Boiler Furnaces

The simple boilers that produced the steam for steam engines consisted of a **furnace**, a space for burning the fuel, and a separate boiler, with a large copper pot heated from beneath. Improvements in iron fabrication techniques made possible the integration of the furnace and boiler.

In fire-tube boilers, the furnace is a large central horizontal tube surrounded by a water-filled boiler. The hot exhaust gases pass out of the furnace and then back through tubes that traverse the boiler. Failure to keep water in fire-tube boilers led to **catastrophic boiler explosions**, resulting in many deaths in the mid-nineteenth century. (Such explosions still occur occasionally.)

Further, material improvements led to the development of the water-tube boiler. Here the water is in the tubes and the hot gasses pass across the tubes. Whereas individual water tubes could still burst, boiler safety was much improved. With the development of pulverized coal firing, water-tube boilers would grow to enormous size. The increase in size led to the possibility of catastrophic furnace explosions.

THE COMBUSTION PROCESS

Combustion is the rapid combination of oxygen with combustible elements of a fuel. *There are three important combustible elements:* (1) carbon, (2) hydrogen, and (3) sulfur.

Not only must the fuel and air be supplied continuously, but the ratio of fuel-to-air must be kept constant within a relatively narrow range.

Figure 6.6.1 shows how fuel and air are introduced and burned in a furnace through a modern low-NO_x burner. [Oxides of Nitrogen (NOx) can be nitric oxide NO, nitrogen dioxide NO_2, nitrous oxide N_2O, nitrosylazide N_4O, etc.] Pulverized coal, carried by a small stream of air termed **primary air**, is injected through the center of the burner and meets with the swirling bulk of the air, termed **secondary air**. The several functions of this burner can be seen in the figure**: a zone** just at the burner outlet in which fuel is ignited and partially burned, but with a strong deficiency of air (A); and a **second zone** in which thermal NO_x is reduced to N_2 (C). The mixing and burning of the remaining air and residual fuel takes place in the furnace. *Radiation from the brightly luminous flame and the recirculation of hot gas due to turbulence provide a stable ignition source.* The combustion process proceeds toward completion through a wide range of fuel-air ratios, fuel-rich just at the burner exit and fuel-lean at the furnace exit.

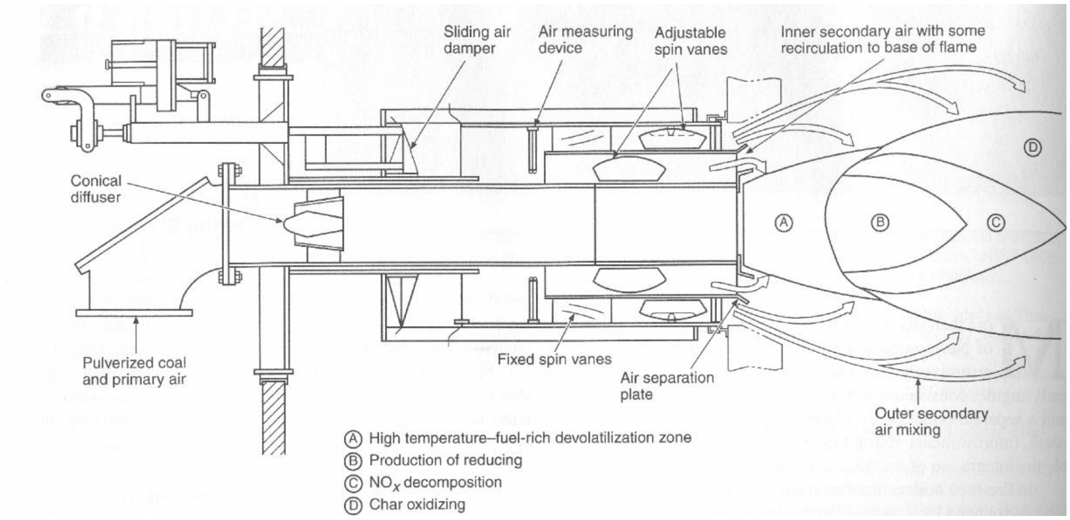

FIGURE 6.6.1 Burner Flame Conditions

FUELS

After several periods of rapidly rising oil prices, coal became the least expensive boiler fuel almost everywhere in the world. However, in 1999 natural gas use surpassed coal use for all thermal energy uses including heating processes and electricity. Other boilers, particularly in gas-producing regions, were designed to burn natural gas when gas prices were maintained low via federal controls.

