ELEMENTS OF INDUSTRIAL HEATING EQUIPMENT

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1.0 SCOPE

This data sheet discusses the fundamentals of combustion, methods for fuel-air mixing, and types of burners as pertains to industrial heating equipment. Combustion controls, safeguard functions, and recommended maintenance test procedures are also described.

Recommendations to protect against explosion and fire are made in other data sheets relating to the specific types of equipment.

2.0 DESCRIPTION

2.1 Hazards

Fuel-fired heating equipment has two major hazards: fires, which must be controlled in intensity and for the quality of combustion, and fuel explosions. Control and prevention are an integral part of proper operational sequence, which is established by the use of combustion controls, interlocks, and combustion safeguards. These devices supervise the following aspects of burner operation: (1) fuel flow and pressure, (2) air flow and pressure, (3) fuel-air ratio, (4) ignition, (5) combustion, (6) combustion chamber atmosphere, and (7) effect of combustion heat.

2.1.1 Combustion

Combustion (or burning) may be considered to be the rapid oxidation of fuel resulting in the release of heat and production of visible light.

2.1.2 Fuel Explosion

Fuel explosion may be considered to be the very rapid chemical reaction (oxidation) of a fuel resulting in the release of heat, production of visible flame, and violent expansion of gases.

Four principal conditions generally exist for a fuel explosion to occur in heating and process equipment:

- A source of *unburned fuel*;
- An *accumulation* of the unburned fuel, usually in the vaporous or gaseous state, *mixed with air* between the upper and lower explosion (or flammable) limits;
- An *ignition source* such as a flame or spark, or a hot surface at or above the autoignition temperature of the fuel-air mixture; and
- A *degree of confinement* of the mixture by an enclosure.

The three items, fuel-air-ignition, parallel the components of the fundamental ‘‘fire triangle.’’ Removal of any one would extinguish or prevent the fire or explosion. The italicized phrases in the above conditions emphasize the need to prevent the accumulation of fuel-air mixtures and, where practical, excessive pressures by releasing the expanding gases from confinement.

2.2 Combustion

2.2.1 Reaction

The actual combustion reaction of fuel and air is complicated. A simplified reaction for methane and air is: $CH_4 + 2O_2 + 8N_2$ — $CO_2 + 2H_2O + 8N_2$ + heat. Air is composed of about 21% oxygen and 79% nitrogen, plus a fractional percentage of trace compounds. The inert nitrogen component of air does not participate in the reaction except for some heat absorption. The trace compounds have been omitted for simplicity.

2.2.2 Fuels

Gaseous fuels are in a physical state ready for combustion. They only need to be mixed with air and provided with the ignition energy.

Liquid fuels, in addition to air and ignition energy, require vaporization into the gaseous state. Some decomposition may occur during vaporization and combustion, yielding carbonaceous residues.

Solid fuels also require production of the gaseous hydrocarbons, leaving carbonaceous residues and other compounds behind. The solid carbons, such as from coal, will react with oxygen at about 2400°F (1320°C) and 2700°F (1480°C) to form carbon monoxide and carbon dioxide.

2.2.3 Perfect (Stoichiometric) Combustion

Perfect or stoichiometric combustion is where exactly the theoretical amount of air, 100% aeration, is available and reacts with the fuel. The products of combustion for commercial fuel gases and oils when burned in stoichiometric mixtures are given in Table 1, columns 5 through 9.

Table 1. Properties of Typical Commercial Fuel Oils and Gases (English)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	ft^3air required for comb. of gal oil	Btu/gal gross	Btu/gal net	Products of Combustion, ft^3/gal				
				H_2O	CO_2	N_2	Total	Percent CO_2
Kerosene	1230	134,000	126,000	169	177	984	1330	13.3
#1 Fuel oil	1250	136,000	127,300	164	186	1005	1350	13.7
#2 Fuel oil	1290	140,000	131,500	170	204	1091	1465	13.9
#4 Fuel oil	1370	149,000	140,000	160	219	1121	1500	14.6
#5 Fuel oil	1380	150,400	141,900					
#6 Fuel oil	1410	153,000	144,400					
	ft^3air required for comb. of ft^3 gas	Btu/ft^3 gross	Btu/ft^3 net	Products of Combustion, ft^3/ft^3 gas				
				H_2O	CO_2	N_2	Total	Percent CO_2
Natural Gas (Pittsburgh)	10.58	1129	1021	2.22	1.15	8.37	11.73	12.1
Coke oven gas	4.99	574	514	1.25	0.51	4.02	5.78	11.2
Carburated water gas	4.60	550	508	0.37	0.76	3.66	5.29	17.2
Blast furnace gas	0.68	92	92	0.02	0.39	1.14	1.54	25.5
Commercial butane	30.47	3225	2997	4.93	3.93	24.07	32.93	14.0
Commercial propane	23.82	2572	2371	4.17	3.00	18.83	25.99	13.7

