CHAPTER 30

AUTOMATIC FUEL-BURNING SYSTEMS

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FUEL-BURNING systems provide a means to mix fuel and air in the proper ratio, ignite it, control the position of the flame envelope within the combustion chamber, and control a fuel-flow rate for safe combustion-heat energy release for space conditioning, water heating, and other processes. This chapter covers the design and use of automatic fuel-burning systems. The fuel can be gaseous (e.g., natural or liquefied petroleum gas), liquid (primarily the lighter grades of fuel oil or biodiesel), or solid (e.g., coal, or renewable items such as wood or corn). For discussion of some of these fuels, their combustion chemistry, and thermodynamics, see Chapter 18 of the 2005 *ASHRAE Handbook—Fundamentals*.

GENERAL CONSIDERATIONS

TERMINOLOGY

The following terminology for combustion systems, equipment, and fuel-fired appliances is consistent with usage in gas-fired appliance standards of the American National Standards Institute (ANSI) and Canadian Standards Association, the National Fire Protection Association's *National Fuel Gas Code* (ANSI Z223.1/NFPA 54), and the Canadian Standards Association's *Natural Gas and Propane Installation Code* (CSA *Standard* B149.1).

Air, circulating. Air distributed to habitable spaces for heating, cooling, or ventilation.

Air, dilution. Air that enters a draft hood or draft regulator and mixes with flue gas.

Air, excess. Air that passes through the combustion chamber in excess of the amount required for complete (stoichiometric) combustion.

Air, primary. Air introduced into a burner that mixes with fuel gas before the mixture reaches the burner ports.

Air, secondary. Air supplied to the combustion zone downstream of the burner ports.

Appliance. Any device that uses a gas, a liquid, or a solid as a fuel or raw material to produce light, heat, power, refrigeration, or air conditioning.

Draft. Negative static pressure, measured relative to atmospheric pressure; thus, positive draft is negative static pressure. Draft is the force (buoyancy of hot flue gas or other form of energy) that produces flow and causes pressure drop through an appliance combustion system and/or vent system. See Chapter 34 for additional information.

Equipment. Devices other than appliances, such as supply piping, service regulators, sediment traps, and vents in buildings.

Flue. General term for passages and conduit through which flue gases pass from the combustion chamber to the outdoors.

Flue gas. Products of combustion plus excess air in appliance flues, heat exchangers, and vents.

Input rate. Fuel-burning capacity of an appliance in Btu/h as specified by the manufacturer. Appliance input ratings are marked on appliance rating plates.

Vent. Passageway used to convey flue gases from appliances or their vent connectors to the outdoors.

Vent gas. Products of combustion plus excess air and dilution air in vents.

SYSTEM APPLICATION

The following considerations are important in the design, specification, and/or application of systems for combustion of fossil fuels.

Safety. Safety is of prime concern in the design and operation of automatic fuel-burning appliances. For more information, see the sections on Safety and Controls. Appliance standards and installation codes (e.g., ANSI *Standard* Z21.47/CSA *Standard* 2.3 for gas-fired central furnaces and ANSI Z223.1/NFPA 54, *National Fuel Gas Code*, in the United States) provide minimum safety requirements. Appliance manufacturers may include additional safety components to address hazards not covered by appliance standards and installation codes.

Suitability for Application. The system must meet the requirements of the application, not only in heating capacity, but also in its ability to handle the load profile. It must be suitable for its environment and for the substance to be heated.

Combustion System Type. System operation is very much a function of the type of burner(s), means for moving combustion products through the system, proper combustion air supply, and venting of combustion gases to the outdoors.

Efficiency. Efficiency can be specified in various ways, depending on the application. Stack loss and heat output are common measures, but for some applications, transient operation must be considered. In very high-efficiency appliances, heat extraction from combustion products may cool vent gas below its dew point, so condensation of water vapor in the combustion products must be handled, and venting design must consider corrosion by combustion products, as well as their lack of buoyancy.

Operating Control. Heat load or process requirements may occur in batches or may be transient events. The burner control system must accommodate those requirements, and the combustion system must be able to respond to the controls.

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Emissions. For safety and air quality reasons, combustion products must not contain excessive levels of noxious materials, notably carbon monoxide, oxides of nitrogen, unburned hydrocarbons, and particulate material such as soot.

Fuel Provision. Liquid and solid fuels, liquefied gases, and some gaseous fuels require space for storage. Gaseous and liquid fuels require appropriate piping for the fuel-burning system. Fuel storage and delivery provisions must be of adequate capacity and must be designed to ensure safe operation.

Sustainability. Fuel-burning appliances consume fuel resources and produce combustion products that are emitted to the atmosphere. The effect of these inherent characteristics can be minimized by using highly efficient systems with very low emissions of undesirable substances. (See the section on Efficiency and Emission Ratings.) Appliances using environmentally neutral (nonfossil) fuel, such as biofuels processed from vegetable oils and biomass material (e.g., forestry waste), are available. New technologies are also emerging. Through photosynthesis, biomass chlorophyll captures energy from the sun by converting carbon dioxide from the atmosphere and water from the ground into carbohydrates, complex compounds composed of carbon, hydrogen, and oxygen. When these carbohydrates are burned, they are converted back into carbon dioxide and water, and release the sun's energy. In this way, biomass stores solar energy and is renewable and carbon-neutral (UCS 2007).

Venting, Combustion Air Supply, and Appliance Installation. Combustion product gases must be handled properly to ensure safety and satisfactory system operation. Adequate air supply must be provided for combustion and ventilation. Appliances must be located to provide safe clearance from combustible material and for convenient service.

Standards and Codes. Building codes typically require that fuel-burning appliances be design-certified or listed to comply with nationally recognized standards. Appliance construction, safe operation, installation practices, and emissions requirements are often specified. In some locations, codes require special restraint for seismic or high wind conditions.

Cost. The choice of fuel-burning system is often based on it being the least expensive way to provide the heat needed for a process. The basic cost of energy tends to narrow the choices, but the total cost of purchase and ownership should dictate the final decision. Initial cost is the cost of the appliance(s), associated equipment and controls, and installation labor. Operating cost includes the cost of fuel, other utilities, maintenance, depreciation, and various ongoing charges, taxes, fees, etc. Energy cost analysis may indicate that one fuel is best for some loads and seasons, and another fuel is best for other times. Substantial operating cost is incurred if skilled personnel are required for operation and maintenance. Sometimes these costs can be reduced by appliances and control systems that automate operation and allow remote monitoring of system performance and maintenance requirements. Warranties should be considered. See Chapter 36 of the 2007 *ASHRAE Handbook—HVAC Applications* for a thorough discussion of costs.

SAFETY

All appliance systems must either operate safely or have a way to sense unsafe operation, and safely and promptly shut off the fuel supply before injury or property damage occurs. Safe and unsafe operation sensing and control is generally designed into the combustion control system. Examples of what controls must detect, evaluate, and act on include the following:

- Time to achieve fuel ignition
- Sufficient combustion air and/or flue gas flow rates
- Fuel flow rate (e.g., gas orifice pressure)
- Loss of flame
- Heat exchange operation (e.g., circulating air blower operating speed and timing for furnaces)
- Flame containment (flame rollout)
- Appliance component temperatures
- Loss of control power supply

EFFICIENCY AND EMISSION RATINGS

Heating capacity may be the primary factor in selecting fuel-burning appliances, but efficiency and emission ratings are often of equal importance to building owners and governmental regulators.

Steady-State and Cyclic Efficiency

Efficiency calculations are discussed in Chapter 18 of the 2005 *ASHRAE Handbook—Fundamentals*. Boiler and furnace efficiencies are discussed in Chapters 31 and 32 of this volume.

Stack Efficiency. Stack efficiency is a widely used rating approach based on measurement of the temperature and composition of gases exhausted by fuel-burning appliances. Knowing the oxygen or carbon dioxide concentration of the flue gases and the fuel's hydrocarbon content provides a measure of stack mass flow. In conjunction with flue gas temperature, these data allow determination of energy loss in the flue gas exiting the stack. The difference between stack loss and energy input is assumed to be useful energy, and stack efficiency is the ratio of that useful energy to energy input, expressed as a percentage. Generally, the rating is applied to steady-state combustion processes. Flue gas carbon dioxide and oxygen concentrations are affected mostly by the fuel's hydrocarbon content and by the appliance's combustion system design. Flue gas temperature is mostly affected by the appliance's heat exchanger design.

Heat Output Efficiency. Some rating standards require actual measurement of heat transferred to the substance being heated. Heat output measurement accounts for all heat losses, not just those in the flue gases. Nonstack heat loss, often called **jacket loss**, is difficult to measure and may be quite small, but can be accounted for by measuring heat output. The ratio of heat output to energy input, expressed as a percentage, is the heat output efficiency.

Load Profile Efficiency. U.S. Federal Trade Commission rules require that some types of residential appliances be rated under protocols that consider load profile. Residential and commercial space-heating furnaces and boilers, for example, are rated by their **annual fuel utilization efficiency (AFUE)**, which considers steady-state efficiency, heat-up and cooldown transients, and off-season energy consumption by gas pilot burners. Residential storage-type water heaters are rated under a protocol that requires measurement of energy consumption over a 24 h period, during which prescribed amounts of heated water are drawn. A water heater **energy factor** E_f is calculated from the measurements. The E_f rating accounts for standby losses (i.e., energy loss through the tank and fittings that does not go into the water). Ratings and discussion of AFUE and energy factors can be found in ASHRAE *Standard* 103 and in product directories by the Gas Appliance Manufacturers Association.

Emissions

Regulated Flue Gas Constituents. Appliance safety standards and environmental regulations specify limits for various substances that may be found in combustion flue gases. Substances most often regulated are carbon monoxide, oxides of nitrogen, and soot. Limits for sulfur oxides, unburned hydrocarbons, and other particulate matter may also be specified. Rules vary with location, type of installation, and type of combustion appliance. Regulations that restrict fuel sulfur content are generally intended to reduce sulfur oxide emissions, which may also reduce particulate emissions under certain conditions.

Flue Gas Concentration Limits. Standards and codes often specify maximum concentration levels permitted in flue gases. Because flue gases may be diluted by air, requirements invariably specify that measured concentration levels be adjusted by calculation to a standard condition. In appliance certification standards,

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that condition is typically the air-free level (i.e., what the concentration would be if there were no excess air). Carbon monoxide, for example, is often limited to 400 parts per million air-free. Air quality regulations sometimes specify the maximum level for a fixed degree of excess air. For oxides of nitrogen, the level is often specified in parts per million at 3% oxygen. The calculation, in effect, adds or subtracts dilution air to reach a condition at which oxygen concentration is 3% of the exhaust gas volume.

Emission per Unit of Useful Heat. In some U.S. jurisdictions, regulations for gas-fired residential furnaces and water heaters require that emission of oxides of nitrogen not exceed a specified level in nanograms per joule of useful heat. Measured flue gas emission levels are compared with the benefit in terms of heat output. Under this rating method, high efficiency is rewarded. Regulations for new installations may differ from those for existing systems and may be more stringent.

Mass Released to Atmosphere. Emissions from large fuel-fired appliances are often regulated at the site in terms of mass released to the atmosphere. Limits may be expressed, for example, in terms of pounds per million Btu burned or tons per year.

GAS-BURNING APPLIANCES

GAS-FIRED COMBUSTION SYSTEMS

Gas-burning combustion systems vary widely, the most significant differences being the type of burner and the means by which combustion products are moved through the system. Gas input rate control also has a substantial effect on combustion system design.

Burners

A primary function of a gas burner is mixing fuel gas and combustion air in the proper ratio before their arrival at the flame. In a **partially-aerated burner (Bunsen burner)**, only part of the necessary combustion air is mixed with the gas ahead of the flame. This primary air is typically about 30 to 50% of the stoichiometric air (i.e., that amount of air necessary for complete combustion of the gas). Combustion occurs at the point where adequate secondary air enters the combustion zone and diffuses into the mixture. In most cases, secondary air entry continues downstream of the burner and heat release is distributed accordingly. The total of primary and secondary air typically ranges from 140 to 180% of the stoichiometric air (i.e., 40 to 80% excess air).

Most often, partially aerated burners are **atmospheric** or **natural-draft burners** (i.e., they operate without power assist of any kind), which have the advantage of quiet operation. Fuel gas is injected from a pressurized gas supply through an injector (orifice) to form a gas jet, which propels discharged gas into the burner throat, entraining primary air by viscous shear. Primary air may also be drawn into the burner throat by venturi action. Fuel gas and air are mixed in a mixing tube before their arrival at the burner ports where burning occurs. A typical partially aerated burner is illustrated in Figure 1.

A **premix burner** is a power burner in which all or nearly all of the combustion air is mixed with the fuel gas before arrival at the flame. Because the necessary air is present at the flame front, combustion and heat release take place in a compact zone and there is no need for secondary aeration. Combustion quality (i.e., emission performance) tends to be better than that of partially aerated burners because of inherent mixing advantages, so premix burners can normally be operated at lower excess air levels (often 15 to 20%). Low excess air increases flame temperature, which enhances heat exchange but imposes greater thermal stress on the combustion chamber and its components. Extremely low excess air may result in higher CO and/or NO_x emissions.

A fan is almost always necessary to force the mixture of gas and air through a premix burner. Airflow is three or four times that through partially aerated burners, and the associated pressure drop is normally too much to be handled by fuel gas entrainment or stack draft. In general, appliances with premix burners are tuned more finely than those with partially aerated burners, to take advantage of their inherent advantages and to ensure reliable operation. A typical premix burner system is illustrated in Figure 2.

Combustion System Flow

In broad terms, flow through the combustion system is by natural draft or is motivated by some sort of fan assist. In a **natural-draft system**, the low density of hot combustion products creates a buoyant flow through the combustion chamber, heat exchanger, and venting system (chimney or stack). Historically, natural-draft systems used atmospheric burners, but emission and efficiency regulations have spawned designs that use fan-assisted burners in conjunction with natural-draft flow through the venting system. Chimneys or venting must be appropriate for natural-draft flow; see the discussion of venting in the Applications section.

Fan-assisted combustion systems have become common. A fan pushes or pulls combustion air and fuel gas through the burner, and combustion products through the combustion chamber and heat exchanger (and, in some cases, the venting). Some fan-assisted systems use atmospheric burners, applying the fan power mainly to force flow through an enhanced heat exchange process. Serpentine heat exchangers, for example, typically require fan assist because they have too much pressure drop to operate in natural-draft mode. In systems with significant burner pressure drop, such as that of a premix burner, fan power is required for the burner as well. Fan-assisted systems can operate with or without pressurizing the vent, depending on the flow rate of the combustion system, flue gas conditions (temperature and buoyancy), resistance of the venting system, and location of an induced-draft fan, if used. For more information, see the discussion of venting in the Applications section.

Push-through or **forced-draft systems** (Figure 3) use a fan to force air into the burner at positive pressure (higher than atmospheric). In some designs, it may also pressurize the combustion chamber and heat exchanger, and, in other designs, also the venting. **Pull-through** or **induced-draft systems** (Figure 4) use a fan in the appliance near the flue collar or vent outlet to pull flue gas through the combustion chamber and heat exchanger. These systems operate with negative pressure at all points before the fan.

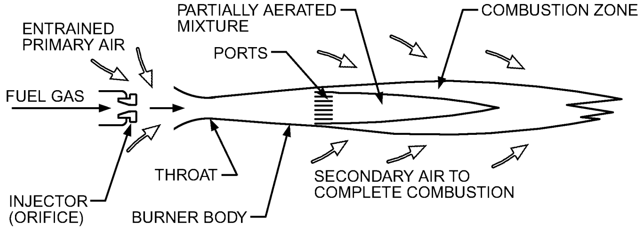

Fig. 1 Partially Aerated (Bunsen) Burner

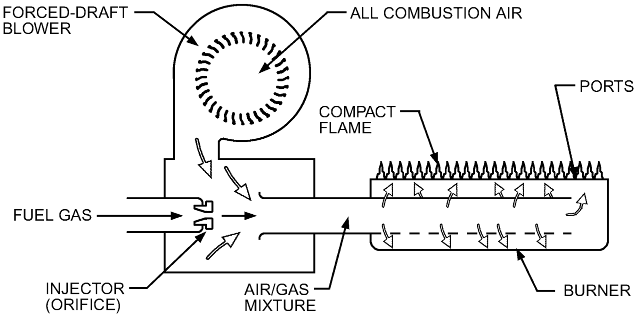

Fig. 2 Premix Burner

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Packaged power burners are often used in factory-built heating appliances and in field-assembled installations. These burners include all gas- and air-handling components, along with ignition controls, housing, mechanical means for mounting to the heating appliance, and connection of fuel gas and electric power. They tend to have a gun-type configuration (i.e., gas and air are mixed in an outlet tube with burner head, the latter inserted into the heating appliance's combustion chamber). Packaged power burners may also include special hardware and controls for gas input rate control, and some may include special features to reduce combustion emissions. Flue gas recirculation (i.e., returning some combustion products to the flame) is sometimes used to reduce production of oxides of nitrogen. A typical packaged power burner is shown in Figure 5.

