discharge of secondary air.

CATHODE: The negative electrode from which current flows.

COMBUSTION: The rapid chemical combination of oxygen with the combustible elements of a fuel resulting in the production of heat.

COMBUSTION CHAMBER: An enclosed space provided for the combustion of fuel.

CONCENTRATION: The strength or density of a solution.

CRUDE OIL: Unrefined oil. When an oil rig first strikes oil underground, the oil as extracted from the ground is in its crude form.

EXCESS AIR: The amount of air supplied to the boiler that is greater than the amount of theoretical air needed to burn the fuel.

GAGE GLASS: The transparent part of a water gage assembly connected directly or through a water column to the boiler, below and above the water line to indicate the water level in a boiler.

HOT WATER-HIGH PRESSURE: A water heating boiler operating at pressures exceeding 160 psi or temperatures above 250 °F.

HOT WATER-LOW PRESSURE: A boiler furnishing hot water at pressures not exceeding 160 psi and temperatures less than 250 °F.

INCHES WATER GAGE: The usual term for expressing a measurement of relatively low pressure or differential by means of a U-tube manometer. One inch w.g. equals 5.2 lb per square foot or 0.036 lb per square inch.

MANIFOLD: A pipe or header for collecting a fluid from or the distributing of a fluid to a number of pipes or tubes.

MECHANICAL STOKER: A device that feeds a solid fuel into a combustion chamber.

MUD DRUM: The lower drum of a watertube boiler in which steam system sediments settle into, and is completely filled with water.

OS&Y VALVE: Outside screw and yoke valve.

OXIDATION: Chemical combination with oxygen.

PRESSURE REDUCING VALVE: A pressure reducing valve for a single temperature system reduces tank pressure to 18 psig. For two temperature systems and systems designed to change from direct to reverse acting, a change in supply pressure will provide a choice of 13 or 18 psig.

PRIMARY AIR: Air that is needed to mix with the fuel. It atomizes and controls the amount of fuel oil capable of being burned.

RETURN CONDENSATE: Condensed water resulting from the removal of latent heat from steam.

SCALING: The formation of deposits in a boiler caused by the minerals in the boiler water.

SECONDARY AIR: Air used in controlling how efficiently the fuel is burned. It is air that diffuses into the flame from the atmosphere.

SLUDGE: The sediment in a steam boiler.

SOOT: Unburned particles of carbon derived from hydrocarbons.

STEAM: The vapor phase of water substantially unmixed with other gases.

STEAM DRUM: The higher drum of a watertube boiler used to contain steam, and is half filled with water.

UMC: Uniform Mechanical Code.

VENTING COLLAR: Outlet opening of an appliance provided for connecting the vent system.

VISCOSITY: The measure of the internal friction of a fluid or its resistance to flow.

WATER HAMMER: The hammering sound caused in a pipe containing condensate or water when live steam is passed through it.

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