Table 1. Properties of Typical Commercial Fuel Oils and Gases (Metric)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	m^3air required for comb. of dm^3 oil	kJ/dm^3 gross	kJ/dm^3 net	Products of Combustion, m^3/dm^3				
				H_2O	CO_2	N_2	Total	Percent CO_2
Kerosene	9.20	37,360	35,130	47	49	274	370	13.3
#1 Fuel oil	9.35	37,920	35,490	46	52	280	378	13.7
#2 Fuel oil	9.65	39.030	36,660	47	57	304	408	13.9
#4 Fuel oil	10.25	41.450	39,030	45	61	313	419	14.6
#5 Fuel oil	10.32	41.930	39,560					
#6 Fuel oil	10.55	42,660	40,260					
	m^3air required for comb. of m^3 gas	kJ/dm^3 gross	kJ/dm^3 net	Products of Combustion, m^3/m^3 gas				
				H_2O	CO_2	N_2	Total	Percent CO_2
Natural Gas (Pittsburgh)	10.58	42.1	37.8	2.22	1.15	8.37	11.73	12.1
Coke oven gas	4.99	21.4	19.2	1.25	0.51	4.02	5.78	11.2
Carburated water gas	4.60	20.5	18.9	0.37	0.76	3.66	5.29	17.2
Blast furnace gas	0.68	3.4	3.4	0.02	0.39	1.14	1.54	25.5
Commercial butane	30.47	120.3	111.0	4.93	3.93	24.07	32.93	14.0
Commercial butane	23.82	95.9	88.4	4.17	3.00	18.83	25.99	13.7

2.2.4 Products of Combustion

Combustion products will change in composition with deficient or excess air. The approximate percentages of the combustion components vary with different percentages of aeration. The flue gas analysis graph, Figure 1, shows that maximum CO_2 is produced when the aeration is 100%. With good mixing of fuel and air, the combustibles H_2 and CO, and oxygen should be nil. Many heating equipment burners are operated with excess air to insure that adequate oxygen is available for reaction with the fuel test.