Pulse combustion is a process in which combustion system flow is motivated by low-frequency pressure pulses created in the combustion chamber by cyclic/repetitive self-generating ignition of an air/gas mixture. It provides low emission levels and enhanced heat transfer. The oscillating nature of flow through the system provides a beneficial "scrubbing" effect on heat exchanger surfaces. Additional discussion of pulse combustion is provided in Chapter 18 of the 2005 *ASHRAE Handbook—Fundamentals.*

Ignition

Safety standards and codes specify requirements for ignition and proof of flame presence. Ignition must be immediate, smooth, and complete. Once flame is established, the ongoing presence of the ignition source or the flame itself must be ensured (i.e., flame supervision by the combustion control must detect loss of pilot and/or main flame and immediately shut off fuel gas flow). **Pilot burners** have been used very effectively for decades in appliances such as small residential water heaters and in very large field-assembled installations. The pilot flame may be detected by a temperature sensor (thermocouple) or by various electronic sensing systems. Pilot flames may be continuous or ignited only when there is a demand for heat (**intermittent pilot** operation).

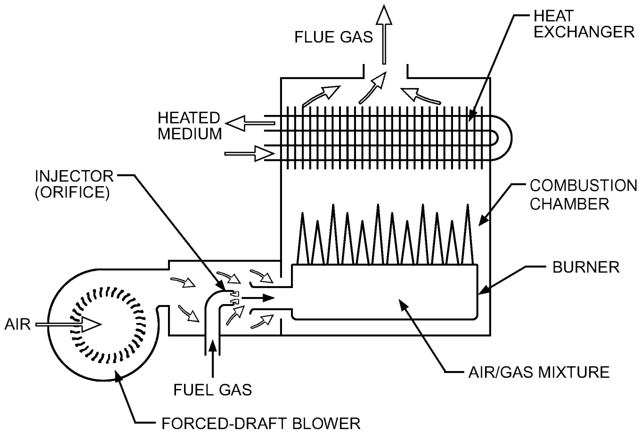

Fig. 3 Forced-Draft Combustion System

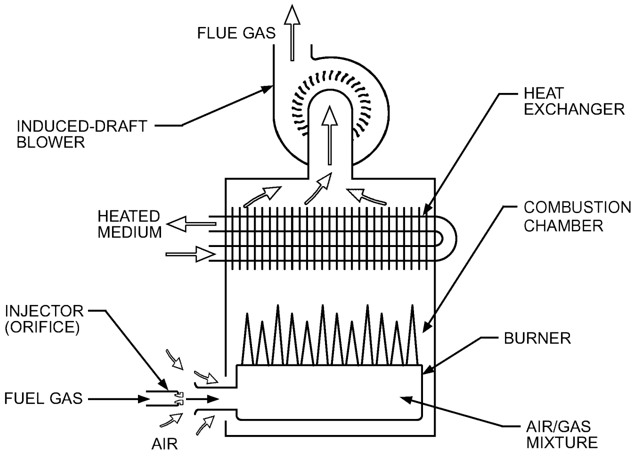

Fig. 4 Induced-Draft Combustion System

In some types of appliances, **direct ignition** is common. A **spark igniter** or a **hot surface igniter** is applied directly at the main burner ports to ignite the gas/air mixture. Direct-ignition systems also include a means, usually electronic, to sense presence of (supervise) the flame.

Ignition system standards and installation codes usually include requirements for other parameters such as flame failure response time, trial for ignition, and combustion chamber purging. For listed or design-certified appliances, applicable requirements have been test-verified by listing or certifying agencies. Other appliances and those installed in some building occupancy classes may be subject to special ignition and flame safety requirements in building and safety codes or by insurance underwriters. (See the section on Controls for more detail.)

Input Rate Control

A wide range of heat input is sometimes required of gas-fired appliances. Space heating, for example, is often done by zones, and must work under a wide range of outdoor conditions. Some water-heating and process applications also require a wide gas input rate range, and transients can be very steep input rate swings. Gas burners with staged or modulating control can be applied to meet these requirements.

Staged systems can be operated at discrete input rate levels, from full rated input to preset lower rates, sometimes with airflow remaining at the full-rate level and sometimes with proportional control of combustion air. Efficiency can be enhanced when combustion air is proportionally controlled, because flame temperature can remain high while the amount of heat exchanger surface per unit of input effectively becomes larger. A common staging approach uses a two-stage gas pressure regulator to change fuel gas pressure at an injector or metering orifice(s). In other designs, staging is accomplished by operating groups of individual burners or combustion chambers, each under control of its own gas valve and, if necessary, having its own ignition control. An extension of this approach is to use multiple individual heating appliances, controlled such that one or more can be called on as needed to meet the demand.

Modulating burner systems vary the input rate continuously, from full rated input to a minimum value. Modulation may be done by a throttling device in the gas burner piping, or with a modulating gas pressure regulator. Modulating systems require special controllers to provide a signal to the gas flow control device that is in some way proportional to the demand. As with staged systems, some designs provide commensurate control of combustion air, whereas

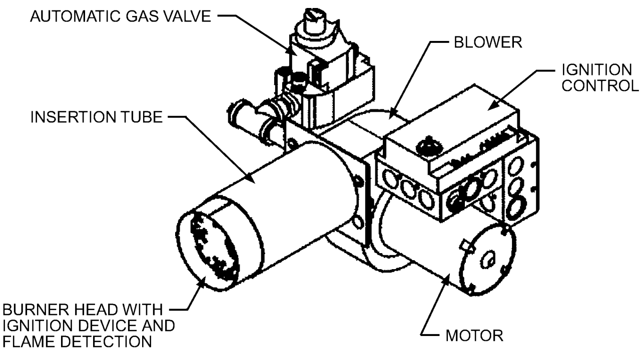

Fig. 5 Packaged Power Burner

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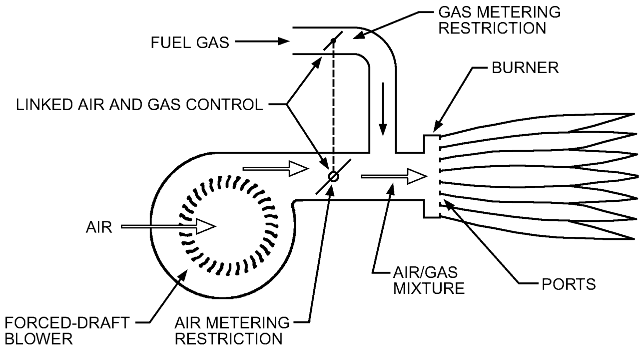

Fig. 6 Combustion System with Linked Air and Gas Flow

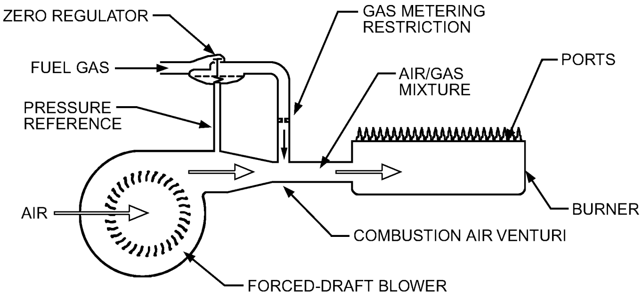

Fig. 7 Tracking Combustion System with Zero Regulator

others control only gas input rate with constant combustion airflow rate. Figure 6 illustrates a system in which combustion air and gas flow rates are throttled and linked.

Tracking burner systems, in which combustion air is controlled and gas follows proportionately, are a variation of modulating systems. These systems are designed to take advantage of the fact that flow of air and gas through orifices, venturis, or similar restrictions follows the Bernoulli equation. Special gas pressure regulators are used in conjunction with equalizer tubes or passages to link gas and air reference pressures. Airflow is controlled by dampers or a variable-speed fan. Changes in airflow bring about Bernoulli-governed changes in air pressure, which in turn change gas pressure proportionately. Usually, the design is such that the air/gas mixture proportions remain essentially constant at all input rates. This maintains high flame temperature and provides higher efficiency as the firing rate decreases. Special gas pressure regulators, referred to as **zero-pressure regulators**, **zero governors**, or **negative-pressure regulators**, are required in these systems. The pressure reference and venturi can be located upstream or downstream of the forced-draft blower; systems are available in either configuration. In either case, the pressure signal at the venturi inlet adjusts the gas pressure as needed to preserve venturi operation. An advantage to placing the venturi at the outlet is that the blower does not handle the combustible gas mixture. Consult manufacturer data for additional information. A tracking burner system is illustrated in Figure 7.

RESIDENTIAL APPLIANCES

Boilers

Residential space heating is often done with gas-fired low-pressure steam or hot-water boilers (i.e., steam boilers operating at 15 psig or less, or hot-water boilers operating at 160 psig or less with 250°F maximum water temperature). Steam or hot water is distributed to convectors, radiators, floor piping, fan coils, or other heat transfer devices in the space to be heated. Space temperature control may be by zone, in which case the boiler and distribution system must be able to accommodate reduced-load operation. Burners and combustion systems can be any of the previously described types, and some designs include input rate control. Rules of the U.S. Federal Trade Commission (FTC) and federal law require residential boilers with input rates less than 300,000 Btu/h to comply with minimum efficiency requirements, following the rating protocol of ASHRAE *Standard* 103. For hot-water boilers, 80% annual fuel utilization efficiency (AFUE) is required; for steam boilers, 75%. For ratings and technical information on rating protocol, see the *Consumers' Directory of Certified Efficiency Ratings* by the Gas Appliance Manufacturers Association (AHRI 2007). Manufacturers' literature also provides technical data and ratings.

Some boilers have low mass and essentially instantaneous response, whereas others have higher water volume and mass, which provides a degree of inherent storage capacity to better handle load change. Both steam and hot-water space-heating boilers are available in models having internal coils for service water heating. These **combination boilers** eliminate the need for a separate water heater, but they must be operated whenever service water may be needed, including times when space heating is not necessary. For a comprehensive discussion of boilers, see Chapter 31.

Forced-Air Furnaces

Central gas-fired, forced-air furnaces are the most common residential space-heating systems in the United States and Canada. Forced-air furnaces are available in configurations for upflow, downflow, and horizontal flow air distribution. Most have induced-draft combustion systems with Bunsen-type burners, and are typically of modular design (i.e., burner and heat exchanger modules are used in multiples to provide appliance models with a range of heating capacities). Some are available with staged or modulated input rate, and some have coordinated control of combustion air and circulating airflow. The FTC and U.S. federal law require furnaces with firing rates less than 225,000 Btu/h to meet minimum efficiency ratings: 75% AFUE for mobile home furnaces and 78% AFUE for other furnaces. The rating protocol for furnaces is different from that for boilers, and is outlined in ASHRAE *Standard* 103 and by AHRI (2007). Manufacturers' literature and AHRI (2007) provide ratings and other technical data. For detailed discussion of furnaces, see Chapter 32.

Water Heaters

In the United States, most residential water heaters are of the storage type (i.e., they have relatively low gas input rates and significant hot-water storage capacity). Typically, a single Bunsen-type burner is applied beneath a flue that rises through the stored water. Flue gas usually flows by natural draft. ANSI and Canadian Standards Association (CSA) appliance standards limit the input rate of these heaters to 75,000 Btu/h and require that water heaters manufactured since mid-2003 be designed to be **flammable vapor ignition resistant (FVIR)** because water heaters are often installed in garages and should not be an ignition source in case gasoline or other volatile or flammable substances may be present.

Instantaneous water heaters, often designed for mounting to a wall, are characterized by low water storage capacity and low mass, and have special burners and control systems designed for immediate response to demand for hot water. Burner input rate is typically linked to water flow rate and temperature, often by both hydraulic and electronic mechanisms. Because there is no storage, input rates tend to be higher than for storage heaters, and must be adequate for instantaneous demand. Standby losses of instantaneous water heaters are typically less than those of storage heaters. However, U.S. water use habits favor storage water heaters, which are used more extensively throughout the country.

In the United States, the efficiency of residential storage-type water heaters is based on a Department of Energy (DOE) protocol that requires measurement of energy consumption over a 24 h period, during which prescribed amounts of heated water are drawn.

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An **energy factor** E_f is calculated from the measurements. The rating accounts for standby losses (i.e., heat lost from stored hot water by conduction and convection through tank walls, flue, and pipe fittings to the environment). Hot-water delivery flow also appears in ratings. For storage heaters, the **first-hour rating** (i.e., volume of water that can be drawn in the first hour of use) is provided. For instantaneous heaters, the **maximum flow rate** in gallons per minute is provided. See AHRI (2007) for ratings and details about the energy factor.

Combination Space- and Water-Heating Appliances

Residential appliances that provide both space and water heating are available in a variety of configurations. One configuration consists of a specially designed storage water heater that heats and stores water for washing activities or for use as a heat transfer medium in a space-heating fan-coil unit. Another configuration, common in Europe and Asia, is a wall-hung boiler that provides hot water for use in either mode. Storage or instantaneous heating capacity must be adequate to meet user demand for showers or other peak activity. Control systems normally prioritize hot-water consumption requirements over the need for space heating, which is allowed only when the hot-water demand has been satisfied. Descriptions and technical data for these and other configurations are available from manufacturers. Ratings are provided in a special section of AHRI (2007). The method for testing and rating of combination space and water heating appliances is specified in ASHRAE *Standard* 124.

Pool Heaters

Pool heaters are a special type of water heater designed specifically for handling high flow rates of water at relatively low water temperature. Various burner and combustion system approaches are used in pool heaters. Input rate control is not normally incorporated because swimming pools are of very high mass and do not change temperature rapidly. Consult manufacturer and pool industry technical data for pool heater selection and application factors.

Conversion Burners

Conversion burners are complete burner and control units designed for installation in existing boilers and furnaces. Atmospheric conversion burners may have drilled-port, slotted-port, or single-port burner heads. These burners are either upshot or inshot types. Figure 8 shows a typical atmospheric upshot gas conversion burner.

Several power burners are available in residential sizes. These are of gun-burner design and are desirable for furnaces or boilers with restricted flue passages or with downdraft passages.

Conversion burners for domestic application are available in sizes ranging from 40,000 to 400,000 Btu/h input, the maximum rate being set by ANSI *Standard* Z21.17/CSA 2.7. However, large gas conversion burners for applications such as apartment building heating may have input rates as high as 900,000 Btu/h or more.

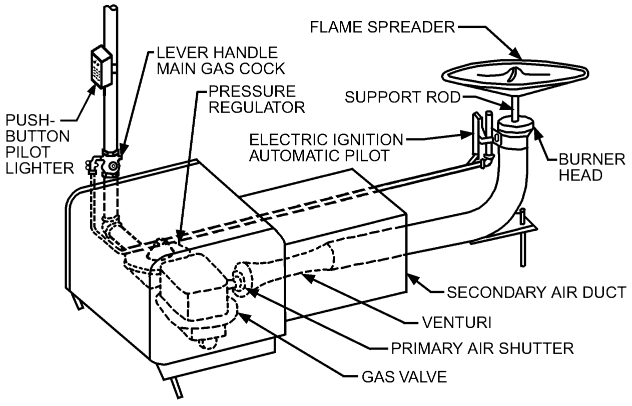

Fig. 8 Typical Single-Port Upshot Gas Conversion Burner

Successful and safe performance of a gas conversion burner depends on numerous factors other than those incorporated in the appliance, so installations must be made in strict accordance with current ANSI *Standard* Z21.8. Draft hoods conforming to current ANSI *Standard* Z21.12 should also be installed (in place of the dampers used with solid fuel) on all boilers and furnaces converted to burn gas. Because of space limitations, a converted appliance with a breeching over 12 in. in diameter is often fitted with a double-swing barometric regulator instead of a draft hood.

COMMERCIAL-INDUSTRIAL APPLIANCES

Boilers

Boilers for commercial and industrial application can be very large, both in physical size and input rate. Virtually any requirement for space heating or other process can be met by large boilers or multiple boilers. The heated medium can be water or steam. (See Chapter 31 for extensive discussion.)

Space Heaters

A wide variety of appliances is available for large air-heating applications. Some of them heat air by means of hot-water coils and are used in conjunction with boilers. Some accomplish space heating by means of a fuel-fired heat exchanger. Others fire directly into the heated space.