OIL AND GAS-BURNING SYSTEM

The burner is the principal component of oil- or gas-firing systems. Its purpose is to introduce fuel and air into the furnace in the proper proportion, swirl, and droplet size to sustain efficient combustion. The combustion efficiency of a burner should be as high as possible to minimize *energy lost as either unburned fuel or excess air*.

Normal use of a boiler requires operation at different outputs to meet varying loads. **The specified operating range for a burner** is the ratio of full load heat production of the burner to the minimum load at which the burner is capable of stable ignition reliable operation.

Because of the chemistry of combustion, more than the quantity of theoretical air is necessary to achieve essentially complete combustion. Many boilers operate with substantially higher excess air levels, some because of particular fuel, the furnace design, or poor attention to optimum performance.

A frequently used burner for gas and oil is the circular burner (Figure 6.6.2). Normally, the capability of an individual circular burner is limited to about 200 million Btu/hr (58,620 kW).

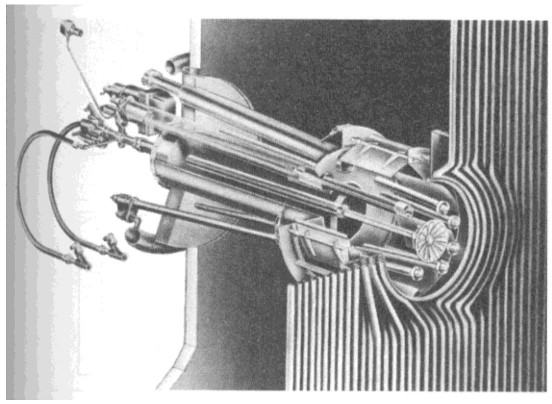

Figure 6.6.2 Circular Register for Gas and oil Firing (Source: The Babcock & Wilcox Co.).

The tangentially displaced doors provide the turbulence necessary to mix the fuel and air and to produce a stable flame. While the fuel is introduced to the burner in a **fuel-rich mixture** in the center, the direction and velocity of the air and the fuel-dispersion pattern thoroughly mix the fuel with the combustion air. A burner specially designed for low NO_x emissions is shown in Figure 6.6.3. An air-flow monitor is incorporated in this burner to allow for balancing air flow from burner to burner.

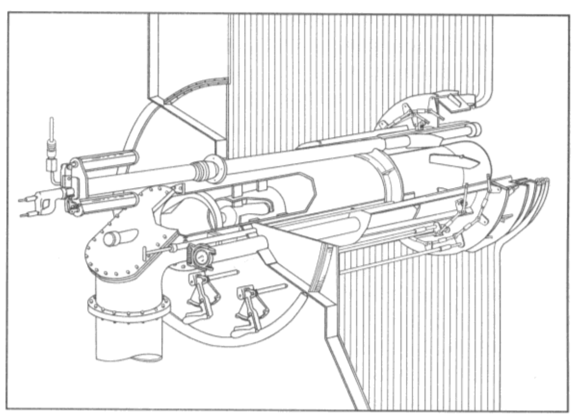

Figure 6.6.3 Burner for Low Emissions of NO_x (Source: The Babcock & Wilcox Co.)

Oil Burners

A main function of an oil burner is to **atomize the oil**, that is, **turn the thick stream of oil into a very fine mist of oil droplets.** This provides the large oil surface area needed for rapid ignition and, as each droplet is surrounded by air, complete combustion.

There are a number of **types of oil atomizers**, but the discussion here is limited to the two most popular types: (1) steam or air atomizers and (2) mechanical atomizers.

For proper atomization, oil heavier than No.2 must be heated to reduce viscosity. Steam or electric heaters are used to raise the oil temperature to the required level-approximately 57°C for No.4 oil, 85°C for No.5, and 93°C to 104°C for No.6. It is also important that oil be free of acid, grit, and other foreign matter that might clog or damage burners or their control valves.