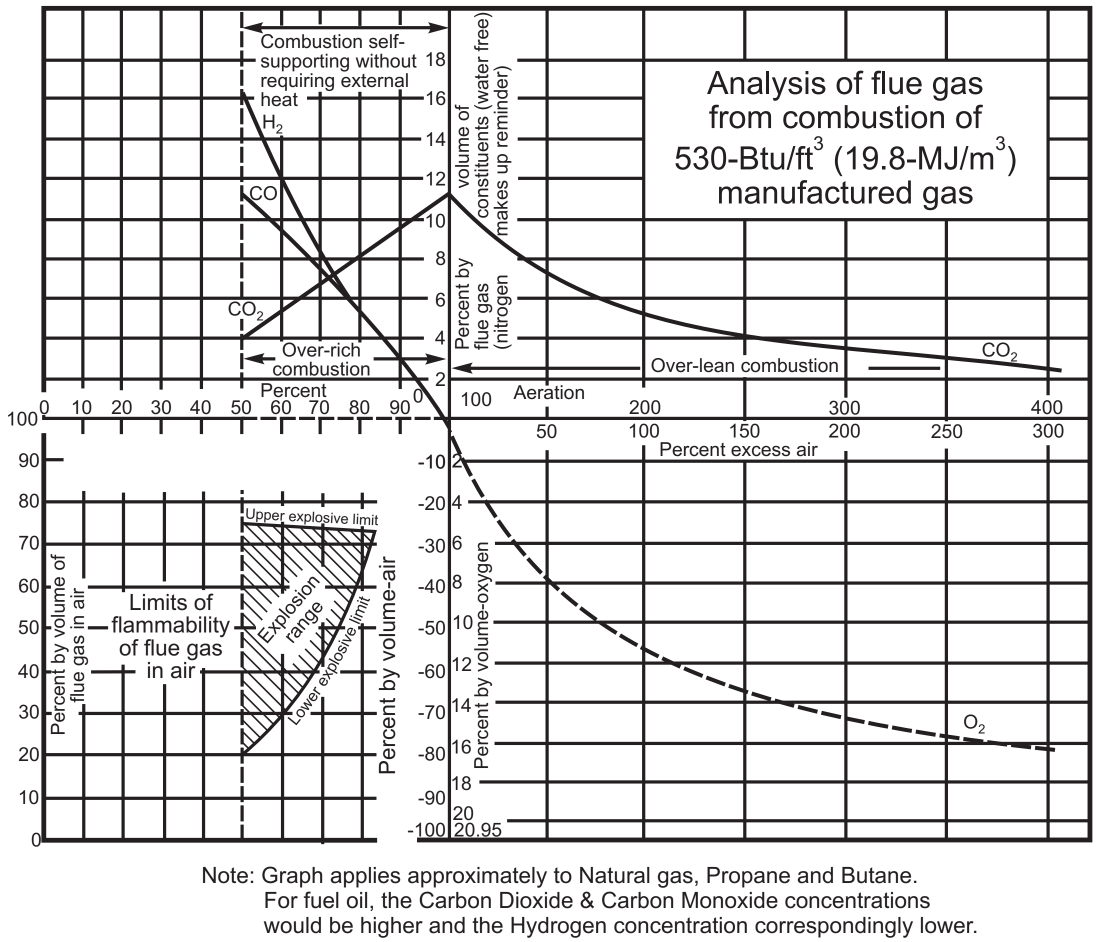

Fig. 1. Effect of fuel-air ratio on firing explosion hazard.

When the products of combustion are a direct factor in the processing of material in a furnace, the burner may be designed and adjusted to operate fuel-rich to produce a reducing atmosphere, or to operate with excess air for an oxidizing atmosphere.

2.2.5 Fuel Heat Value

Fuels have varying heat content, measured in Btu (Joules), depending upon their chemical composition. (See Table 1, columns 3 and 4.) The net heating value is the gross heating value minus the latent heat of vaporization of water vapor formed by combustion of the hydrogen in the fuel.

2.2.6 Fuel-Air Relations

The quantity of air needed for complete combustion of a fuel has a direct relationship to the Btu (Joules) content (Table 1, Column 2). Methane, the main component of natural gas, requires about 10 ft^3 of air per 1 ft^3 of methane (10 m^3/m^3). Propane will require about 23 ft^3 of air per 1 ft^3 of propane (23 m^3/m^3). This relationship can be applied to all common fuels, gases, liquids and solids. The rule of thumb is 1 ft^3 of air per 100 Btu fuel content (1 m^3 air/40 MJ fuel).

2.3 Properties of Burners

There are four characteristics that must be considered in all types of burners:

2.3.1 Turndown Ratio

Turndown ratio is the range of fuel input rates within which a burner will operate. It is expressed as the ratio of the maximum to minimum heat input rates or, in the case of burners with fixed air orifices, the square root of the ratio of maximum to minimum pressure drops across the orifice.

Turndown ratio is important when it is necessary to vary the heat input rate (Btu/hr [Watts]) during a heating cycle. It is affected by limitations on the input rates. The minimum input rate is limited by flashback which may occur when the flame speed is too high relative to the mixture velocity. Input rate also depends on the type of ratio-control equipment used; for example, some burners depend on a minimum flow to function properly. The maximum input rate is limited by the blow-off rate which occurs when the mixture speed greatly exceeds the flame speed. A high rate also requires more costly equipment because of the higher pressures needed.

2.3.2 Flame Stability

Flame stability reflects the ability of a burner to maintain ignition when cold and at normal pressures and ratios without the aid of a pilot.

2.3.3 Flame Shape

Flame shape depends upon the mixture pressure, amount of primary air and, more importantly, burner design. Good mixing tends to produce short, bushy flames, whereas delayed mixing produces long, slender flames.

2.3.4 Combustion Volume

Combustion volume is the space occupied by the fuel, air, and products of combustion in the flame envelope.

2.4 Gas/Air Ratio Control

When gas is used for fuel, a certain amount of air must be mixed with the fuel to provide the heat output and flame characteristics desired. This gas and air mixing can be accomplished in several ways.

2.4.1 Atmospheric Inspirators

The atmospheric inspirator is the simplest and most commonly used mixer (Fig. 2). As gas passes through an orifice, it causes a negative pressure at the air orifice, drawing in the air which mixes with the gas. Since both air and gas orifices are adjustable, the desired ratio can be obtained. This type mixing requires only a low or medium pressure, 6 in. W.C. (1.5 kPa) (15 mbar), gas supply.

2.4.2 Aspirators

The aspirator-type mixer (Fig. 3) is similar to the atmospheric inspirator. In this case, air under pressure, 4 in. W.C. to 4 psi (0.9 to 27.9 kPa), (9 to 276 mbar), is the prime mover. A zero pressure regulator is installed in the gas line to keep the gas at atmospheric pressure at the burner. This method of mixing is good for low pressure gas supplies and has a wide turndown range.