Forced-air fuel-burning furnaces for commercial and industrial application are essentially like those for residential use, but have larger heating and air-handling capacity. Input rates for single furnaces certified under ANSI *Standard* Z21.47/CSA *Standard* 2.3 (ANSI 2006) may be as high as 400,000 Btu/h. High capacity can also be provided by parallel (twinned) application of two furnaces. Most manufacturers provide kits to facilitate and address the special safety, mechanical, and control issues posed by twinned application. See manufacturer data and Chapter 32 for additional information about forced-air furnaces and their application.

Duct furnaces are fuel-fired appliances for placement in field-assembled systems with separate air-moving means. Combustion products heat air through heat exchangers mounted in the airstream. The combustion components, heat exchangers, and controls are prepackaged in a cabinet suitable for mounting in a duct system. For proper operation of the duct furnace, the airflow rate must be within the range specified by the manufacturer. See manufacturer data and Chapter 32 for additional information.

Unit heaters are free-standing appliances for heating large spaces without ductwork. They are often placed overhead, positioned to direct heat to specific areas. Typically, they incorporate fuel-fired heat exchangers and a fan or blower to move air through the exchangers and into the space. However, in some designs the fuel-fired exchangers are replaced by air-heating coils using hot water as the heating medium. Chapter 27 provides further information on unit heaters.

Direct gas-fired makeup-air heaters do not have heat exchangers. They heat large spaces by firing combustion products directly into the space, accompanied by a large quantity of dilution airflow. They have special burners capable of operation in high airflow and controls that allow operation over a wide fuel input rate range. As their name implies, they are used in applications requiring heated makeup air in conjunction with building exhaust systems. (See Chapter 27 for additional information.)

Infrared heaters radiate heat directly to surfaces and objects in a space. Air may be heated by convective heat transfer from the objects. They are suitable for overall heating of a building, but their selection is often based on their ability to radiate heat directly to people in limited areas without intentionally heating items or air in the space, such as in work stations in large open spaces that are not

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otherwise heated. Indirect infrared heaters use a radiating surface, such as a tube, between the combustion products and the space. Direct infrared heaters use the burner surface, typically a glowing ceramic or metal matrix, as the radiator. Chapter 15 provides additional information. See also manufacturers' data.

Water Heaters

Large-load water-heating applications, such as for large residence buildings, schools and hospitals, restaurants, and industrial processes, require water-heating appliances with correspondingly high fuel input rates, usually in conjunction with substantial hot-water storage. Large tank-type heaters with multiple flues are used in many intermediate-sized applications. They may operate as natural-draft systems, but forced- and induced-draft designs are common. Large applications or those with very high short-term water draw are often handled by means of large unfired storage tanks in conjunction with water-tube or other low-volume, high-input heaters. Fan-assisted combustion systems are increasingly common in those heaters. Premix burners may be used mainly to help meet emissions restrictions. Chapter 49 of the 2007 *ASHRAE Handbook—HVAC Applications* extensively discusses water-heating issues and appliances. ASHRAE *Standards* 118.1 and 118.2 provide methods of testing for rating commercial and residential water heaters, respectively.

Pool Heaters

Fuel-fired pool heaters are available in very large sizes, with fuel input rates ranging to several million Btu/h. They are designed to handle low-temperature water at high flow rates, and have sensitive temperature controls to ensure swimmer comfort and energy efficiency. Heating pool water with appliances not designed for that purpose can result in severe problems with combustion product condensation, corrosion, and/or scaling. See manufacturers' data for complete information.

APPLICATIONS

Gas-burning appliances cannot perform as intended unless they are properly installed and set up. Once an appliance of appropriate type, size, and features is selected, the location, fuel supply, air for combustion and ventilation, and venting must be considered and specified correctly. Other factors, notably elevation above sea level, must also be considered and handled.

Location

Listed appliances are provided with rating plate and installation information, with explicit requirements for location. The required clearance to combustible material is particularly important, to eliminate the hazard of fire caused by overheating. Other requirements may be less obvious. Adequate space must be provided for connecting ductwork, piping, and wiring, and for convenient maintenance and service. There must be access to chimneys and vents, and vent terminal locations must comply with specific requirements for safe discharge of combustion products without injury to people or damage to surroundings. Outdoor appliances must be located in consideration of wind effects and similar factors.

Local building codes provide basic rules for unlisted appliances and may impose additional requirements on listed appliances.

Gas Supply and Piping

Natural Gas. Natural gas is usually provided by the local gas utility. Most North American utilities provide substantial and reliable supply pressure, but it is important to verify adequate supply pressure during maximum simultaneous gas consumption by all appliances sharing the supply, and to design adequate supply piping between the utility supply point and the gas-burning appliance. On listed appliances, rating plates specify the minimum supply pressures at which the appliances will operate safely and as intended. This information is also provided in installation instructions, and is available from manufacturers before purchasing appliances.

Gas piping between the utility company meter and the appliance must provide adequate pressure when all concurrent loads operate at their maximum rate. Tables provided in ANSI Z223.1/NFPA 54 (*National Fuel Gas Code*), CSA B149.1 (CSA 2005), local codes, and elsewhere provide procedures for ensuring adequate pressure. For residential and light commercial services, utility companies typically provide gas at 7 in. of water. Building distribution piping is usually designed for a full-load pressure drop of less than 0.3 or 0.5 in. of water. Industrial and large-building applications are often supplied with gas at higher pressures; in that case, the distribution piping can be designed for larger pressure drop, but the end result must supply pressure to an individual appliance within the range required by its manufacturer. A pressure regulator may be required at the appliance to reduce pressure to comply with the rating plate pressure requirement.

Liquefied Petroleum Gas (LPG). LPG can contain a range of gas components. If it is not commercial propane or butane, the actual composition must be ascertained and accommodated. LPG is stored on site as a liquid at moderate pressure; it is vaporized as gas is drawn. A pressure regulator at the tank reduces pressure for distribution to the appliance through piping, subject to the same considerations as for natural gas. In the United States and Canada, normal supply pressure for residential and light commercial applications is 11 in. of water. Appliance rating plates and installation instructions typically require that supply pressure be maintained at or near that level. Piping must be designed to ensure adequate pressure when concurrent connected loads operate at their maximum input rates.

An important but sometimes overlooked issue is the need to provide heat to vaporize liquefied petroleum in the tank to deliver gas. In most residential applications, heat for vaporization is simply taken from outdoor air through the tank walls. This natural heat source may become inadequate, however, as the air temperature falls, draw rate increases, or tank liquid level falls. Commercial propane and butane have boiling point temperatures of –44°F and +32°F, respectively. As the LPG tank approaches the boiling point temperature, tank pressure falls to the point where the gas cannot be supplied at the required rate. In these cases and in high-demand applications, supplemental heat may be necessary to vaporize LPG. Information on selection and application of vaporization equipment is available from LPG dealers and distributors, from the National Propane Gas Association, and in various codes and standards.

Air for Combustion and Ventilation

In application of fuel-burning appliances, inadequate provision of air for combustion and ventilation is a serious mistake. In the worst scenario, shortage of combustion air results in incomplete combustion and production of poisonous carbon monoxide, which can kill. Inadequate ventilation of the space in which an appliance is installed can result in high ambient temperatures that stress the appliance itself or other appliances or materials in the vicinity. For those reasons, building codes and manufacturers' installation instructions include requirements for combustion and ventilation air supply. Requirements vary, with several factors having to do with how easily air can get to the appliance from the outdoors. Infiltration is seldom adequate, and it is usually necessary to provide dedicated means for supply of air for combustion and ventilation. In cold regions, measures should be taken to prevent the freezing of water pipes and other equipment by cold air in the appliance space. For more information, see Ackerman et al. (1995) and Dale et al. (1997).

Draft Control

Natural-draft appliances typically include a **draft hood** or **diverter** to decouple the combustion system from undesirable draft effects, notably the draft or pull of the chimney. These devices provide a path for dilution air to mix with flue gas before entering the connector between the appliance and the chimney, and to accommodate updraft and downdraft variations that occur in the field because of wind. A **barometric draft control** is a similar device that uses a damper to control the flow of dilution air into the vent. The damper of a barometric draft control can be manually adjusted to regulate the draft imposed on the appliance. Often, this is accomplished with special weights, in conjunction with measurement with a draft gage. Draft controls should be supplied by the appliance manufacturer as part of the appliance combustion controls. See Chapter 34 for design considerations for vent and chimney draft control.

Venting

Safety and technical factors must be considered in venting appliances, including some less obvious considerations. Consequences of incorrect venting are very serious, and can include production of lethal carbon monoxide, spilling of heat and combustion moisture indoors, and deterioration of the vent or chimney caused by condensation of water vapor from vent gas. High-efficiency appliances can produce combustion products at temperatures near or below their dew point. Venting those flue gases requires use of special materials and installation practices, and provision for condensate drainage and disposal.

Comprehensive guidance for design of venting systems is provided in Chapter 34. For many North American gas-fired appliances, however, ANSI Z21.47/CSA 2.3 and ANSI 21.13/CSA 4.9 require categorization by the type of vent system necessary for safe and effective operation. Appliances are tested to determine the temperature and pressure of vent gas released into the vent. The categories, which apply only to appliances design-certified as complying with standards having category specifications, are as follows:

Category	Vent Static Pressure	Vent Gas Temperature High Enough to Avoid Excessive Condensate Production in Vent?
I	Nonpositive	Yes
II	Nonpositive	No
III	Positive	Yes
IV	Positive	No

Category I and II appliances with a forced- or induced-draft blower to move combustion air and combustion products through the appliance flue create no pressure at the appliance flue exit (entrance to the venting system), and therefore do not augment draft in the vent.

Most local building codes include vent sizing tables and requirements that must be used for design of venting systems for category I appliances. Those tables are adopted from the *National Fuel Gas Code*, which distinguishes between appliances with draft hoods and appliances having fan-assisted combustion systems without draft hoods. In both cases, vent gases flow into the vent at category I conditions, but there is less dilution air with fan-assisted appliances than with draft-hood-equipped appliances. Vent gas flow and condensation tendencies differ accordingly. The tables specify

- Maximum (NAT Max) input rates for single-appliance vent systems and multiple-appliance vent connectors of given sizes for draft hood-equipped appliances
- Minimum (Fan Min) and maximum (Fan Max) input rates for single-appliance vent systems and multiple-appliance vent connectors of given sizes for fan-assisted appliances
- Maximum (Fan + NAT) input rates for multiple-appliance common vents of given sizes for combinations of draft-hood-equipped and fan-assisted appliance systems
- Maximum (Fan + Fan) input rates for multiple-appliance common vents of given sizes for fan-assisted appliance systems

Category II appliances are rare because it is difficult to vent low-temperature flue gas by its own buoyancy. Category III and IV appliances, with positive vent pressure, are common. Those appliances must be vented in accordance with the manufacturers' installation instructions, and require special venting materials. Category II and IV appliances also require venting designs that provide for collection and disposal of condensate. Condensate tends to be corrosive and may require treatment.

Appliances designed for installation with piping and terminals for both venting of flue gas and intake of combustion air directly to the appliance are called **direct-vent** (and sometimes, erroneously, **sealed combustion**) systems. (Sealed combustion systems take combustion air from outside the space being heated, not necessarily outdoors, and all flue gases are discharged outdoors; this is not a balanced system.) The vent and combustion air intake terminals of direct-vent appliances should be located outdoors, close to each other, so that they form a balanced system that is not adversely affected by winds from various directions. Vent pipe and combustion air intake pipe materials are provided or specified by the appliance manufacturer, and their use is mandatory. A variation in which only vent materials are specified, with combustion air taken directly from inside the conditioned space, is referred to as a **direct-exhaust** system. Most category III and IV systems are direct-vent or direct-exhaust systems.

Unlisted appliances must be vented in accordance with local building codes and the manufacturers' installation instructions. Clearance from vent piping to combustible material, mechanical support of vent piping, and similar requirements are also included in local codes.

Building Depressurization

Appliance operation can be affected by operation of other appliances and equipment in the building that change building pressure with respect to outdoor pressure. Building pressure can be reduced by bathroom and kitchen exhaust fans, cooktop range downdraft exhausters, clothes dryers, fireplaces, other fuel-burning appliances, and other equipment that removes air from the building. If building pressure is significantly lower than outdoor pressure, venting flue gases to the outdoors might be adversely affected and potentially hazardous combustion products may be spilled into the inhabited space, especially from category I and II appliances. Category III and IV appliances are less susceptible to venting and spillage problems, because these appliances produce pressure to force the flue gases through their vents to the outdoors. In addition, direct-vent appliances of all vent categories take their combustion air directly from the outdoors, which makes them even less susceptible to building depressurization. Wind can produce building depressurization, if building infiltration and exfiltration are unfavorably imbalanced.

Gas Input Rate

Gas input rate is the rate of heat energy input to an appliance, measured in Btu per hour.

The unit heating value of the fuel gas is expressed in Btu per cubic foot. **Higher heating value (HHV)** is commonly used to specify the heat available from gas when combusted. HHV includes all of the heat available by burning fuel gas delivered at 60°F and 14.735 psia (30 in. Hg) (i.e., standard conditions for the gas industry in North America) when combustion products are cooled to 60°F and water vapor formed during combustion is condensed at 60°F. 2005 See Chapter 18 of the 2005 *ASHRAE Handbook—Fundamentals* for more information on HHV.

In practical laboratory or field situations, fuel gas is not delivered at standard conditions. Determination of appliance input rate must include compensation for the actual temperature and pressure conditions.

In the laboratory, gas input rate is calculated with the following equation:

$$Q = \mathrm{HHV} \times \mathrm{VFR}\frac{(T_s \times P)}{(T \times P_s)}$$

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where

Q = gas input rate, Btu/h
HHV = gas higher heating value at standard temperature and pressure, Btu/ft^3
VFR = fuel gas volumetric flow rate at meter temperature and pressure, ft^3/h
T_s = standard temperature, 520°R (60°F + 460°R)
P = fuel gas pressure in gas meter, psia
T = absolute temperature of fuel gas in meter, °R (fuel gas temperature in °F + 460°R)
P_s = standard pressure, 14.735 psia

Example 1. Calculate the gas input rate for 1025 Btu/ft^3 HHV fuel gas, 75°F fuel gas temperature, 14.175 psia barometer pressure (1000 ft altitude), 100 ft^3/h of fuel gas volumetric flow rate clocked at the meter with 7.0 in. of water fuel gas pressure in the gas meter.

$$P = B + P_f$$

where

B = local barometric pressure, psia
P_f = fuel gas pressure in gas meter, in. of water
P = 14.175 psia + (7.0 in. of water × 0.03613 psi/in. of water) = 14.42791 psia
T = 75°F + 460°R = 535°R

Thus,

$$Q = \frac{1025\,\text{Btu/ft}^3 \times 100\,\text{ft}^3\text{/h} \times (520\,°\text{R} \times 14.42791\text{ psia})}{535\,°\text{R} \times 14.735\text{ psia}}$$

$$= 97{,}550\text{ Btu/h gas input rate}$$

In the field, input can be measured in two ways:

- With a gas meter, usually furnished by the gas supplier at the gas entrance point to a building
- By using the appliance burner gas injector (orifice) size and the manifold pressure [pressure drop through the injector (orifice)]

Gas input rate is calculated with the following equation, when fuel gas volumetric flow rate is measured using the gas supplier's meter.

$$Q = \text{HC} \times \text{VFR}$$

where

Q = gas input rate, Btu/h
HC = local gas heat content, Btu/ft^3
VFR = fuel gas volumetric flow rate, ft^3/h

Effect of Gas Temperature and Barometric Pressure Changes on Gas Input Rate

In the field, gas temperature is typically unknown, but is sometimes assumed to be a standard temperature such as 60°F; some meters have built-in temperature compensation to that temperature. Some gas suppliers also tabulate data for both local barometric pressure and local metering pressure. Add the meter gage pressure to the barometric pressure to get a correct fuel-gas absolute pressure. This methodology is used in ANSI Z223.1/NFPA 54 (NFPA 2006), the *National Fuel Gas Code*, sections 11.1.1, 11.1.2, and A.11.1.1, and Table A.11.1.1.

Also see the installation codes in the references for methods for using gas meters and for using injector (orifice) size with pressure drop to measure fuel gas flow rate.

Fuel Gas Interchangeability

Gas-burning appliances are normally set up for operation at their rated input with fuel gas of specified properties. Because fuel gases vary greatly, other gases cannot be substituted indiscriminately.