Natural Gas Burners

Natural gas is the ideal boiler fuel, requiring no preparation for combustion and minimal post-combustion pollution control. Basically **gas burners mix fuel and air in either of two ways**: (1) premix or (2) external mix. With the advent of stringent NO_x emission regulations, changes were required in the design and operation of large gas burners.

In a premix burner, gas and a portion of the air are mixed before the mix is introduced to the burner nozzle. A common method involves mixing gas and air in the suction side of a mechanical blower.

In external mix gas burners, the fuel and air are mixed external to the nozzle. When external-mix gas burners have individual elements (Figure 6. 6. 6), part or all of the gas discharges in front of the impeller. This provides a local fuel-rich zone and thus serves as an ignition stabilizer at high gas flow rates.

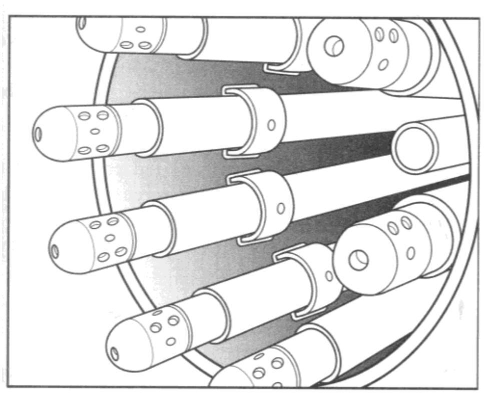

Figure 6.6.6 External-Mix Gas Burner with Individual Spuds

Oil-Fired Systems

The fuel-oil supply system should be designed to ensure a continuous, steady flow of fuel that will meet the requirements of the boiler over the entire load range. This includes coordinating the main fuel control valve, burner safety shutoff valve, and associated piping volume to prevent fuel pressure transients that might exceed stable flame burner limits as a result of placing burners in or taking them out of service (Figure 6.6.7).