2.4.3 Constant Pressure Mixing

In constant pressure mixing both gas and air supplies are at a constant pressure. Since both control valves have similar pressure-drop characteristics and are linked mechanically, they will produce proportional movement for changes in firing rates.

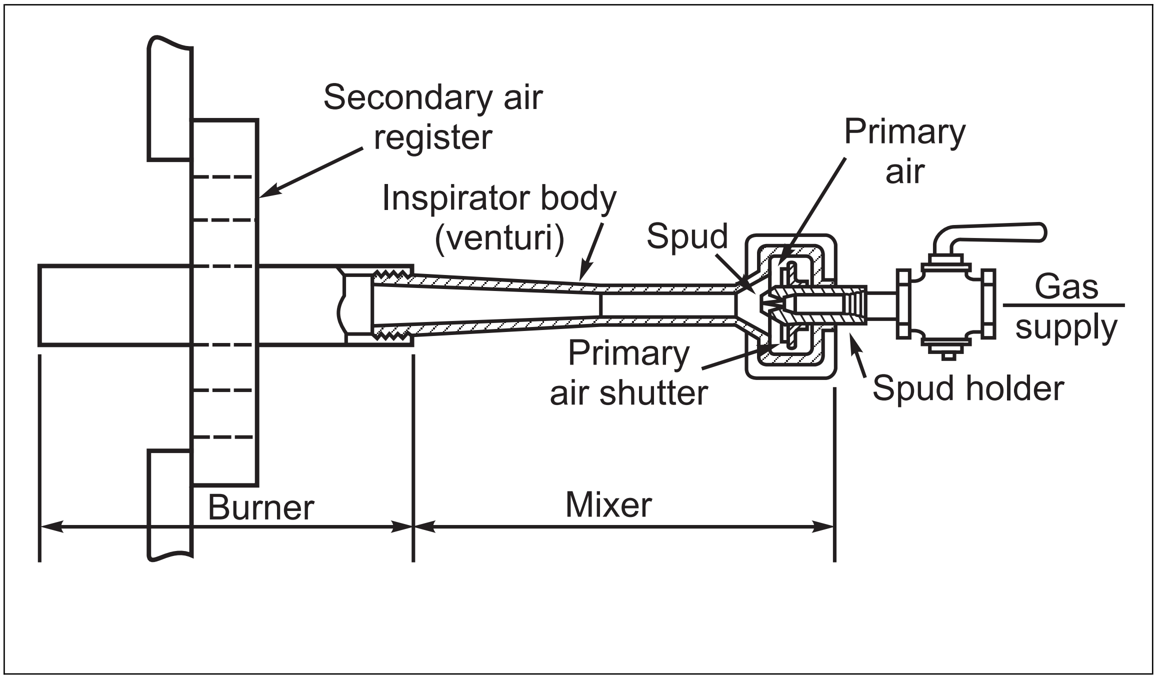

Fig. 2. Atmospheric inspriator mixer.