In most gas appliances, input rate is controlled by establishing a specified gas pressure difference (often referred to as **manifold pressure**) across one or more precisely sized orifices. Per the Bernoulli equation, gas velocity through the orifice is proportional to the square root of the pressure difference and inversely proportional to the square root of the density. The input rate also depends on the heat content of the gas and orifice size. Simplified to the basics, it is expressed as follows for particular conditions of temperature and barometric pressure:

$$Q = K \times \text{HHV} \times D_o^2 \sqrt{\frac{P_m}{\text{SG}}} \tag{1}$$

where

Q = input rate, Btu/h
K = constant accounting for measurement units, orifice discharge coefficient, and atmospheric conditions
HHV = gas higher heating value, Btu/ft^3
D_o = orifice diameter, in.
P_m = manifold pressure, in. of water
SG = gas specific gravity, dimensionless

If a substitute gas is introduced, only the higher heating value and specific gravity change. The orifice diameter, manifold pressure, and factors accounted for in the constant K do not change. Therefore, the new input is directly proportional to the gas higher heating value and inversely proportional to the square root of the specific gravity:

$$\frac{Q_2}{Q_1} = \frac{\left(\dfrac{\text{HHV}_2}{\sqrt{\text{SG}_2}}\right)}{\left(\dfrac{\text{HHV}_1}{\sqrt{\text{SG}_1}}\right)} \tag{2}$$

where subscripts 1 and 2 indicate the original and substitute gases, respectively. The ratio of higher heating value to the square root of the specific gravity has been named the **Wobbe index W**. The units of the Wobbe index are the same as those of the heating value because the specific gravity is dimensionless. Substituting for Wobbe index,

$$\frac{\text{HHV}}{\sqrt{\text{SG}}} = W \tag{3}$$

$$\frac{Q_2}{Q_1} = \frac{W_2}{W_1} \tag{4}$$

$$Q_2 = Q_1 \frac{W_2}{W_1} \tag{5}$$

In other words, when one gas is substituted for another in an appliance and no other changes are made, the input rate changes in proportion to their Wobbe indices. Preservation of input rate does not necessarily ensure proper operation of an appliance, however. Ignition and burning characteristics can differ significantly for gases that have the same Wobbe index. To ensure safe, efficient operation, appliance manufacturers typically limit the range of gases that may be used.

Converting an appliance for use with a gas substantially different from the gas it was originally set up for requires changing the gas-handling components and/or adjustments. Typical natural gas and commercial propane, for example, have Wobbe indices of about 1335 and 2040 Btu/ft^3, respectively. Based on that difference, substituting propane in an unaltered natural gas appliance results in overfiring of the appliance by about 53%, leading to appliance overheating and high production of soot and carbon monoxide. To accommodate the change, it is necessary to change the gas orifice size and, usually, the gas pressure regulator setting to achieve the

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same gas input rate. Acceptable performance may require additional appliance modifications to avoid other problems (e.g., resonance, poor flame carryover between ganged burners) that manufacturers must identify and resolve. The components necessary for conversion are normally provided by the appliance manufacturer, along with instructions for their installation and checkout of appliance operation.

Natural gas is increasingly being transported across oceans as **liquefied natural gas (LNG)**, shipped at high pressure and low temperature in specially designed ships. It is regasified in facilities at the destination, then distributed by utilities in conventional pipelines and service piping. Depending on the characteristics of a utility's existing gas supply, LNG can differ significantly in its mix of various hydrocarbons, inert gases, etc., and its burning characteristics may be of concern relative to the existing gas. Depending on the extent of the difference, a utility may mix it with other components to improve its compatibility with the existing appliance load. The Wobbe index is useful in evaluating the need for such accommodation.

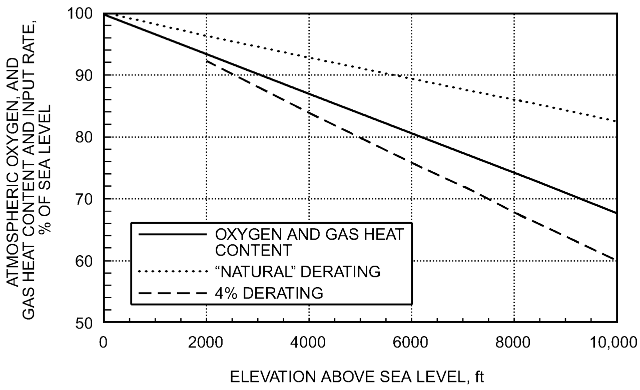
Altitude

When gas-fired appliances are operated at altitudes substantially above sea level, three notable effects occur:

- Oxygen available for combustion is reduced in proportion to the atmospheric pressure reduction
- With gaseous fuels, the heat of combustion per unit volume of fuel gas (gas heat content) is reduced because of reduced fuel gas density in proportion to the atmospheric pressure reduction
- Reduced air density affects the performance and operating temperature of heat exchangers and appliance cooling mechanisms

In addition to reducing the gas heat content of fuel gas, reduced fuel gas density also causes increased gas velocity through flow metering orifices. The net effect is for gas input rate to decrease naturally with increases in altitude, but at less than the rate at which atmospheric oxygen decreases. This effect is one reason that derating is required when appliances are operated at altitudes significantly above sea level. Early research by American Gas Association Laboratories with draft hood-equipped appliances established that appliance input rates should be reduced at the rate of 4% per 1000 ft above sea level, for altitudes higher than 2000 ft above sea level (Figure 9).

Experience with recently developed appliances having fan-assisted combustion systems demonstrated that the 4% rule may not apply in all cases. It is therefore important to consult the manufacturer's listed appliance installation instructions, which are based on both how the combustion system operates and other factors such as impaired heat transfer. Note also that manufacturers of appliances having tracking-type burner systems may not require derating at altitudes above 2000 ft. In those systems, fuel gas and combustion airflow are affected in the same proportion by density reduction.



Note: Natural derating applies for fixed injector (orifice) size and pressure.

Fig. 9 Altitude Effects on Gas Combustion Appliances

In terms of end use, it is important for the appliance specifier to be aware that the heating capacity of appliances is substantially reduced at altitudes significantly above sea level. To ensure adequate delivery of heat, derating of heating capacity must also be considered and quantified.

By definition, fuel gas HHV value remains constant for all altitudes because it is based on standard conditions of 14.735 psia (30.00 in. Hg) and 60°F (520°R). Some fuel gas suppliers at high altitudes (e.g., at Denver, Colorado, at 5000 ft) may report fuel gas heat content at local barometric pressure instead of standard pressure. Local gas heat content can be calculated using the following equation:

$$\mathrm{HC} = \mathrm{HHV} \times \frac{B}{P_s}$$

where

HC = local gas heat content at local barometric pressure and standard temperature conditions, Btu/ft^3
HHV = gas higher heating value at standard temperature and pressure of 520°R and 14.735 psia, respectively, Btu/ft^3
B = local barometric pressure, psia (not corrected to sea level: do not use barometric pressure as reported by weather forecasters, because it is corrected to sea level)
P_s = standard pressure = 14.735 psia

For example, at 5000 ft, the barometric pressure is 12.23 psia. If HHV of a fuel gas sample is 1000 Btu/ft^3 (at standard temperature and pressure), the local gas heat content would be 830 Btu/ft^3 at 12.23 psia barometric pressure 5000 ft above sea level.

$$\mathrm{HC} = 1000\ \mathrm{Btu/ft^3} \times 12.23\ \mathrm{psia}/14.735\ \mathrm{psia} = 830\ \mathrm{Btu/ft^3}$$

Therefore, the local gas heat content of a sample of fuel gas can be expressed as 830 Btu/ft^3 at local barometric pressure of 12.23 psia and standard temperature or as 1000 Btu/ft^3 (HHV). Both gas heat contents are correct, but the application engineer must understand the difference to use each one correctly. As described earlier, the local heat content HC can be used to determine appliance input rate.

When gas heat value (either HHV or HC) is used to determine gas input rate, the gas pressure and temperature in the meter must also be considered. Add the gage pressure of gas in the meter to the local barometric pressure to calculate the heat content of the gas at the pressure in the meter. The gas temperature in the meter also affects the heat content of the gas in the meter. The gas heat value is directly proportional to the gas pressure and inversely proportional to its absolute temperature in accordance with the perfect gas laws, as illustrated in the following example calculations for gas input rate with either the HHV or the local heat content.

Example 2. Calculate the gas input rate for 1000 Btu/ft^3 HHV fuel gas, 100 ft^3/h volumetric flow rate of 75°F fuel gas at 12.23 psia barometer pressure (5000 ft altitude) with 7 in. of water fuel gas gage pressure in the gas meter.

HHV Method:

$$Q = \mathrm{HHV} \times \mathrm{VFR}_s$$

where

Q = fuel gas input rate, Btu/h
HHV = fuel gas higher heating value at standard temperature and pressure, Btu/ft^3
VFR$_s$ = fuel gas volumetric flow rate adjusted to standard temperature and pressure, ft^3/h
= $\mathrm{VFR}(T_s \times P)/(T \times P_s)$
VFR = fuel gas volumetric flow rate at local temperature and pressure conditions, ft^3/h
T_s = standard temperature, 520°R (60°F + 460°R)
P = gas meter absolute pressure, psia (local barometer pressure + gas pressure in meter relative to barometric pressure)

= 12.23 psia + (7 in. of water × 0.03613 psi/in. of water)
= 12.48291 psia gas meter absolute pressure

T = absolute temperature of fuel gas, °R (fuel gas temperature in °F + 460°R)

P_s = standard pressure, 14.735 psia

Substituting given values into the equation for VFR_s gives

$$\mathrm{VFR}_s = \frac{100\ \mathrm{ft}^3/\mathrm{h} \times 520°\mathrm{F} \times 12.48291\ \mathrm{psia}}{(75°\mathrm{F} + 460°\mathrm{R})14.735\ \mathrm{psia}} = 82.341\ \mathrm{ft}^3/\mathrm{h}$$

Then,

$$Q = 1000\ \mathrm{Btu/ft}^3 \times 82.341\ \mathrm{ft}^3/\mathrm{h} = 82{,}341\ \mathrm{Btu/h}$$

Local Gas Heat Content Method: The local gas heat content is simply the HHV adjusted to local gas meter pressure and temperature conditions. The gas input rate is simply the observed volumetric gas flow rate times the local gas heat content.

$$Q = \mathrm{HC} \times \mathrm{VFR}$$

where

Q = gas input rate, Btu/h

HC = gas heat content at local gas meter pressure and temperature conditions, Btu/ft^3

VFR = fuel gas volumetric flow rate, referenced to local gas meter pressure and temperature conditions, ft^3/h

$$\mathrm{HC} = \mathrm{HHV}(T_s \times P)/(T \times P_s)$$

T_s = standard temperature, 520°R (60°F + 460°R)

P = gas meter absolute pressure, psia (local barometer pressure + gas pressure in gas meter relative to barometric pressure)

P_s = standard pressure = 14.735 psia

B = local barometric pressure = 12.230 psia

T = absolute temperature of fuel gas, 535°R (75°F fuel gas temperature + 460°R)

Substituting given values into the equation for HC gives

$$\mathrm{HC} = \frac{1000 \times 520[12.23 + (7.0 \times 0.03613)]}{535 \times 14.735} = 823.41\ \mathrm{Btu/ft}^3$$

Then,

$$Q = 823.41\ \mathrm{Btu/ft}^3 \times 100\ \mathrm{ft}^3/\mathrm{h} = 82{,}341\ \mathrm{Btu/h}$$

The gas input rate is exactly the same for both calculation methods.

OIL-BURNING APPLIANCES

An oil burner is a mechanical device for preparing fuel oil to combine with air under controlled conditions for combustion. Fuel oil is atomized at a controlled flow rate. Air for combustion is generally supplied with a forced-draft fan, although natural or mechanically induced draft can be used. Ignition is typically provided by an electric spark, although gas pilot flames, oil pilot flames, and hot-surface igniters may also be used. Oil burners operate from automatic temperature- or pressure-sensing controls.

Oil burners may be classified by application, type of atomizer, or firing rate. They can be divided into two major groups: residential and commercial/industrial. Further distinction is made based on design and operation; different types include pressure atomizing, air or steam atomizing, rotary, vaporizing, and mechanical atomizing. Unvented, portable kerosene heaters are not classified as residential oil burners or as oil heat appliances.

RESIDENTIAL OIL BURNERS

Residential oil burners ordinarily consume fuel at a rate of 0.5 to 3.5 gph, corresponding to input rates of about 70,000 to 500,000 Btu/h. However, burners up to 7 gph (about 1,000,000 Btu/h input) sometimes fall in the residential classification because of basic similarities in controls and standards. (Burners with a capacity of 3.5 gph and above are classified as commercial/industrial.) No. 2 fuel oil is generally used, although burners in the residential size range can also operate on No. 1 fuel oil. Burners in the 0.5 to 2.5 gph range are used not only for boilers and furnaces for space heating, but also for separate tank-type residential water heaters, infrared heaters, space heaters, and other commercial appliances.

Central heating appliances include warm-air furnaces and steam or hot water boilers. Oil-burning furnaces and boilers operate essentially the same way as their gas counterparts. NFPA *Standard* 31 prescribes correct installation practices for oil-burning appliances.

Steam or hot-water boilers are available in cast iron and steel. In addition to supplying space heating, many boilers are designed to provide hot water using tankless integral or external heat exchangers. Residential boilers designed to operate as direct-vent appliances are available.

Over 95% of residential burners manufactured today are high-pressure atomizing gun burners with retention-type heads (Figure 10). This type of burner supplies oil to the atomizing nozzle at pressures that range from 100 to 300 psi. A fan supplies air for combustion, and generally an inlet damper regulates the air supply at the burner. A high-voltage electric spark ignites the fuel by either **constant ignition** (on when the burner motor is on) or **interrupted ignition** (on only to start combustion). Typically, these burners fire into a combustion chamber in which draft is maintained. Increasingly, however, these burners are being fired into applications (including direct-vent and high-efficiency condensing applications) that have a low level of positive combustion chamber pressure.

Modern retention-head oil burners use 3450 rpm motors, and their fans achieve a maximum static pressure of about 3 in. of water. Older residential oil burners, which can still be found in the field, used lower-speed motors (1750 rpm) and achieved a maximum static pressure of about 1 to 1.5 in. of water. With higher fan static pressure, burner airflow is less sensitive to variations in appliance draft conditions. Higher-static-pressure burners operate better in applications with positive combustion chamber pressure. In many cases, these burners can be operated without a flue draft regulator.

Traditionally, oil burners are operated with a fuel pressure of 100 psi, and burners' nozzles are all rated for firing rate and spray angle at this pressure. Increasingly higher pressures (130 to 150 psi) are specified by manufacturers for some burners and applications, to achieve better atomization and combustion performance (Figure 11). Nozzle fuel firing rate increases in proportion to the square root of the fuel pressure.

Oil nozzle line heaters are used in some applications. These are very small electric heaters located adjacent to the nozzle adapter and typically integrated with the burner. These include positive-temperature-coefficient heaters that self-regulate to achieve a fuel temperature in the 120 to 150°F range. Heating fuel in this way improves atomization quality and reduces fuel firing rate.

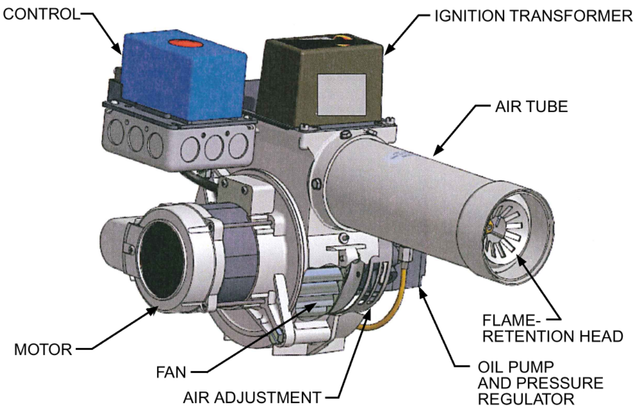


Fig. 10 High-Pressure Atomizing Gun Oil Burner

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Electric fuel solenoid valves may be installed in the fuel line between the fuel pump and the nozzle and may be mounted directly on the fuel pump. These valves serve to provide sharp fuel flow starts and stops during cyclic operation and augment the function of the fuel pump and pressure-operated flow control valves. In addition, solenoid valves can be used to achieve pre- and post-purge operation in which the burner motor runs to provide purge airflow through the burner and appliance. The post purge can be useful in reducing nozzle temperatures after shutdown and preventing odors indoors, particularly with non-direct-vent applications.

Pressure-operated valves integrated with oil burner nozzle assemblies are also available. These valves also provide positive fuel cutoff after burner shutdown and avoid after-drip caused by heat transfer from the still-hot combustion chamber to the nozzle assembly and accumulation of fuel vapor pressure in the nozzle assembly and fuel line. When used, these nozzle valves require the fuel pump discharge pressure to be increased, using the integral pump pressure regulator to compensate for the added pressure drop of the valve.