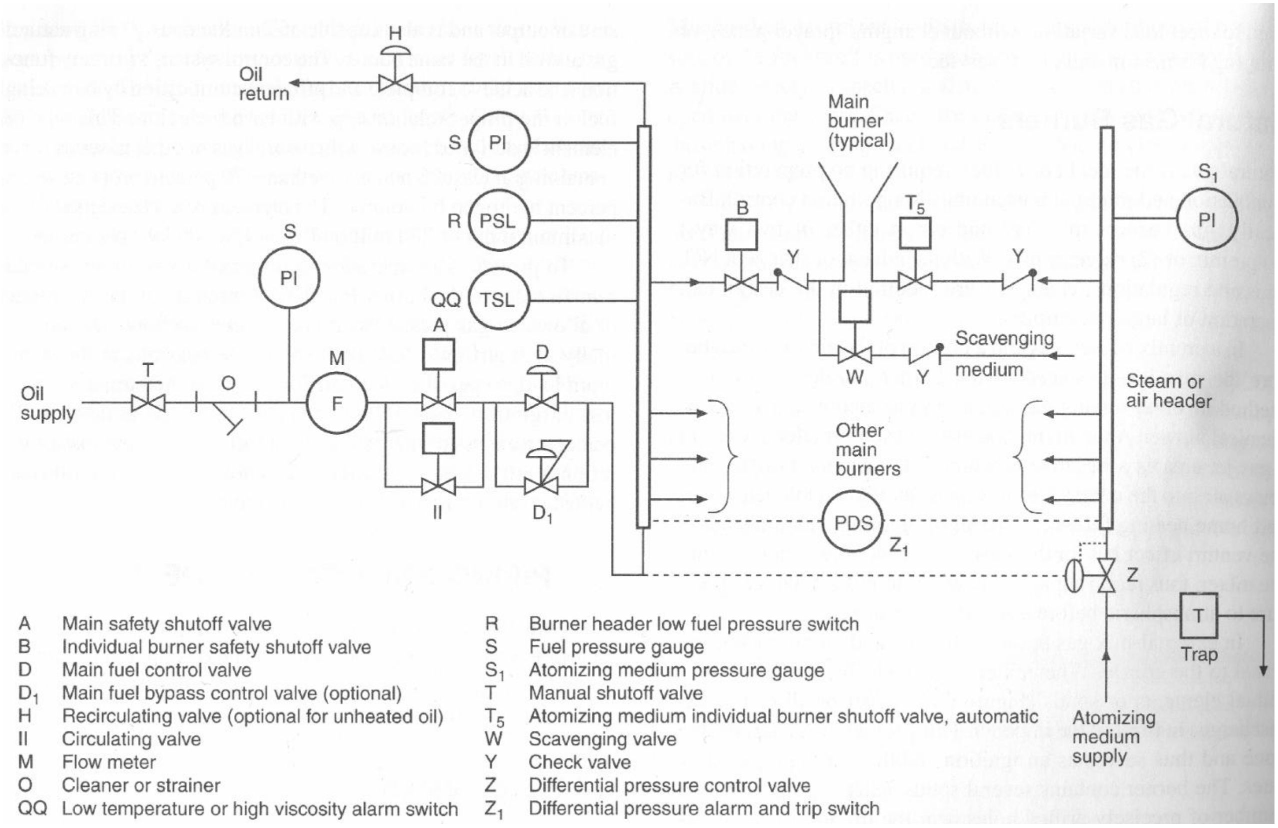

Figure 6.6.7 Type Main Oil Burner- Steam or Air Atomizing

Fill and recirculation lines should be connected to storage tanks so that they always discharge below the liquid level. This will avoid excess evaporation and the generation of static electrical charges in free-falling fuel.

Burner shutoff valves should be located as close to the burner as possible to minimize the volume of oil that might remain in the burner line downstream of the valve. This will minimize the oil that could drain into the furnace following an emergency trip or burner shutdown. Positive means must be provided to prevent oil from leaking into an idle burner.

Fuel oil must be delivered to the burners at a specific temperature and pressure for proper atomization. Provisions must be made for adequately recirculating the oil to control its viscosity at the burners for initial light off and subsequent operation.

Systems must also prevent excessively hot oil from entering fuel-oil pumps; otherwise, the pumps might vapor-bind and interrupt the supply of oil to the burners.

BOILER-FURNACE HAZARDS

Explosion and fire are the most serious potential hazards in boiler-furnaces and their associated pipes, ducts, fans, and fuel bunkers. Explosions occur when an ignition source contacts a combustible mixture of fuel and air. When a combustible mixture has accumulated in a large, confined space of the equipment, a very damaging explosion can occur. Such accumulations can result from an equipment malfunction or an operator error associated with an inadequate or improper purge or incorrect operation of burner equipment. Because even a minute ignition source might initiate a substantial explosion and ignition sources abound in a furnace, for example, static electricity, hot slag, or glowing fly ash in a hopper, safe operation must emphasize avoiding creation of a large combustible mixture.

Hazards of Oil Firing

Fuel oil is a complex blend of hydrocarbons having a wide variety of molecular weights and boiling, freezing, and flash points. At a sufficiently high temperature fuel oil will partially volatize, thereby creating new and unpredictable liquids, gases, and solids.

At a sufficiently high temperature fuel oil will partially volatize, thereby creating new and unpredictable liquids, gases, and solids. Boilers have been fired with unrefined crude oil containing very volatile light ends, such as propane, butane, and pentane. However, with the rise of oil prices this is no longer common. Refined boiler fuels have had the light ends removed to produce gasoline and other valuable products and are thus less volatile. A new fuel form termed *Orimulsion* is a blend of bitumen (e.g., tar) and water. Any water-containing fuels can pose a hazard when separated water, rather than fuel, is pumped through the burner.

No.1 and No.2 fuel oil, and fuels commonly known as kerosenes, furnace oil, and diesel oil, are called *distillates*, whereas No.5 and No.6 fuel oil are referred to as *residuals*. Most large boilers designed for oil are designed for Nos. 5 or 6 oil. Distillates are used in boilers designed for natural gas as the primary fuel. Very volatile oils, crude oil, and many byproduct fuels require that electrical motors, switches, and other components be designed to explosion-proof standards.