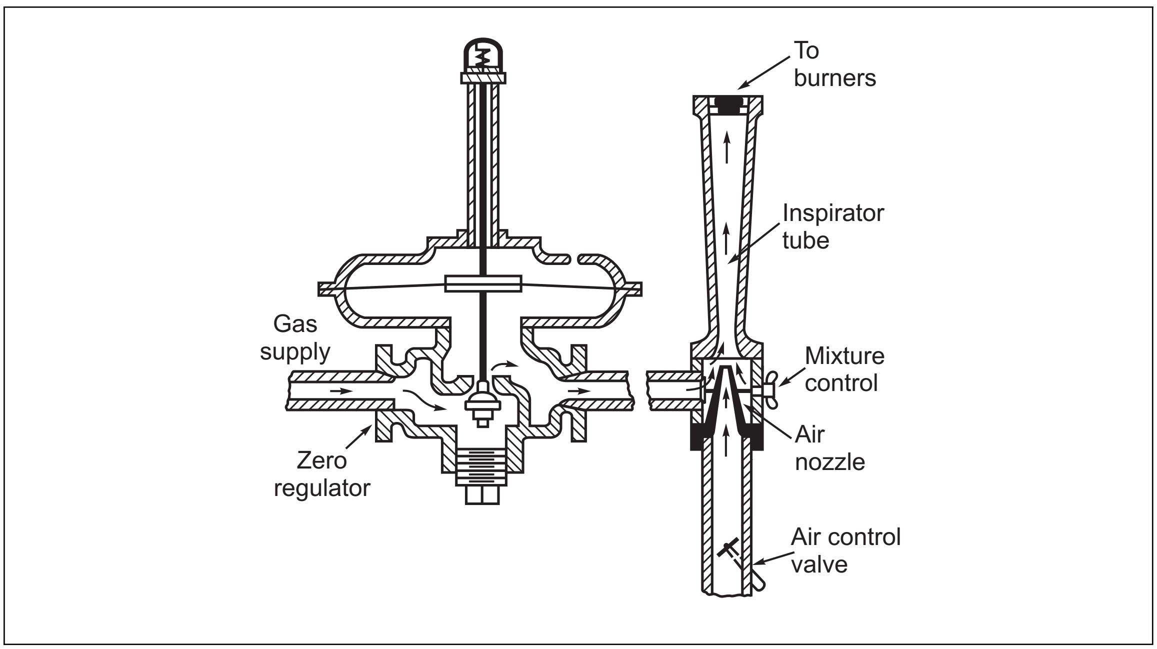

Fig. 3. Aspirator mixer.

2.4.4 Variable Pressure Mixing

In variable pressure mixing the gas and air orifices are set for the desired ratio before firing, and a sensing line between the gas regulator and air line keeps the two volumes in proportion at different firing rates (Fig. 4).

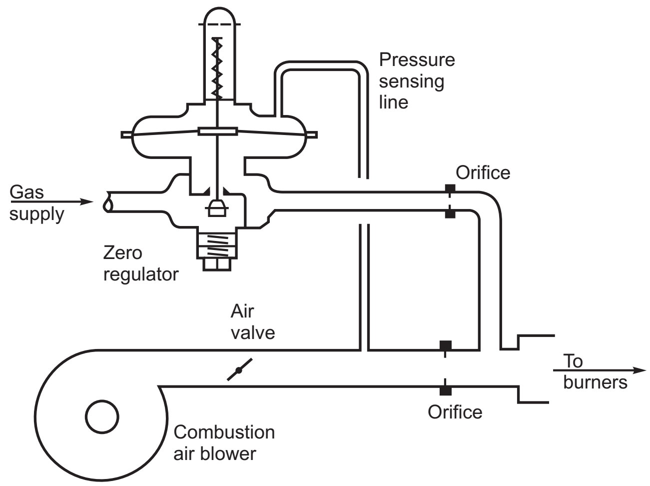

Fig. 4. Variable pressure mixer.

2.4.5 Mechanical Mixing

Mechanical mixing proportions 100% of the gases in the proper ratio ahead of the burner and delivers the mixture at higher pressures. This results in fast ignition, clean burning, and maximum heat release.

The *blower-type mechanical mixer* proportions the air and gas in the suction side of a blower (Fig. 5). They are mixed in the blower before passing to the burner.

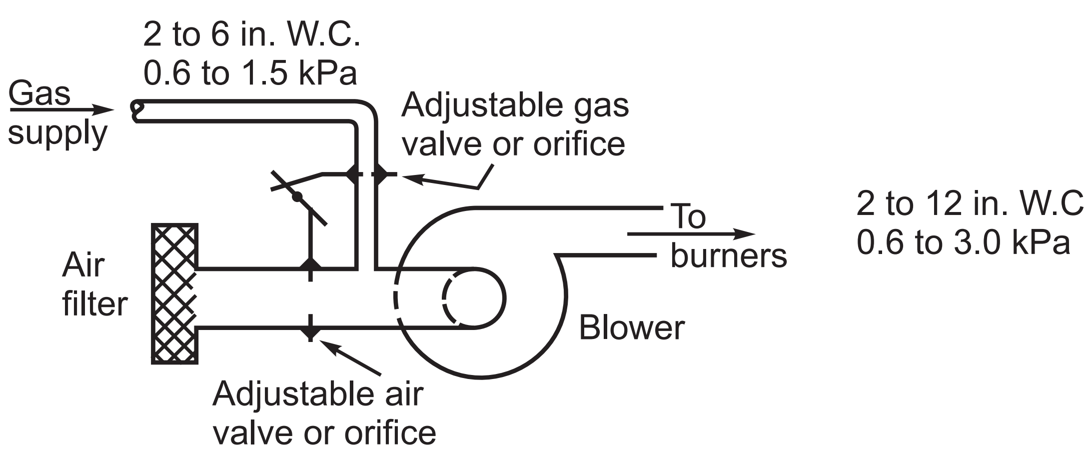

Fig. 5. Blower mixer.