The following designs are still in operation but are not a significant part of the residential market:

- The low-pressure atomizing gun burner differs from the high-pressure type in that it uses air at a low pressure to atomize oil.
- The pressure atomizing induced-draft burner uses the same type of oil pump, nozzle, and ignition system as the high-pressure atomizing gun burner.
- Vaporizing burners are designed for use with No. 1 fuel oil. Fuel is ignited electrically or by manual pilot.
- Rotary burners are usually of the vertical wall flame type.

Beyond the pressure atomizing burner, considerable developmental effort has been put into advanced technologies such as air atomization, fuel prevaporization, and pulsed fuel flow. Some of these are now used commercially in Europe. Reported benefits include reduced emissions, increased efficiency, and the ability to quickly vary the firing rate. See Locklin and Hazard (1980) for a historical review of technology for residential oil burners. More recent developments are described in the *Proceedings of the Oil Heat Technology Conferences and Workshops* (McDonald 1989-1998).

In Europe, there is increasing use of low-NO_x, **blue flame burners** for residential and commercial applications. Peak flame temperatures (and thermal NO_x emissions) are reduced by using high flame zone recirculation rates. In a typical boiler, a conventional yellow flame retention head oil burner has a NO_x emission of 90 to 110 ppm. A blue flame burner emits about 60 ppm. The blue flame burners require flame sensors for the safety control, which responds to the fluctuating light emitted. Blue flame burners are somewhat more expensive than conventional yellow flame burners. See Butcher et al. (1994) for additional discussion of NO_x and small oil burners.

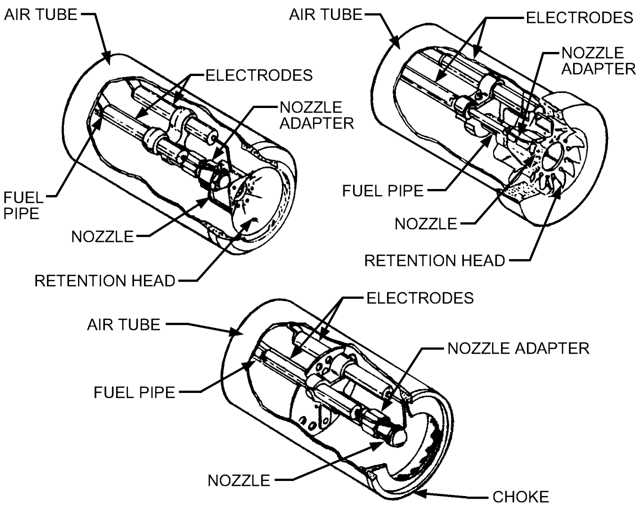

Fig. 11 Details of High-Pressure Atomizing Oil Burner

COMMERCIAL/INDUSTRIAL OIL BURNERS

Commercial and industrial oil burners are designed for use with distillate or residual grades of fuel oil. With slight modifications, burners designed for residual grades can use distillate fuel oils.

The commercial/industrial burners covered here have atomizers, which inject the fuel oil into the combustion space in a fine, conical spray with the apex at the atomizer. The burner also forces combustion air into the oil spray, causing an intimate and turbulent mixing of air and oil. Applied for a predetermined time, an electrical spark, a spark-ignited gas, or an oil igniter ignites the mixture, and sustained combustion takes place. Safety controls are used to shut down the burner upon failure to ignite.

All of these burners are capable of almost complete burning of the fuel oil without visible smoke when they are operated with excess air as low as 20% (approximately 12% CO_2 in the flue gases). Atomizing oil burners are generally classified according to the method used for atomizing the oil, such as pressure atomizing, return-flow pressure atomizing, air atomizing, rotary cup atomizing, steam atomizing, mechanical atomizing, or return-flow mechanical atomizing. Descriptions of these burners are given in the following sections, together with usual capacities and applications. Table 1 lists approximate size range, fuel grade, and usual applications. All burners described are available as gas/oil (dual-fuel) burners.

Pressure-Atomizing Oil Burners

This type of burner is used in most installations where No. 2 fuel oil is burned. The oil is pumped at pressures of 100 to 300 psi through a suitable burner nozzle orifice that breaks it into a fine mist and swirls it into the combustion space as a cone-shaped spray. Combustion air from a fan is forced through the burner air-handling parts surrounding the oil nozzle and is directed into the oil spray.

For smaller-capacity burners, ignition is usually started by an electric spark applied near the discharge of the burner nozzle. For burner capacities above 20 gph, a spark-ignited gas or an oil igniter is used.

Pressure-atomizing burners are designated commercially as forced-draft, natural-draft, or induced-draft burners. The forced-draft burner has a fan and motor with capacity to supply all combustion air to the combustion chamber or furnace at a pressure high enough to force the gases through the heat-exchange equipment without the assistance of an induced-draft fan or a chimney draft. Mixing of the fuel and air is such that a minimum of refractory material is required in the combustion space or furnace to support combustion. The natural-draft burner requires a draft in the combustion space.

Burner range, or variation in burning rate, is changed by simultaneously varying the oil pressure to the burner nozzle and regulating the airflow by a damper. This range is limited to about 1.6 to 1 for any given nozzle orifice. Burner firing mode controls for various capacity burners differ among manufacturers. Usually, larger burners have controls that provide variable heat inputs. If burner capacity is up to 15 gph, a staged control is typically used; if it is up to 25 gph, a **modulation control** is typically used. In both cases, the low burning rate is about 60% of the full-load capacity of the burner.

For pressure-atomizing burners, no preheating is required for burning No. 2 oil. No. 4 oil must be preheated to about 100°F for proper burning. When properly adjusted, these burners operate well with less than 20% excess air (approximately 12% CO_2); no visible smoke (approximately No. 2 smoke spot number, as determined by ASTM *Standard* D2156); and only a trace of carbon monoxide in the flue gas in commercial applications. In these applications, the

Table 1 Classification of Atomizing Oil Burners

Type of Oil Burner	Heat Range, 1000 Btu/h	Flow Volume, gph	Fuel Grade	Usual Application
Pressure-atomizing	70 to 7000	0.5 to 50	No. 2 (less than 25 gph)	Boilers Warm-air furnaces
			No. 4 (greater than 25 gph)	Appliances
Return-flow pressure-atomizing or modulating pressure-atomizing	3500 and above	25 and above	No. 2 and heavier	Boilers Warm-air furnaces
Air-atomizing	70 to 1000	0.5 to 70	No. 2 and heavier	Boilers Warm-air furnaces
Horizontal rotary cup	750 to 37,000	5 to 300	No. 2 for small sizes	Boilers
			No. 4, 5, or 6 for larger sizes	Large warm-air furnaces
Steam-atomizing (register-type)	12,000 and above	80 and above	No. 2 and heavier	Boilers
Mechanical atomizing (register-type)	12,000 and above	80 and above	No. 2 and heavier	Boilers Industrial furnaces
Return-flow mechanical atomizing	45,000 to 180,000	300 to 1200	No. 2 and heavier	Boilers

regulation of combustion airflow is typically based on smoke level or flue gas monitoring using analyzers for CO, O_2, or CO_2.

Burners with lower firing rates used to power appliances, residential heating boilers, or warm-air furnaces are usually set up to operate to about 50% excess air (approximately 10% CO_2).

Good operation of these burners calls for (1) a relatively constant draft (either in the furnace or at the breeching connection, depending on the burner selected), (2) clean burner components, and (3) good-quality fuel oil that complies with the appropriate specifications.

Return-Flow Pressure-Atomizing Oil Burners

This burner is a modification of the pressure-atomizing burner; it is also called a modulating-pressure atomizer. It has the advantage of a wide load range for any given atomizer: about 3 to 1 turndown (or variation in load) as compared to 1.6 to 1 for the straight pressure atomizing burner.

This wide range is accomplished by means of a return-flow nozzle, which has an atomizing swirl chamber just ahead of the orifice. Good atomization throughout the load range is attained by maintaining a high rate of oil flow and high pressure drop through the swirl chamber. The excess oil above the load demand is returned from the swirl chamber to the oil storage tank or to the suction of the oil pump.

The burning rate is controlled by varying oil pressure in both the oil inlet and oil return lines. Except for the atomizer, load range, and method of control, the information given for the straight pressure-atomizing burner applies to this burner as well.

Air-Atomizing Oil Burners

Except for the nozzle, this burner is similar in construction to the pressure-atomizing burner. Atomizing air and oil are supplied to individual parts within the nozzle. The nozzle design allows the oil to break up into small droplet form as a result of the shear forces created by the atomizing air. The atomized oil is carried from the nozzle through the outlet orifice by the airflow into the furnace.

The main combustion air from a draft fan is forced through the burner throat and mixes intimately with the oil spray inside the combustion space. The burner igniter is similar to that used on pressure-atomizing burners.

This burner is well suited for heavy fuel oils, including No. 6, and has a wide load range, or turndown, without changing nozzles. Turndown of 3 to 1 for the smaller sizes and about 6 or 8 to 1 for the larger sizes may be expected. Load range is varied by simultaneously varying the oil pressure, the atomizing air pressure, and the combustion air entering the burner. Some designs use relatively low atomizing air pressure (5 psi and lower); other designs use air pressures up to 75 psi. The burner uses from 2.2 to 7.7 ft^3 of compressed air per gallon of fuel oil (on an air-free basis).

Because of its wide load range, this burner operates well on modulating control.

No preheating is required for No. 2 fuel oil. The heavier grades of oil must be preheated to maintain proper viscosity for atomization. When properly adjusted, these burners operate well with less than 15 to 25% excess air (approximately 14 to 12% CO_2, respectively, at full load); no visible smoke (approximately No. 2 smoke spot number); and only a trace of carbon monoxide in the flue gas.

Horizontal Rotary Cup Oil Burners

This burner atomizes the oil by spinning it in a thin film from a horizontal rotating cup and injecting high-velocity primary air into the oil film through an annular nozzle that surrounds the rim of the atomizing cup.

The atomizing cup and frequently the primary air fan are mounted on a horizontal main shaft that is motor-driven and rotates at constant speed (3500 to 6000 rpm) depending on the size and make of the burner. The oil is fed to the atomizing cup at controlled rates from an oil pump that is usually driven from the main shaft through a worm and gear.

A separately mounted fan forces secondary air through the burner windbox. Secondary air should not be introduced by natural draft. The oil is ignited by a spark-ignited gas or an oil-burning igniter (pilot). The load range or turndown for this burner is about 4 to 1, making it well suited for operation with modulating control. Automatic combustion controls are electrically operated.

When properly adjusted, these burners operate well with 20 to 25% excess air (approximately 12.5 to 12% CO_2, respectively, at full load), no visible smoke (approximately No. 2 smoke spot number), and only a trace of carbon monoxide in the flue gas.

This burner is available from several manufacturers as a package comprising burner, primary air fan, secondary air fan with separate motor, fuel oil pump, motor, motor starter, ignition system (including transformer), automatic combustion controls, flame safety equipment, and control panel.

Good operation of these burners requires relatively constant draft in the combustion space. The main assembly of the burner, with motor, main shaft, primary air fan, and oil pump, is arranged for mounting on the boiler front and is hinged so that the assembly can be swung away from the firing position for easy access.

Rotary burners require some refractory in the combustion space to help support combustion. This refractory may be in the form of throat cones or combustion chamber liners.

Steam-Atomizing Oil Burners (Register Type)

Atomization is accomplished in this burner by the impact and expansion of steam. Oil and steam flow in separate channels through the burner gun to the burner nozzle. There, they mix before

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discharging through an orifice, or series of orifices, into the combustion chamber.

Combustion air, supplied by a forced-draft fan, passes through the directing vanes of the burner register, through the burner throat, and into the combustion space. The vanes give the air a spinning motion, and the burner throat directs it into the cone-shaped oil spray, where intimate mixing of air and oil takes place.

Full-load oil pressure at the burner inlet is generally some 100 to 150 psi, and the steam pressure is usually kept higher than the oil pressure by about 25 psi. Load range is accomplished by varying these pressures. Some designs operate with oil pressure ranging from 150 psi at full load to 10 psi at minimum load, resulting in a turndown of about 8 to 1. This wide load range makes the steam atomizing burner suited to modulating control. Some manufacturers provide dual atomizers within a single register so that one can be cleaned without dropping load.

Depending on the burner design, steam atomizing burners use from 1 to 5 lb of steam to atomize a gallon of oil. This corresponds to 0.5 to 3.0% of the steam generated by the boiler. Where no steam is available for start-up, compressed air from the plant air supply may be used for atomizing. Some designs allow use of a pressure atomizing nozzle tip for start-up when neither steam nor compressed air is available.

This burner is used mainly on water-tube boilers, which generate steam at 150 psi or higher and at capacities above 12,000,000 Btu/h input.

Oils heavier than grade No. 2 must be preheated to the proper viscosity for good atomization. When properly adjusted, these burners operate well with 15% excess air (14% CO_2) at full load, without visible smoke (approximately No. 2 smoke spot number), and with only a trace of carbon monoxide in the flue gas.

Mechanical Atomizing Oil Burners (Register Type)

Mechanical atomizing, as generally used, describes a technique synonymous with pressure atomizing. Both terms designate atomization of the oil by forcing it at high pressure through a suitable stationary atomizer.

The mechanical atomizing burner has a windbox, which is a chamber into which a fan delivers combustion and excess air for distribution to the burner. The windbox has an assembly of adjustable internal air vanes called an air register. Usually, the fan is mounted separately and connected to the windbox by a duct.

Oil pressure of 90 to 900 psi is used, and load range is obtained by varying the pressure between these limits. The operating range or turndown for any given atomizer can be as high as 3 to 1. Because of its limited load range, this type of burner is seldom selected for new installations.

Return-Flow Mechanical Atomizing Oil Burners

This burner is a modification of a mechanical atomizing burner; atomization is accomplished by oil pressure alone. Load ranges up to 6 or 8 to 1 are obtained on a single-burner nozzle by varying the oil pressure between 100 and 1000 psi.

The burner was developed for use in large installations such as on ships and in electric generating stations where wide load range is required and water loss from the system makes use of atomizing steam undesirable. It is also used for firing large hot-water boilers. Compressed air is too expensive for atomizing oil in large burners.

This is a register burner similar to the mechanical atomizing burner. Wide range is possible by using a return-flow nozzle, which has a swirl chamber just ahead of the orifice or sprayer plate. Good atomization is attained by maintaining a high rate of oil flow and a high pressure drop through the swirl chamber. Excess oil above the load demand is returned from the swirl chamber to the oil storage tank or to the oil pump suction. Control of burning rate is accomplished by varying the oil pressure in both the oil inlet and the oil return lines.

DUAL-FUEL GAS/OIL BURNERS

Dual-fuel, combination gas/oil burners are forced-draft burners that incorporate, in a single assembly, the features of the commercial/industrial-grade gas and oil burners described in the preceding sections. These burners have controls to ensure that the burner flame relay or programmer cycles the burner through post- and prepurge before starting again on the other fuel. Burner manufacturers for larger boilers design the special mechanical linkages needed to deliver the correct air/fuel ratios at full fire, low fire, or any intermediate rate. Smaller burners may have straight **on/off** firing. Larger burners may have low-fire starts on both fuels and use a common flame scanner. Smaller dual-fuel burners usually include pressure atomization of the oil. Air atomization systems are included in large oil burners.

Dual-fuel burners often have automatic changeover controls that respond to outdoor temperature. A special temperature control, located outdoors and electrically interlocked with the dual-fuel burner control system, senses outdoor temperature. When the outdoor temperature drops to the outdoor control set point, the control changes fuels automatically after putting the burner through post- and prepurge cycles. A manual fuel selection switch can be retained as a manual override on the automatic feature. These control systems require special design and are generally provided by the burner manufacturer.

The dual-fuel burner is fitted with a gas train and oil piping that is connected to a two-pipe oil system following the principles of the preceding sections. An oil reserve must be maintained at all times for automatic fuel changeover.

Boiler flue chimney connectors are equipped with special double-swing barometric draft regulators or, if required, sequential furnace draft control to operate an automatic flue damper.

Dual-fuel burners and their accessories should be installed by experienced contractors to ensure satisfactory operation.

EQUIPMENT SELECTION

Economic and practical factors (e.g., the degree of operating supervision required by the installation) generally dictate the selection of fuel oil based on the maximum heat input of the oil-burning appliance. For heating loads and where only one oil-burning appliance is operated at any given time, the relationship is as shown in Table 2 (which is only a guide). In many cases, a detailed analysis of operating parameters results in the burning of lighter grades of fuel oil at capacities far above those indicated.

Fuel Oil Storage Systems

All fuel-oil storage tanks should be constructed and installed in accordance with NFPA *Standard* 31 and with local ordinances.