For heavy oils (Nos. 4, 5, and 6), preheating is necessary to reduce the viscosity of the oil flowing to the burners and ensure proper atomization. This preheating is an important part of an integrated safety system designed to avoid flame interruptions.

Oils from different sources, even with similar specifications, can sometimes cause problems when stored in the same tank due to chemical reactions. When oil shipments having widely different viscosities or gravities are stored in the same tank, a significant change in fuel input rate can occur and impair complete combustion. In any event, fuel oils should be tested for their conformance to specifications soon after receipt.

Where the same burner is used for heavy and light oil, special care must be taken that the correct valve settings are selected. When very light oils with low electrical conductivity are used, static electricity can build up and provide an uncontrolled ignition source. Light or heavy, oil leaks a potential fire hazard. Assembly and disassembly of pipes and equipment should be done with care to avoid leaks. Leaks that do occur should be promptly stopped and cleaned up.

Hazards of Gas Firing

Hazards in gas-fired systems start with gas leaks and the development of fuel-rich mixtures within the boiler or ductwork. Potentially hazardous accumulations can also develop in other building areas, particularly where gas piping is routed through spaces that are not adequately ventilated. Unlike oil, gas leaks are not visible and plant noise can prevent the leak from being heard. Odorants might or might not be present at sufficient concentration to be detected via the nose.
Within the furnace it is possible for air-fuel ratios to be altered severely without producing any visible evidence at the burners, furnace, or stack, thus allowing a combustible mixture **to accumulate over time**. Combustion control systems, when responding to steam flow or pressure due to an increase in demand for fuel, are potentially dangerous unless protected to prevent the creation of a fuel-rich mixture and a loss of ignition.

Industrial and Commercial Heat Utilization Equipment

Heat utilization equipment has potential hazards involving both heat generation and the process materials. Fuel-fired systems, electrically heated systems, and heat transfer systems all have their individual hazards. The hazards of exposure of adjacent materials and overheating are common to any type of heating system. The hazards and control methods are discussed in subsequent sections.

The process hazards within the equipment can involve combustible materials, flammable liquids, or flammable gases; such hazards would occur in the curing of solvent-based coating materials, roasting or drying of combustible products, or heat treating in a flammable special atmosphere. The principal method of fire or explosion prevention is to prevent over heating or an accumulation of a gas or vapor-air mixture in the explosive range.

Heat utilization equipment is so varied in size, complexity, location, and use that it has been difficult to develop rules that apply to every type of oven, furnace, or dryer. Users and designers must use engineering and supervisory skills to bring together the proper combination of controls, protective devices, and operator training necessary for proper equipment operation.

Heat utilization equipment failures have resulted because someone either ignored safety procedures and designs or was unaware they existed, due to inadequate training of operators and maintenance technicians, faulty equipment design on the part of users, or improper selection of combustion safeguards.

INDUSTRIAL HEAT, UTILIZATION EQUIPMENT

Types of Industrial Heat Utilization Equipment

Industrial heat utilization equipment includes a variety of forges, furnaces, kettles, kilns, and ovens that are heated by gas, oil, solid fuels, or electricity. They can be fired directly, with the products of combustion entering the process space, or indirectly, with radiant tubes or other heat exchanger methods. Heat transfer media, such as organic fluids, are also used where steam or hot water does not provide the temperature or thermal efficiencies desired for the equipment. Figures 6.8.1 and 6.8.2 illustrate typical industrial heat utilization equipment.

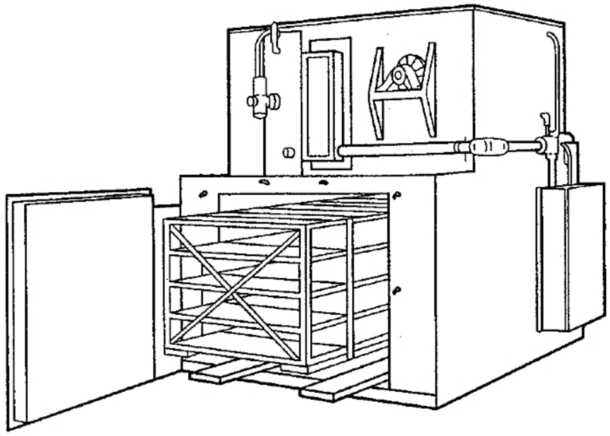

FIGURE 6.8.1 Typical Industrial Oven (Source: Fireye, Inc.)