Carburetor-type mechanical mixers are combination gas-air valves which respond to changes in demand while maintaining the preset volume ratio. The three designs (piston, cone and orifice, and slide valve) can be set at an infinite number of ratios. Figure 6 illustrates the cone and orifice type of carburetor.

2.5 Gas Burners

The three basic types of gas burners are the premix, nozzle mix and semi-nozzle mix burners.

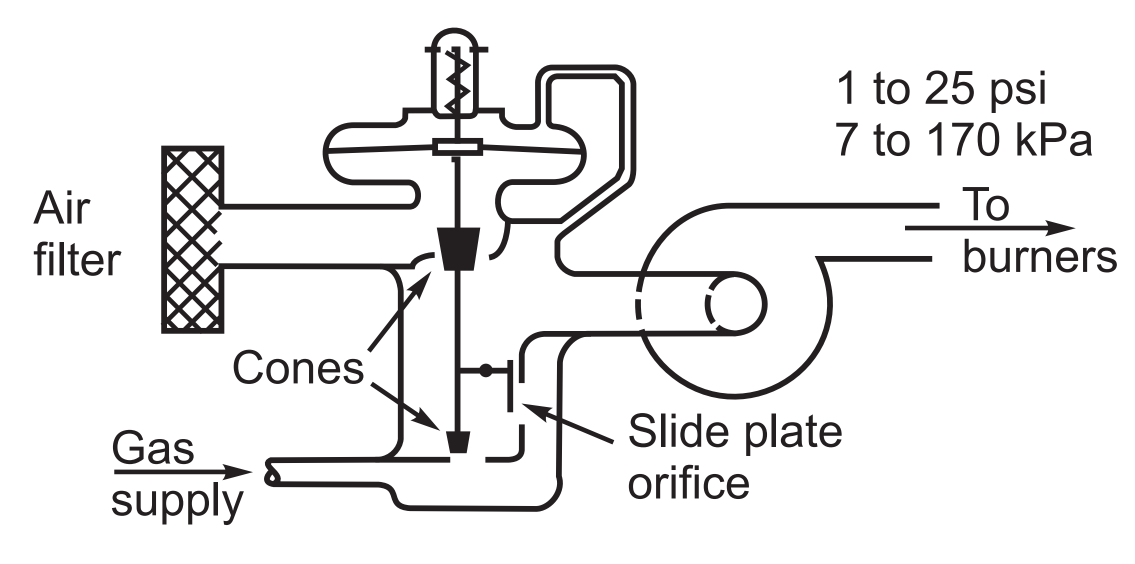

Fig. 6. Cone-slide type carburetor mixer.

2.5.1 Premix

Premixing gas and air before the nozzle puts the mixture within its flammable limits (Fig. 7). There are three methods of premixing:

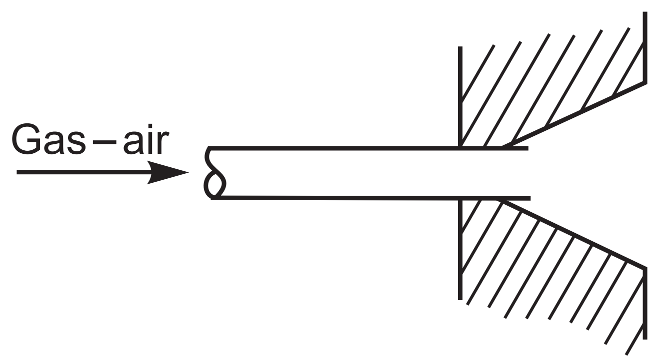

Fig. 7. Premix burner.

1. *Blower or mechanical mixing* is used as previously described in Gas/Air Ratio (Fig. 5). Low pressure systems, <0.5 psi (3.4 kPa) (34 mbar), are located as close as possible to the nozzle to limit piping losses. Since each system is designed for a specific mixture pressure and nozzle area, no valves can be put in the mixture piping. High pressure systems, 5 psi (34 kPa), (0.34 bar), are usually used as central mixing stations for a number of systems which can be separately valved.

2. The *gas jet mixer*, venturi, or inspirator operates as previously described under Atmospheric Inspirators in Gas/Air Ratio Control (Fig. 2 and Fig. 3). This type of mixer can use high- and low-pressure gas, but the mixture pressures produced are limited; 5 psi (34 kPa) (0.34 bar) of gas are needed for 1 in. W.C. (0.25 kPa) (2.5 mbar) of mixture at the discharge of the mixing tube. Higher mixture pressures are obtainable with a mixing-tube gas jet mixer since gas is injected into an air stream.

3. An *air jet mixer* operates similarly to an aspirator. Air pressures range from 4 in. W.C. to 4 psi (0.9 to 27.6 kPa) (9 to 276 mbar).