Storage Capacity. Dependable and economical operation of oil-burning appliances requires ample and safe storage of fuel oil at the site. Design responsibility should include analysis of specific storage requirements as follows:

- Rate of oil consumption.
- Dependability of oil deliveries.
- Economical delivery lots. The cost of installing larger storage capacity should be balanced against the savings indicated by accommodating larger delivery lots. Truck lots and railcar lots vary with various suppliers, but the quantities are approximated as follows:

Small truck lots in metropolitan area	500 to 2000 gal
Normal truck lots	3000 to 5000 gal
Transport truck lots	5000 to 9000 gal
Rail tanker lots	8000 to 12000 gal

Tank Size and Location. Standard oil storage tanks range in size from 55 to 50,000 gal and larger. Tanks are usually built of steel; concrete construction may be used only for heavy oil. Unenclosed

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Table 2 Guide for Fuel Oil Grades Versus Firing Rate

Maximum Heat Input of Appliance, 1000 Btu/h	Volume Flow Rate, gph	Fuel Grade
Up to 3500	Up to 25	2
3500 to 7000	25 to 50	2, 4, 5
7000 to 15,000	50 to 100	5, 6
Over 15,000	Over 100	6

tanks located in the lowest story, cellar, or basement should not exceed 660 gal capacity each, and the aggregate capacity of such tanks should not exceed 1320 gal unless each 660 gal tank is insulated in an approved fireproof room having a fire resistance rating of at least 2 h.

If storage capacity at a given location exceeds about 1000 gal, storage tanks should be underground and accessible for truck or rail delivery with gravity flow from the delivering carrier into storage. If the oil is to be burned in a central plant such as a boiler house, the storage tanks should be located, if possible, so that the oil burner pump (or pumps) can pump directly from storage to the burners. For year-round operation, except for storage or supply capacities below 2000 gal, at least two tanks should be installed to facilitate tank inspection, cleaning, repairs, and clearing of plugged suction lines.

When the main oil storage tank is not close enough to the oil-burning appliances for the burner pumps to take suction from storage, a supply tank must be installed near the oil-burning appliances and oil must be pumped periodically from storage to the supply tank by a transport pump at the storage location. Supply tanks should be treated the same as storage tanks regarding location within buildings, tank design, etc. On large installations, it is recommended that standby pumps be installed as a protection against heat loss in case of pump failure.

Because all piping connections to underground tanks must be at the top, such tanks should not be more than 10.5 ft from top to bottom to avoid pump suction difficulties. (This dimension may have to be less for installations at high altitudes.) At sea level, the total suction head for the oil pump must not exceed 14 ft.

Connections to Storage Tank. All piping connections for tanks over 275 gal capacity should be through the top of the tank. Figure 12 shows a typical arrangement for a cylindrical storage tank with a heating coil as required for No. 5 or 6 fuel oils. The heating coil and oil suction lines should be located near one end of the tank. The maximum allowable steam pressure in such a heating coil is 15 psi. The heating coil is unnecessary for oils lighter than No. 5 unless a combination of high pour point and low outdoor temperature makes heating necessary.

A watertight access port with internal ladder provides access to the inside of the tank. If the tank is equipped with an internal heating coil, a second access port is required in order to permit withdrawal of the coil.

The fill line should be vertical and should discharge near the end of the tank away from the oil suction line. The inlet of the fill line must be outside the building and accessible to the oil delivery vehicle unless an oil transfer pump is used to fill the tank. When possible, the inlet of the fill line should be at or near grade where filling may be accomplished by gravity. For gravity filling, the fill line should be at least 2 in. in diameter for No. 2 oil and 6 in. in diameter for No. 4, 5, or 6 oils. Where filling is done by pump, the fill line for No. 4, 5, or 6 oils may be 4 in. in diameter.

An oil return line bringing recirculated oil from the burner line to the tank should discharge near the oil suction line inlet. Each storage tank should be equipped with a vent line sized and arranged in accordance with NFPA *Standard* 31.

Each storage tank must have a device for determining oil level. For tanks inside buildings, the gaging device should be designed and installed so that oil or vapor will not discharge into a building from the fuel supply system. No storage tank should be equipped with a glass gage or any gage that, if broken, would allow oil to escape from the tank. Gaging by a measuring stick is permissible for outside or underground tanks.

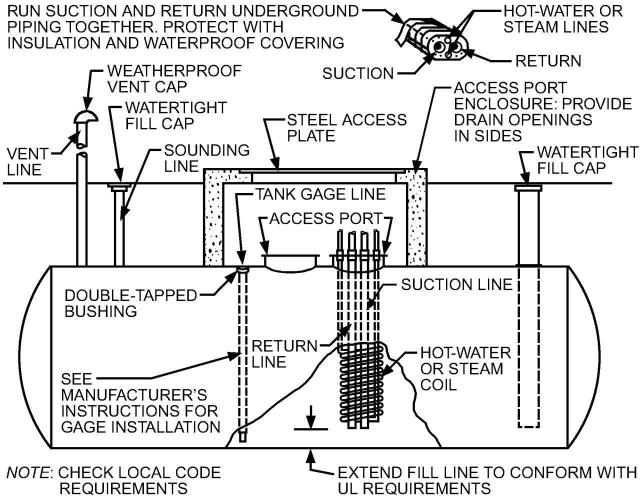

Fig. 12 Typical Oil Storage Tank (No. 6 Oil)

Fuel-Handling Systems

The fuel-handling system consists of the pumps, valves, and fittings for moving fuel oil from the delivery truck or car into the storage tanks and from the storage tanks to the oil burners. Depending on the type and arrangement of the oil-burning appliances and the grade of fuel oil burned, fuel-handling systems vary from simple to quite complicated arrangements.

The simplest handling system would apply to a single burner and small storage tank for No. 2 fuel oil, similar to a residential heating installation. The storage tank is filled through a hose from the oil delivery truck, and the fuel-handling system consists of a supply pipe between the storage tank and the burner pump. Equipment should be installed on light-oil tanks to indicate visibly or audibly when the tank is full; on heavy-oil tanks, a remote-reading liquid-level gage should be installed.

Figure 13 shows a complex oil supply arrangement for two burners on one oil-burning appliance. For an appliance with a single burner, the change in piping is obvious. For a system with two or more appliances, the oil line downstream of the oil discharge strainer becomes a main supply header, and the branch supply line to each appliance includes a flowmeter, automatic control valve, etc. For light oils requiring no heating, all oil-heating equipment shown in Figure 13 would be omitted. Both a suction and a return line should be used, except for gravity flow in residential installations.

Oil pumps (steam or electrically driven) should deliver oil at the maximum rate required by the burners (this includes the maximum firing rate, the oil required for recirculating, plus a 10% margin).

The calculated suction head at the entrance of any burner pump should not exceed 10 in. Hg for installations at sea level. At higher elevations, the suction head should be reduced in direct proportion to the reduction in barometric pressure.

Oil temperature at the pump inlet should not exceed 120°F. Where oil burners with integral oil pumps (and oil heaters) are used and suction lift from the storage tank is within the capacity of the burner pump, each burner may take oil directly from the storage tank through an individual suction line unless No. 6 oil is used.

Where two or more tanks are used, the piping arrangement into the top of each tank should be the same as for a single tank so that any tank may be used at any time; any tank can be inspected, cleaned, or repaired while the system is in operation.

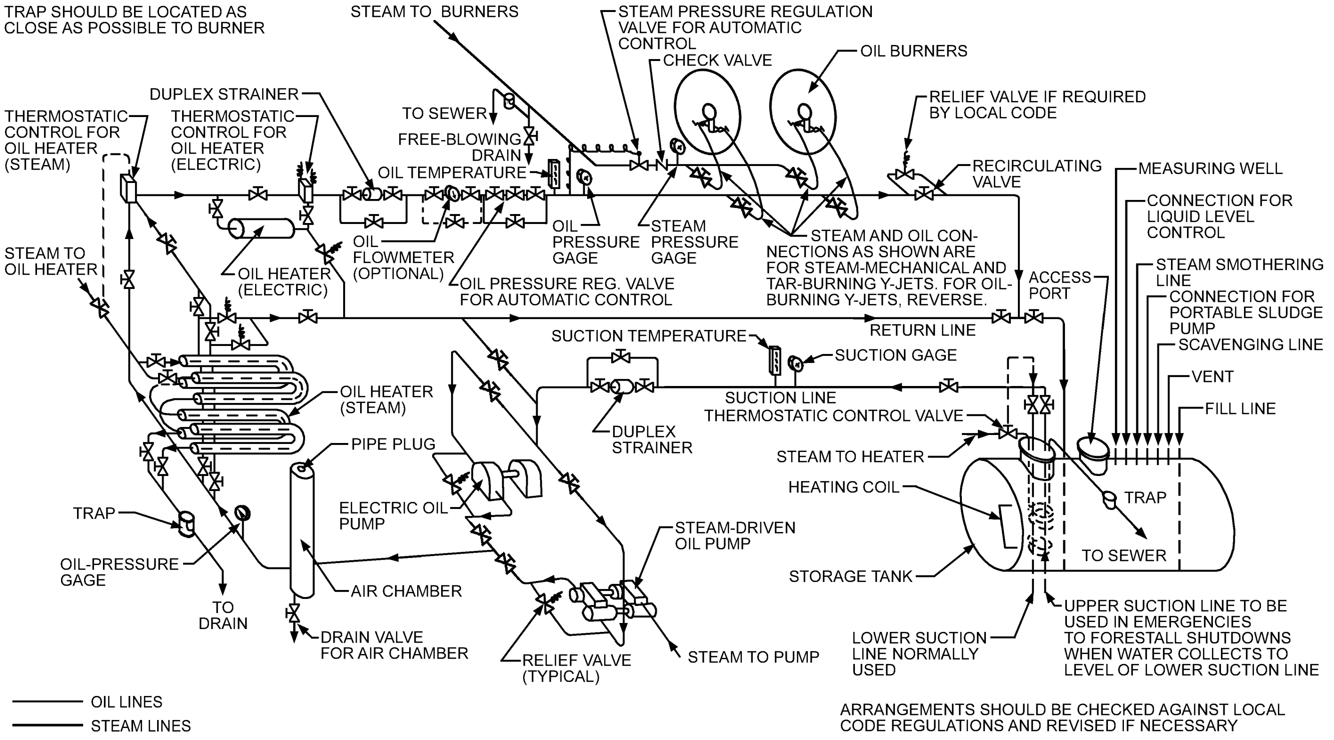

Fig. 13 Industrial Burner Auxiliary Equipment

The length of suction line between storage tank and burner pumps should not exceed 100 ft. If the main storage tank(s) are located more than 100 ft from the pumps, a supply tank should be installed near the pumps, and a transfer pump should be installed at the storage tanks for delivery of oil to the supply tank.

Central oil distribution systems comprising a central storage facility, distribution pumps or provision for gravity delivery, distribution piping, and individual fuel meters are used for residential communities, notably mobile home parks. Provisions of NFPA *Standard* 31, Installation of Oil Burning Equipment, should be followed in installing a central oil distribution system.

Fuel Oil Preparation System

Fuel oil preparation systems consist of oil heater, oil temperature controls, strainers, and associated valves and piping required to maintain fuel oil at the temperatures necessary to control the oil viscosity, facilitate oil flow and burning, and remove suspended matter.

Preparation of fuel oil for handling and burning requires heating the oil if it is No. 5 or 6. This decreases its viscosity so it flows properly through the oil system piping and can be atomized by the oil burner. No. 4 oil occasionally requires heating to facilitate burning. No. 2 oil requires heating only under unusual conditions.

For handling residual oil from the delivering carrier into storage tanks, the viscosity should be about 156 centistokes (cSt). For satisfactory pumping, viscosity of oil surrounding the inlet of the suction pipe must be 444 cSt or lower; for oil with a high pour point, the temperature of the entire oil content of the tank must be above the pour point.

Storage tank heaters are usually made of pipe coils or grids using steam or hot water at or less than 15 psi as the heating medium. Electric heaters are sometimes used. For control of viscosity for pumping, the heated oil surrounds the oil suction line inlet. For heating oils with high pour points, the heater should extend the entire length of the tank. All heaters have suitable thermostatic controls. In some cases, storage tanks may be heated satisfactorily by returning or recirculating some of the oil to the tank after it has passed through heaters located between the oil pump and oil burner.

Heaters to regulate viscosity at the burners are installed between the oil pumps and the burners. When required for small packaged burners, the heaters are either assembled integrally with the individual burners or mounted separately. The heat source may be electricity, steam, or hot water. For larger installations, the heater is mounted separately and is often arranged in combination with central oil pumps, forming a central oil pumping and heating set. The separate or central oil pumping and heating set is recommended for installations that burn heavy oils, have a periodical load demand, and require continuous circulation of hot oil during down periods.

Another system of oil heating to maintain pumping viscosity that is occasionally used for small- or medium-sized installations consists of an electrically heated section of oil piping. Low-voltage current is passed through the pipe section, which is isolated by nonconducting flanges.

The oil-heating capacity for any given installation should be approximately 10% greater than the maximum oil flow. Maximum oil flow is the maximum oil-burning rate plus the rate of oil recirculation.

Controls for oil heaters must be dependable to ensure proper oil atomization and avoid overheating of oil, which results in coke deposits inside the heaters. In steam or electric heating, an interlock should be included with a solenoid valve or switch to shut off the steam or electricity. During periods when the oil pump is not operating, the oil in the heater can become overheated and deposit carbon. Overheating also can be a problem with oil heaters using high-temperature hot water. Provisions must be made to avoid overheating the oil when the oil pump is not operating.

Oil heaters with low- or medium-temperature hot water are not generally subject to coke deposits. Where steam or hot water is used in oil heaters located after the oil pumps, the pressure of the steam or water in the heaters is usually lower than the oil pressure. Consequently, heater leakage between oil and steam causes oil to flow into the water or condensing steam. To prevent oil from entering the boilers, the condensed steam or the water from such heaters should be discarded from the system, or special equipment should be provided for oil removal.

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Hot water oil heaters of double-tube-and-shell construction with inert heat transfer oil and a sight glass between the tubes are available. With this type of heater, oil leaks through an oil-side tube appear in the sight glass, and repairs can be made to the oil-side tube before a water-side tube leaks.

This discussion of oil-burning equipment also applies to oil-fired boilers and furnaces (see Chapters 31 and 32).

SOLID-FUEL-BURNING APPLIANCES

A mechanical stoker is a device that feeds a solid fuel into a combustion chamber. It supplies air for burning the fuel under automatic control and, in some cases, incorporates automatic ash and refuse removal.

CAPACITY CLASSIFICATION OF STOKERS

Stokers are classified according to their coal-feeding rates. Although some residential applications still use stokers, their main application is in commercial and industrial areas. The U.S. Department of Commerce, in cooperation with the Stoker Manufacturers Association, use the following classification:

Class 1: Capacity less than 60 lb of coal per hour
Class 2: Capacity 60 to less than 100 lb of coal per hour
Class 3: Capacity 100 to less than 300 lb of coal per hour
Class 4: Capacity 300 to less than 1200 lb of coal per hour
Class 5: Capacity 1200 lb of coal per hour and over

Class 1 stokers are used primarily for residential heating and are designed for quiet, automatic operation. These stokers are usually underfeed types and are similar to those shown in Figure 14, except that they are usually screw-feed. Class 1 stokers feed coal to the furnace intermittently, in accordance with temperature or pressure demands. A special control is needed to ensure stoker operation in order to maintain a fire during periods when no heat is required.

Class 2 and 3 stokers are usually of the screw-feed type, without auxiliary plungers or other means of distributing the coal. They are used extensively for heating plants in apartment buildings, hotels, and industrial plants. They are of the underfeed type and are available in both the hopper and bin-feed type. These stokers are also built in a plunger-feed type with an electric motor, steam, or hydraulic cylinder coal-feed drive.

Class 2 and 3 stokers are available for burning all types of anthracite, bituminous, and lignite coals. The tuyere and retort design varies according to the fuel and load conditions. Stationary grates are used on bituminous models, and clinkers formed from the ash accumulate on the grates surrounding the retort.

Class 2 and 3 anthracite stokers are equipped with moving grates that discharge ash into a pit below the grate. This ash pit may be located on one side or both sides of the grate and, in some installations, is big enough to hold the ash for several weeks of operation.

Class 4 stokers vary in details of design, and several methods of feeding coal are practiced. Underfeed stokers are widely used, although overfeed types are used in the larger sizes. Bin-feed and hopper models are available in underfeed and overfeed types.

Class 5 stokers are spreader, underfeed, chain or traveling grate, and vibrating grate. Various subcategories reflect the type of grate and method of ash discharge.