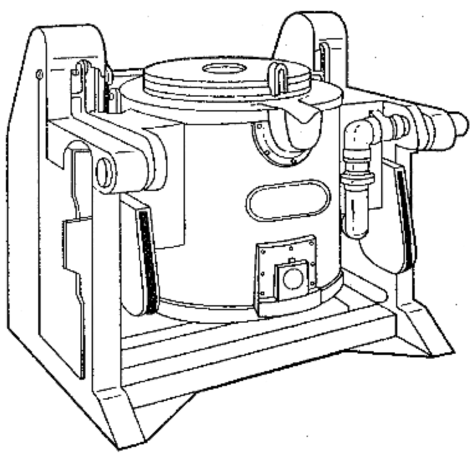

FIGURE 6.8.2 Fuel Fire Melting Furnace (Source: Fireye, Inc.)

Fire and Explosion Problems

When heat utilization equipment is installed, the following factors need to be considered:

(1) the proximity and combustibility of the contents of the building where the equipment is located;

(2) construction of the building;

(3) setting;

(4) ventilation;

(5) location within the building;

(6) removal of waste heat, gas, and smoke;

(7) maximum temperature required; and
(8) handling of heated materials in connection with equipment.

Fire in combustibles can be prevented by insulation or by separating them from the source of heat. Overheating can be prevented by temperature controls.

Explosion hazards exist where there are flammable vapor-air mixtures from gas or oil fuel or from volatiles released from the material being dried. Explosions or fires can be prevented by ventilation and controls that keep the flammable vapor content below 25 percent of the lower flammable limit (LFL) of the vapor-air mixture.

OVENS AND FURNACES

This discussion covers the location, design, construction, operation, protection, and maintenance of the industrial heating enclosures known as ovens or furnaces. It does not cover small-cabinet or stove-type ovens for domestic use. The source of heat for industrial heating can be gas burners, oil burners, electric heaters, infrared lamps, induction heaters, or steam radiation systems. In practically all cases, there are fire or explosion hazards from either the fuel used, volatiles produced material in the oven, or by a combination of both.

There is no clear distinction between an oven and a furnace. The dictionary definition of an oven is "a compartment receptacle for heating, baking, or drying by means of heat"; a furnace is "an enclosed chamber or structure in which heating is produced for heating a building, reducing ores and met baking pottery, etc." It has been an industry rule of thumb classify heating devices that do not "indicate color" [i.e., operate at temperatures of less than approximately (540° as ovens. However, this rule does not always apply.

NFPA Classification of Ovens and Furnaces

The classification system for heat processing equipment as forth in NFPA 86, *Standard for Ovens and Furnaces*, is as follows:

Class A ovens or furnaces are heat utilization equipment operating at approximately atmospheric pressure wherein a potential explosion and/or fire hazard may occasioned by the presence of flammable volatiles or combustible material processed or heated in the oven. Such flammable volatiles and/or combustible material may, for instance, originate from paints, powder, or finishing processes including dipped, coated, or sprayed on impregnated materials; or wood, paper and plastic pallets; or packaging materials. Potentially flammable materials, sue as quench oil, waterborne finishes, cooling oil, and so on, in sufficient quantities to present a hazard, are ventilated according to Class A standards.

Class B ovens or furnaces are heat utilization equipment operating at approximately atmospheric pressure wherein there are no flammable volatiles or combustible material being heated.

Class C furnaces are those in which there is a potential hazard due to a flammable or other special atmosphere being used for treatment of material in process. This type of furnace may use any type of heating system and includes the special atmosphere supply system(s). Also included in the Class C standards are integral quench and molten salt bath furnaces. See NFP *86C, Standard for Industrial Furnaces Using a Special Processing Atmosphere.*

Class D furnaces are vacuum furnaces that operate at temperatures above ambient to over 2760°C and at pressures below atmospheric using any type of heating system. These furnaces may include the use of special processing atmospheres. During gas quenching, these furnaces may operate at pressures from below atmospheric to over 7 bar.