2.5.2 Nozzle Mix

In a nozzle mix burner the air and fuel are kept separated until they reach the point of ignition (Fig. 8). Typical gas burner assemblies such as those used on boiler furnaces are shown in Fig. 9. An advantage of this type of burner is that flashback is eliminated since no flammable mixture exists in the supply systems. This allows greater flexibility of use in the form of wider turndown range, greater stability, more variety of flame shapes, and variation in combustion volume. Another advantage is that since a portion of the combustion air is not used for premixing, lower pressure air blowers can be used.

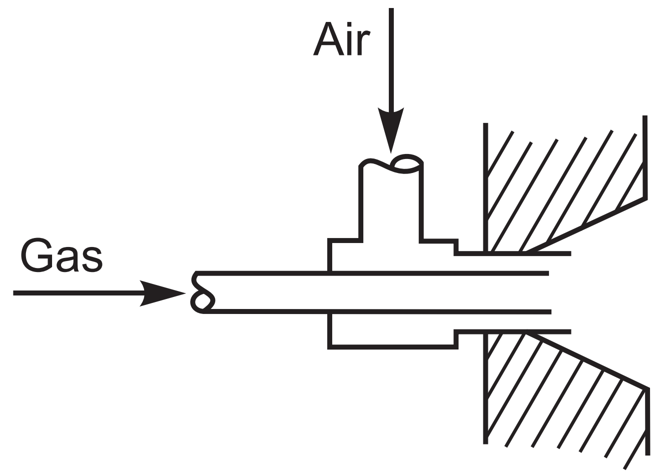

Fig. 8. Nozzle mix burner.

As an example of the flexibility of nozzle mix burners, short, intense flames are obtained by increasing the air and fuel velocities, thus increasing the mixing rate. Long, luminous flames are obtained by lowering the air and gas velocities and thereby delaying mixing. Flat, spiral flames are obtained by spinning the mixture, changing the forward velocity to lateral. The latter also allows a reduction in combustion volume.

The increased turndown range of nozzle mix burners permits a lower input rate at low fire since flashback is eliminated.

2.5.3 Semi-Nozzle Mix

Semi-nozzle mix burners are basically nozzle mix burners with the capability of premixing 0 to 20% fuel with the primary air to meet specific heat output needs (Fig. 10). The secondary air for complete combustion may be obtained from auxiliary ports of an open register design or another pressurized combustion air inlet.

2.6 Properties of Oil

Fuel oil is classified in five grades: #1 kerosene, #2 light or diesel oil, #4 and 5 heavier blends of #2 and #6, and #6 (Bunker C) heavy. (See Table 1.)

Oils have several properties that affect their application. The *flashpoints* of oils from different suppliers or sources should be the same to avoid ignition and operating difficulties. An excess amount of *water and sediment* in the oil can cause inconsistent operation and outages. Excess *carbon residue* can result in increased maintenance outages. *Ash* can also accumulate excessively, and cause corrosion problems. High *sulphur levels* can result in excess emissions and corrosion in the exhaust circuit. The *specific gravity* establishes a guide to the relation of thedensity and heat content of the fuel.

The *viscosity* of the oil determines the type of pumping, piping, heating, and atomization required. Heavy oil systems require heating to allow pumping, and additional heating to lower the viscosity for adequate atomization and combustion (Fig. 11).