STOKER TYPES BY FUEL-FEED METHODS

Class 5 stokers are classified according to the method of feeding fuel to the furnace: (1) spreader, (2) underfeed, (3) chain or traveling grate, and (4) vibrating grate. The type of stoker used in a given installation depends on the general system design, capacity required, and type of fuel burned. In general, the spreader stoker is the most widely used in the capacity range of 75,000 to 400,000 lb/h because it responds quickly to load changes and can burn a wide variety of coals. Underfeed stokers are mainly used with small industrial boilers of less than 30,000 lb/h. In the intermediate range, the large underfeed stokers, as well as the chain and traveling grate stokers, are being displaced by spreader and vibrating grate stokers. Table 3 summarizes the major features of the different stokers.

Spreader Stokers

Spreader stokers use a combination of suspension burning and grate burning. As shown in Figure 15, coal is continually projected into the furnace above an ignited fuel bed. The coal fines are partially burned in suspension. Large particles fall to the grate and are burned in a thin, fast-burning fuel bed. Because this firing method provides extreme responsiveness to load fluctuations and because ignition is almost instantaneous on increased firing rate, the spreader stoker is favored over other stokers in many industrial applications.

The spreader stoker is designed to burn about 50% of the fuel in suspension. Thus, it generates much higher particulate loadings than other types of stokers and requires dust collectors to trap particulate material in the flue gas before discharge to the stack. To minimize carbon loss, fly carbon reinjection systems are sometimes used to return particles into the furnace for complete burnout. Because this process increases furnace dust emissions, it can be used only with highly efficient dust collectors.

Grates for spreader stokers may be of several types. All grates are designed with high airflow resistance to avoid formation of blowholes through the thin fuel bed. Early designs were simple stationary grates from which ash was removed manually. Later designs allowed intermittent dumping of the grate either manually or by a power cylinder. Both types of dumping grates are frequently used for small and medium-sized boilers (see Table 3). Also, both types are sectionalized, and there is a separate undergrate air chamber for each grate section and a grate section for each spreader stoker. Consequently, both the air supply and the fuel supply to one section

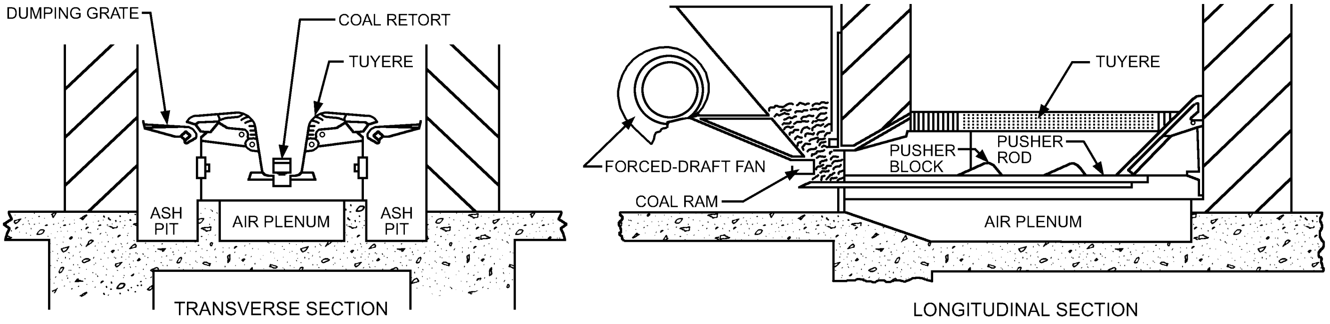

Fig. 14 Horizontal Underfeed Stoker with Single Retort

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Table 3 Characteristics of Various Types of Stokers (Class 5)

Stoker Type and Subclass	Typical Capacity Range, lb/h	Maximum Burning Rate, Btu/h·ft^2	Characteristics
Spreader			Capable of burning a wide range of coals; best to follow fluctuating loads; high fly ash carryover; low-load smoke
Stationary and dumping grate	20,000 to 80,000	450,000	
Traveling grate	100,000 to 400,000	750,000	
Vibrating grate	20,000 to 100,000	400,000	
Underfeed	20,000 to 30,000	400,000	Capable of burning caking coals and a wide range of coals (including anthracite); high maintenance; low fly ash carryover; suitable for continuous-load operation
Single- or double-retort			
Multiple-retort	30,000 to 500,000	600,000	
Chain grate and *traveling grate*	20,000 to 100,000	500,000	Low maintenance; low fly ash carryover; capable of burning a wide variety of weakly caking coals; smokeless operation over entire range
Vibrating grate	1,400 to 150,000	400,000	Characteristics similar to chain and traveling grate stokers, except that these stokers have no difficulty in burning strongly caking coals

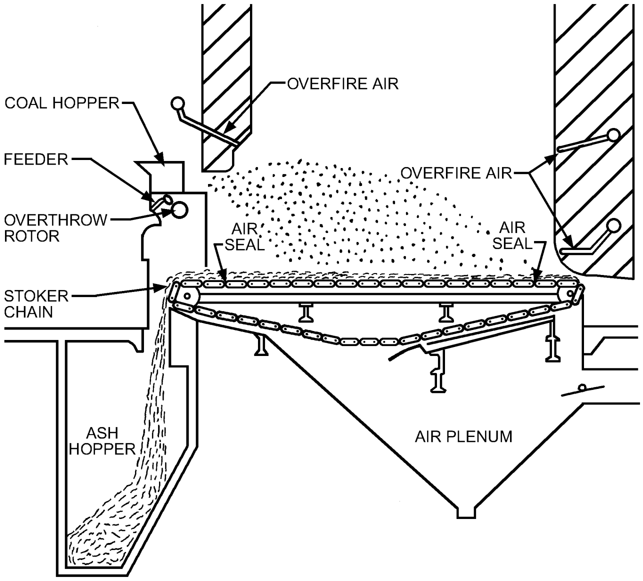

Fig. 15 Spreader Stoker, Traveling Grate Type

can be temporarily discontinued for cleaning and maintenance without affecting operation of other sections of the stoker.

For high-efficiency operation, a continuous ash-discharging grate, such as the traveling grate, is necessary. Introduction of the spreader stoker with the traveling grate increased burning rates by about 70% over the stationary and dumping grate types. Although both reciprocating and vibrating continuous ash discharge grates have been developed, the traveling grate stoker is preferred because of its higher burning rates.

Fuels and Fuel Bed. All spreader stokers (particularly those with traveling grates) can use fuels with a wide range of burning characteristics, including caking tendencies, because the rapid surface heating of the coal in suspension destroys the caking tendency. High-moisture, free-burning bituminous and lignite coals are commonly burned; coke breeze can be burned in mixture with a high-volatile coal. However, anthracite, because of its low volatile content, is not a suitable fuel for spreader stoker firing. Ideally, the fuel bed of a coal-fired spreader stoker is 2 to 4 in. thick.

Burning Rates. The maximum heat release rates range from 400,000 Btu/h·ft^2 (a coal consumption of approximately 40 lb/h) on stationary, dumping, and vibrating grate designs to 750,000 Btu/h·ft^2 on traveling grate spreader stokers. Higher heat release rates are practical with some waste fuels in which a greater portion of fuel can be burned in suspension than is possible with coal.

Underfeed Stokers

Underfeed stokers introduce raw coal into a retort beneath the burning fuel bed. They are classified as horizontal or gravity feed. In the horizontal type, coal travels within the furnace in a retort parallel with the floor; in the gravity-feed type, the retort is inclined by 25°. Most horizontal-feed stokers are designed with single or double retorts (and, rarely, triple retorts), whereas gravity-feed stokers are designed with multiple retorts.

In the horizontal stoker (see Figure 14), coal is fed to the retort by a screw (for smaller stokers) or a ram (for larger stokers). Once the retort is filled, the coal is forced upward and spills over the retort to form and feed the fuel bed. Air is supplied through tuyeres at each side of the retort and through air ports in the side grates. Over-fire air provides additional combustion air to the flame zone directly above the bed to prevent smoking, especially at low loads.

Gravity-feed stokers are similar in operating principle. These stokers consist of sloping multiple retorts and have rear ash discharge. Coal is fed into each retort, where it is moved slowly to the rear while simultaneously being forced upward over the retorts.

Fuels and Fuel Bed. Either type of underfeed stoker can burn a wide range of coal, although the horizontal type is better suited for free-burning bituminous coal. These stokers can burn caking coal, if there is not an excess amount of fines. The ash-softening temperature is an important factor in selecting coals because the possibility of excessive clinkering increases at lower ash-softening temperatures. Because combustion occurs in the fuel bed, underfeed stokers respond slowly to load change. Fuel-bed thickness is extremely nonuniform, ranging from 8 to 24 in. The fuel bed often contains large fissures separating masses of coke.

Burning Rates. Single-retort or double-retort horizontal stokers are generally used to service boilers with capacities up to 30,000 lb/h. These stokers are designed for heat release rates of 400,000 Btu/h·ft^2.

Chain and Traveling Grate Stokers

Figure 16 shows a typical chain or traveling grate stoker. These stokers are often used interchangeably because they are fundamentally the same, except for grate construction. The essential difference is that the links of chain grate stokers are assembled so that they move with a scissors-like action at the return bend of the stoker, whereas in most traveling grates there is no relative movement between adjacent grate sections. Accordingly, the chain grate is more suitable for handling coal with clinkering ash characteristics than is the traveling grate stokers.

Operation of the two types is similar. Coal, fed from a hopper onto the moving grate, enters the furnace after passing under an adjustable gate that regulates the thickness of the fuel bed. The layer of coal on the grate entering the furnace is heated by radiation from the furnace gases or from a hot refractory arch. As volatile matter is driven off by this rapid radiative heating, ignition occurs. The fuel

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continues to burn as it moves along the fuel bed, and the layer becomes progressively thinner. At the far end of the grate, where combustion of the coal is completed, ash is discharged into the pit as the grates pass downward over a return bend.

Often, furnace arches (front and/or rear) are included with these stokers to improve combustion by reflecting heat to the fuel bed. The front arch also serves as a bluff body, mixing rich streams of volatile gases with air to reduce unburned hydrocarbons. A chain grate stoker with overfire air jets eliminates the need for a front arch for burning volatiles. As shown in Figure 17, the stoker was zoned, or sectionalized, and equipped with individual zone dampers to control the pressure and quantity of air delivered to the various sections.

Fuels and Fuel Bed. The chain grate and traveling grate stokers can burn a variety of fuels (e.g., peat, lignite, subbituminous coal, free-burning bituminous coal, anthracite coal, and coke), as long as the fuel is sized properly. However, strongly caking bituminous coals have a tendency to mat and prevent proper air distribution to the fuel bed. Also, a bed of strongly caking coal may not be responsive to rapidly changing loads. Fuel bed thickness varies with the type and size of the coal burned. For bituminous coal, a 5 to 7 in. bed is common; for small-sized anthracite, the fuel bed is reduced to 3 to 5 in.

Burning Rates. Chain and traveling grate stokers are offered for a maximum continuous burning rate of 350,000 to 500,000 Btu/h·ft^2, depending on the type of fuel and its ash and moisture content.

Vibrating Grate Stokers

The vibrating grate stoker, as shown in Figure 17, is similar to the chain grate stoker in that both are overfeed, mass-burning, continuous ash discharge stokers. However, in the vibrating stoker, the sloping grate is supported on equally spaced vertical plates that oscillate back and forth in a rectilinear direction, causing the fuel to move from the hopper through an adjustable gate into the active combustion zone. Air is supplied to the stoker through laterally exposed areas beneath the stoker formed by the individual flexing of the grate support plates. Ash is automatically discharged into a shallow or basement ash pit. The grates are water cooled and are connected to the boiler circulating system.

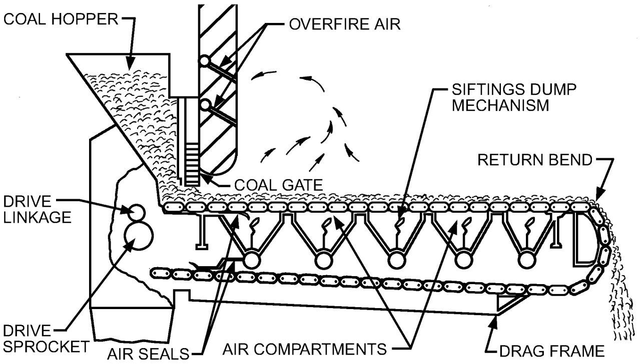

Fig. 16 Chain Grate Stoker

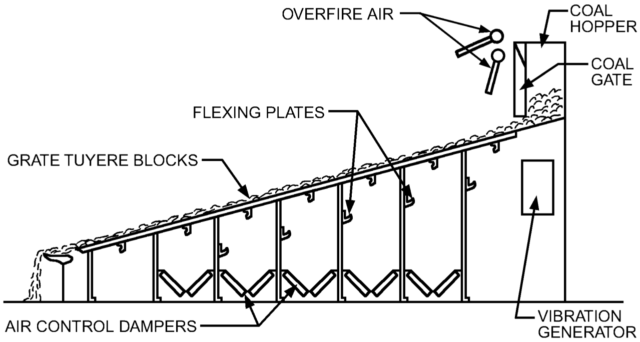

Fig. 17 Vibrating Grate Stoker

The rates of coal feed and fuel bed movement are determined by the frequency and duration of the vibrating cycles and regulated by automatic combustion controls that proportion the air supply to optimize heat release rates. Typically, the grate is vibrated about every 90 s for durations of 2 to 3 s, but this depends on the type of coal and boiler operation. The vibrating grate stoker is increasingly popular because of its simplicity, inherently low fly ash carryover, low maintenance, wide turndown (10 to 1), and adaptability to multiple-fuel firing.

Fuels and Fuel Bed. The water-cooled vibrating grate stoker is suitable for burning a wide range of bituminous and lignite coals. The gentle agitation and compaction of the vibratory actions allow coal having a high free-swelling index to be burned and a uniform fuel bed without blowholes and thin spots to be maintained. The uniformity of air distribution and fuel bed conditions produce both good response to load swings and smokeless operation over the entire load range. Fly ash emission is probably greater than from the traveling grate because of the slight intermittent agitation of the fuel bed. The fuel bed is similar to that of a traveling grate stoker.

Burning Rates. Burning rates of vibrating grate stokers vary with the type of fuel used. In general, however, the maximum heat release rate should not exceed 400,000 Btu/h·ft^2 (a coal use of approximately 40 lb/h) to minimize fly ash carryover.

CONTROLS

This section covers controls required for automatic fuel-burning systems. Chapter 15 of the 2005 *ASHRAE Handbook—Fundamentals* addresses basic automatic control.

Automatic fuel-burning appliances require control systems that supervise combustion and take proper corrective action in the event of a failure in the appliance or related installation equipment. Requirements are similar for gas, oil, and solid fuel (stoker) burners.

Controls can be classified as safety or operating. **Safety controls** monitor potentially hazardous operating conditions such as ignition, combustion, temperature, and pressure, and function as required to ensure safe operation. **Operating controls** handle appliance operation at the required input rate when heat is required.

Figure 18 illustrates the basic elements of a control system for a fuel-fired appliance. In this diagram, the limit control and the ignition safety control, including its sensor, are safety controls.

SAFETY CONTROLS AND INTERLOCKS

Safety controls protect against hazards related to the combustion process. Personnel and material near the appliance must be

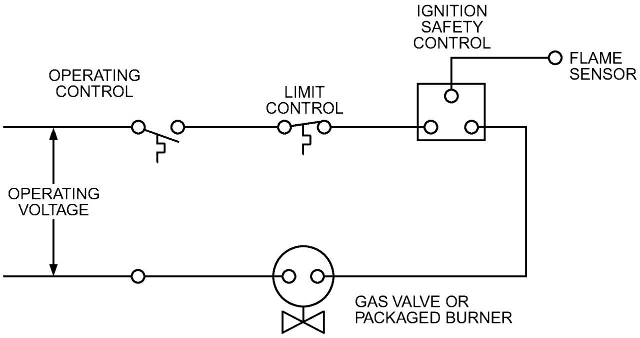

Fig. 18 Basic Control Circuit for Fuel-Burning Appliance

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protected against explosion, fire, or excessive temperature. Common safety control functions include the following:

- Ignition and flame monitoring
  - Ignition proving (e.g., gas pilot thermocouple, flame rectification)
  - Proof of flame
- Draft proof (e.g., sail switch, pressure switch)
- Limit controls
  - Excessive temperature of heated medium (e.g., air or water)
  - Excessive pressure of heated medium (e.g., steam or hot water)
  - Low water level in steam or hot-water boilers
  - Low fuel-oil pressure
  - Low or excessive fuel-oil temperature when burning heavy oils
  - Low atomizing air pressure or atomizing steam pressure
  - Low fuel-gas pressure (e.g., empty propane tank)
- Flue gas spillage switch
- Flame rollout detection
- Carbon monoxide sensors
- Similar devices to prevent hazards from abnormal conditions
- Safety-related mechanical malfunction controls (e.g., open furnace blower door, burner out of position or rotary cup burner motor failure)
- Field interlocks having safety function

Ignition and Flame Monitoring

Failure to ignite fuel or failure of an established flame can cause explosion, if unburned fuel is subsequently provided with an ignition source. Ignition and flame safeguard controls, properly applied and used, prevent these occurrences. Some ignition controls monitor existence of an ignition source such as a pilot burner, allowing introduction and continued flow of fuel only when the ignition source is proven. Others use devices that ignite the main flame directly, in conjunction with high-speed flame detection capabilities and rapid shutdown of the fuel supply, if ignition is not immediate or if the flame is lost. Ignition controls often include programming features that govern the entire sequence of operation when a burner is started, operated, and stopped.

In residential gas-fired appliances, burner ignition is generally achieved by a small standing gas pilot flame, by an intermittent pilot system, or by a direct ignition system. Standing pilot systems prove existence of the ignition source by sensing its heat with a thermocouple. In intermittent pilot systems, a spark or hot surface igniter lights the pilot burner when there is a call for heat, thus saving pilot burner fuel when no heat is needed. Flame rectification (the ability of a flame to change an alternating current to direct current) is commonly used to prove the existence of the pilot flame (in intermittent pilot systems) or main burner flame (in direct-ignition systems). In direct-ignition systems, a spark or hot surface device ignites the main burner directly, eliminating the need for a pilot burner. If flame is not immediately established during ignition or if an established flame is lost, the gas supply system is quickly shut off. Flame rollout (flame escaping the appliance combustion chamber) protection detects flame in appliance combustion air inlet areas by sensing high temperatures and shuts off the fuel supply.

Most residential oil-burners use high-energy sparking for ignition. Sparking may be continuous (present for the entire duration of burner operation) or intermittent (present only long enough to establish presence of the flame). Most residential oil burners use an oil primary control that operates the burner motor and ignition spark transformer in conjunction with a flame detector. Flame proof is typically achieved by sensing visible or ultraviolet light emitted by the flame. A cadmium cell is used to detect visible light: its resistance changes when exposed to light from a burner flame, and that change is interpreted and acted upon by the primary control.

Commercial appliances with high fuel input rates normally use some form of a proven ignition source, often a standing or intermittent pilot burner, which itself may be quite large. North American safety standards do not allow use of direct-ignition systems for appliances with input greater than 400,000 Btu/h. Standing pilots or a proved igniter system must be used. The latter may closely resemble the direct-ignition system, except that the existence of the ignition source must be proven before fuel gas is allowed to flow to the main burner. As in the direct-ignition system, main burner gas flow is shut down if flame is not established quickly or if it goes out after ignition. Flame proving in large appliances is typically by flame rectification or ultraviolet light sensing.

Draft Proving

Fuel-burning appliances often include forced- or induced-draft blowers to move combustion air and combustion products through the appliance and venting systems. Sometimes blowers are applied outside the appliance in the venting system. Draft-proving controls supervise proper operation of these components to allow gas flow, ignition, and combustion only if appliance draft is adequate, typically using pressure and/or flow sensors to verify sufficient draft.

Limit Controls

In a warm-air furnace or space heater, excessive air temperature must be prevented. In a hot-water boiler, water temperature and pressure must not exceed the ratings of external piping and terminal equipment. Steam pressure must not exceed ratings of pressure vessels and steam system equipment. Fuel oil must be provided at pressures and temperatures that allow proper operation of oil burners. These requirements and restrictions are the focus of limit controls required by installation codes and appliance standards, and applied by appliance manufacturers and field installers. Design and principle of operation vary greatly, but in all cases limit controls must provide reliable detection of a fault and shut down the fuel-burning appliance.

Other Safety Controls

Requirements for safety devices are a function of the particular appliance and installation circumstances, and must be considered in that context. Appliances listed or design-certified as complying with recognized safety standards generally have appropriate safety devices as required by those standards. Building codes typically require appliances to be listed or design-certified by recognized testing laboratories, and that appliances not listed or design-certified comply with requirements within the code. Field circumstances may impose a need for control interlocks that relate to safety. Mechanical-draft venting systems, for example, must be proven to be in operation before an appliance ignition attempt and during burner operation. An appropriate field-installed interlock to prove mechanical-draft venting system operation before an ignition attempt would be considered a safety control.

Prescriptive Requirements for Safety Controls

Industrial safety codes and insurers often require that fuel-fired appliances be provided with specific components and construction features related to safety. Codes and requirements such as ASME *Standard* CSD-1 for boilers or those of insurance organizations may apply. Prescriptive governmental requirements may also apply to some types of installations. Often, requirements are based on the type of appliance, its capacity or size, or the intended use, such as type of building occupancy.

Reliability of Safety Controls

Devices suitable for use as safety controls must meet special quality and reliability requirements. Electrical contacts, for example, must be capable of switching the intended load through high cycle counts under extreme environmental conditions. Products designed for safety control application are invariably listed, or design-certified as complying with recognized standards that impose a wide range of construction and testing requirements. The degree

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of reliability of safety controls must be extremely high, and normally far exceeds that required of operating controls to meet appliance safety standards.

OPERATING CONTROLS

Operating controls start and stop burner operation in response to demands of the application load, and often incorporate capabilities for load matching and other application-related features. In contrast to safety controls, their purpose is to satisfy the application's fundamental purpose (e.g., warm air, hot water, steam pressure). Related functions may involve operating ancillary components of the appliance or system, such as blowers or pumps, which must operate at the appropriate speed.

Load matching is the most significant differentiating feature of operating controls. The major categories are on/off, staged, and modulated control. Fuel input rate varies for the latter two modes, but combustion airflow rate may also be controlled.

An **on/off control** starts and stops the flow of fuel to the burner to satisfy heat demand. An appliance with on/off control can operate only at its rated input regardless of the rate at which combustion heat may be needed. In a typical system, demand is sensed by a temperature or pressure sensor. When the temperature or pressure falls to an *on* set point, the control initiates combustion, which proceeds until the temperature or pressure increases to an *off* set point. The difference between the *off* and *on* values is called the **differential**. On/off control is satisfactory for systems with high thermal inertia (i.e., those in which heat input does not rapidly change the controlled temperature or pressure).

A **staged control** operates an appliance at multiple fixed input rates in response to heat demand. The input rates are determined by burner system hardware and settings. A residential gas-fired appliance, for example, may include a gas pressure regulator capable of providing high and low gas pressures to the gas orifice(s). Applying electrical power to a solenoid associated with the pressure regulator enables a second orifice pressure and thus a second gas input rate. In large appliances such as commercial boilers, staging is often accomplished with multiple burner assemblies, operated singly or together as necessary to match the load. As in on/off control, combustion initiation and changes between high and low input rates are in response to demand, as determined by the sensor and control logic.

Staged control logic is sometimes provided within an appliance control to enhance load response of the appliance. For example, a heating appliance control can provide staged burner operation without a staged room thermostat by beginning burner operation on burner stage 1 when a single-stage thermostat calls for heat. If burner stage 1 does not satisfy the thermostat within a specified time period, the appliance control turns on burner stage 2 until the thermostat is satisfied, at which time the burner is completely shut off until the thermostat's next call for heat.

Figure 19 illustrates the characteristics of a three-stage control system that provides heat in response to a temperature sensor and is required to maintain temperature at a set point t_S. If the controlled temperature is above t_S, no heat is provided. When the temperature drops to $t_{1_{On}}$, the first-stage burner is operated; if the temperature then rises back to t_S, the burner is turned off. If the first stage is inadequate, the temperature continues to fall; when it reaches $t_{2_{On}}$, the second stage is operated. A third stage is available if the second stage is not adequate, operating when the temperature falls to its *on* temperature $t_{3_{On}}$. Successful handling of the load results in raising of the controlled temperature and stepped sequential reduction of the heat input as the *off* temperatures $t_{3_{Off}}$, $t_{2_{Off}}$, and $t_{1_{Off}}$ (= t_S) are reached. The individual stages operate subject to a **stage differential**, which is the difference between the temperature at which a stage is shut off and the (lower) temperature at which it is again turned on. Interstage differential and overall differential, as shown in Figure 19, are analogous. The *on* and *off* temperatures may or may not overlap, depending on the relative size of the stage differentials. In sophisticated electronic controls, the differential settings are adjustable to meet the particular requirements of the application.

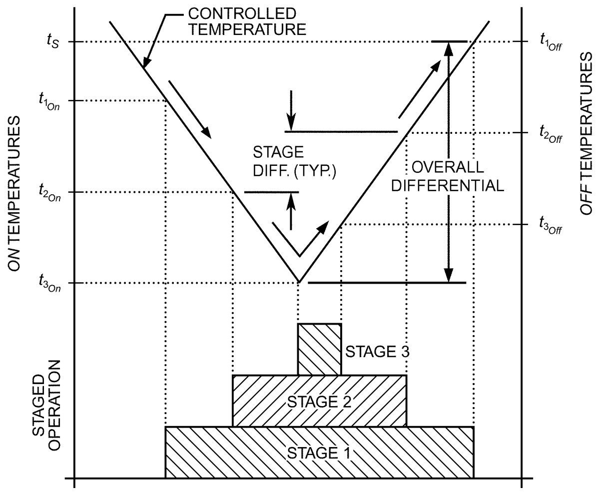

Fig. 19 Control Characteristics of Three-Stage System

Staged control logic often includes features that enhance load response or appliance operation. As shown in Figure 19, load matching might be best if the control initiates the lowest input rate on a call for heat and proceeds to higher inputs only if the demand cannot be met at lower rates. Appliance or application characteristics may dictate other approaches. For example, if appliance ignition is most reliable at high input rate, a staged control might require that ignition begin at a high input rate with an immediate reduction to a lower input rate to meet the actual heat demand.

Combustion airflow may or may not be staged. If not, operation at lower input rates, particularly in appliances with fan-assisted combustion, results in lean operation (a high percentage of excess air). There may be little effect, but in general, heat transfer efficiency suffers if the combustion air-to-fuel ratio (A/F) is not maintained at an optimum level on each stage.

A **modulating control** regulates input rate to follow load demands more closely than on/off or staged controls. Fuel input rate may be varied by throttling (mechanical restriction of flow by a valve) or by pressure regulation to control injector (orifice) pressure. Demand is often indicated by a temperature or pressure sensor, and the input rate increases as the temperature or pressure falls from set point values. In large fuel-oil appliances, a fuel oil control valve and burner damper respond over a range of positions within the operating range of the burner.

Air/fuel proportioning controls are a variation of modulating controls in which the proper ratio of air to fuel is maintained throughout the burner's fuel input range. In response to the need for heat, both fuel input rate and combustion airflow rate are modulated, maintaining an optimal air/fuel ratio to maximize efficiency. The controls may change blower speed or (particularly in large commercial appliances) link air dampers to fuel input rate control.

Tracking controls are proportioning controls that maintain the proper air/fuel ratio by applying basic Bernoulli-equation fluid flow behavior. Gas-fired appliances are especially suitable for this approach. As combustion air or gas flow rate changes, such as through metering orifices or venturis, pressure changes in proportion to the square of the air or gas velocity. The pressure differential created by forcing air through a venturi, for example, can be used to regulate gas flow through an orifice. When the relationship is established, a change of airflow rate results in a pressure differential change that causes a proportional (tracking) change in gas flow rate. In one approach, airflow rate is varied according to heating demand by changing blower speed or adjusting a damper position, and gas flow rate tracks the change. Variations may use intermediate ratio controllers. Other systems control gas input rate, and combustion air rate tracks. In the ideal case, the air-to-fuel ratio remains constant at all input rates, and efficiency increases substantially when firing rate is reduced.

Combustion quality is monitored and controlled in some large installations in order to ensure efficient operation or satisfactory emission characteristics. Air or fuel can be controlled in response to devices that sense concentrations of various combustion product constituents. Butcher (1990) used the measured intensity of light emitted from flames of fixed-input oil burners to judge basic flame quality. Flame steady-state intensity is compared to a predetermined flame intensity set point. Deviation of flame intensity beyond an optimum intensity range indicates poor flame quality.

Operating controls often provide functions not directly related to combustion. These **appliance controls** include such as operating air-circulating blowers or pumps according to the fuel combustion system's needs. A blower or pump can be operated in response to a temperature or pressure sensor or according to a time protocol imposed with electronic or digital capabilities. Additional algorithms in the appliance control can further enhance appliance operation.

Integrated and Programmed Controls

Integrated Controls. Many appliance controls combine safety and operating functions into electronic microprocessors with various sensors and electromechanical devices to handle most of the control functions necessary to operate fuel-burning appliances. Figure 20 illustrates an integrated control approach typical of residential forced-air furnaces or boilers with fan-assisted combustion and a limit control. Other safety devices, such as a flame roll-out switch, typically are present. For a forced-air furnace, the remote thermostat would be a wall thermostat. For a hot-water boiler, the operating control might be a wall thermostat, possibly with a second sensor to control boiler water temperature. Ignition and flame safety algorithms are provided in the microprocessor-based control. The ignition device and flame sensor are connected to the control. Note that the control operates both the circulating blower or pump and a combustion blower. Both are controlled in accordance with an appropriate sequence of operation. A draft-proving device is connected to the control to confirm operation of the combustion blower prior to igniter operation and opening of the gas valve, and during subsequent burner operation. Typically, light-emitting diodes (LEDs) are provided on the control to indicate operating status and to facilitate diagnosis of operating problems.

Programmed controls for ignition and flame safeguard have been used in large fuel-fired appliances for many years. More recently, programming has been applied in integrated controls for smaller appliances. These controls handle not only the ignition sequence, but also operating functions, and provide status and diagnostic information. Accomplishing those functions with separate components would be difficult and clumsy.

When power is supplied, an integrated control conducts a self-check to ensure that the appliance and control system are in safe working order, and then typically indicates readiness by flashing one or more LEDs. The self-check may include verifying that the flame-proving device does not indicate flame before the ignition sequence has started and the draft-proving device does not indicate draft before the combustion blower has started. Self-checking for safe conditions may continue during burner operation and during standby after the thermostat is satisfied. If unacceptable operation is detected, the control will take corrective action or attempt safe shutoff of the appliance. On a call for heat, an operating sequence typically proceeds as follows:

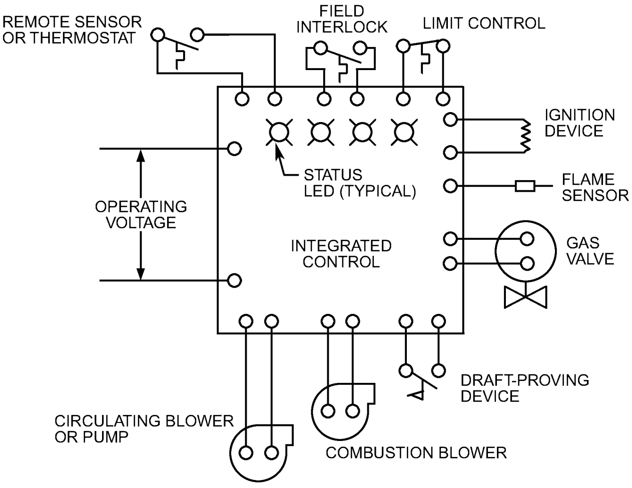

Fig. 20 Integrated Control System for Gas-Fired Appliance

1. The call for heat is indicated by an assigned LED flashing sequence.
2. The combustion blower starts and its operation is verified by the draft-proving device.
3. When the combustion blower has run long enough to purge the combustion chamber of residual fuel and combustion products (i.e., flush it with four air changes), the ignition device energizes.
4. The control allows enough time for the ignition device to become operative. In some applications, operation is verified electronically.
5. The gas valve opens.
6. Flame detection checks for main burner ignition. If flame presence is not proven within a very short predetermined time, or if continuous proof of flame fails at any time while the gas valve is open, the gas valve closes. Programming typically requires rapid detection of flame failure, and gas shutoff in accordance with safety standards.
7. If flame presence is detected, the air circulating blower or hot-water pump is started. Depending on the application, blower or pump operation could start with burner operation or after a time delay.
8. When the call for heat is satisfied, the gas valve closes to extinguish the burner flame.
9. The combustion blower operates for a short period to flush the combustion chamber with air (post purge).
10. The circulating blower or pump stops, usually after an application-specific delay.
11. The status LED(s) return to the standby mode.

This sequence can be varied as necessary to accommodate the requirements of specific appliances and applications. For example, staged or modulated operation may be included.

Status LEDs are turned on and off in particular patterns to display coded diagnostic information for many different normal and abnormal conditions (e.g., failure to prove draft, failure to detect flame, overtemperature). Appliance standards and installation codes require that appliance controls lock out operation of the burner system in response to certain failure conditions, when manual intervention by a qualified service agency is necessary.

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