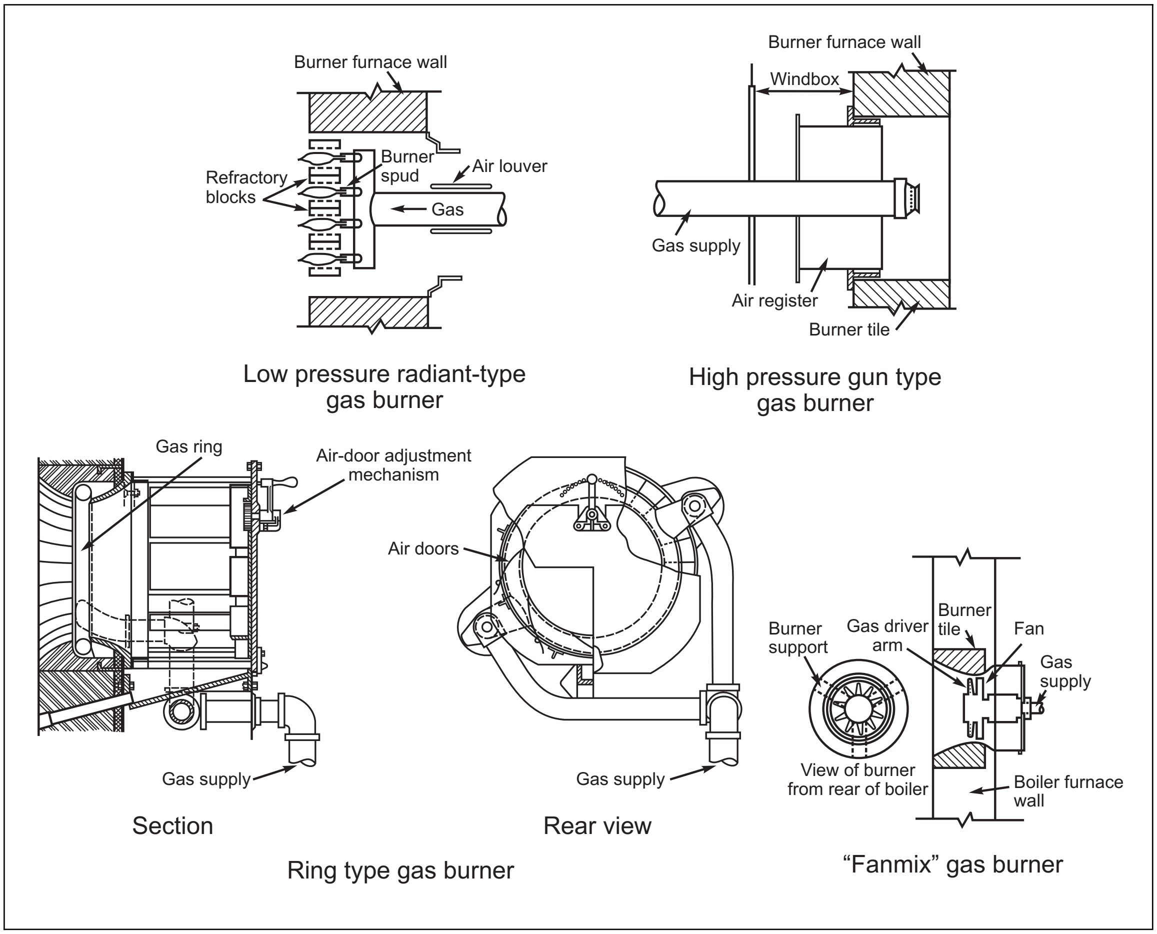

Fig. 9. Typical gas burners.

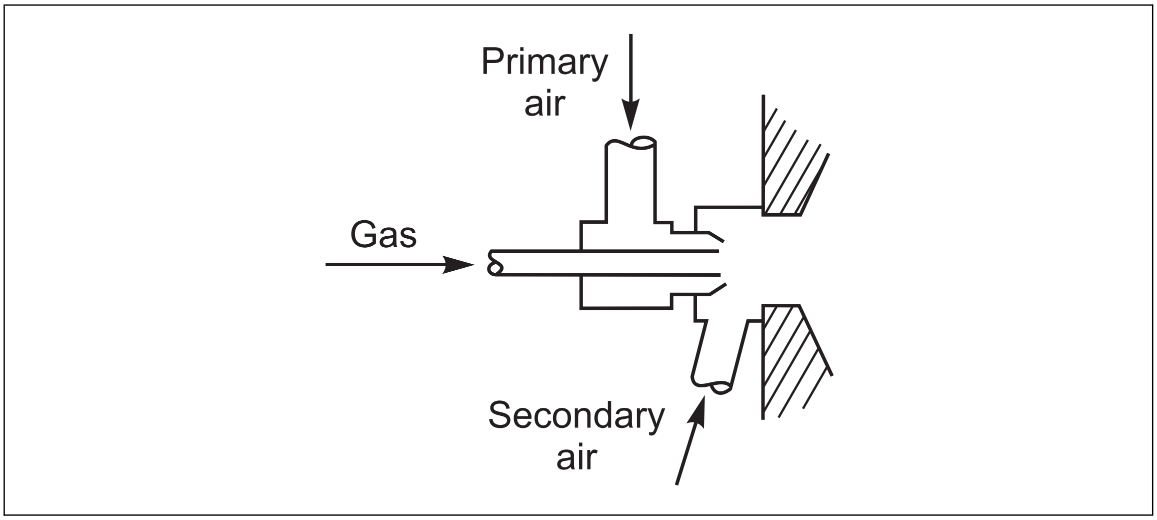

Fig. 10. Semi-nozzle burner.

2.7 Oil/Air Ratio Control

Controls in an oil supply system match the quantity of fuel to the demand and maintain the proper ratio of combustion air to fuel.

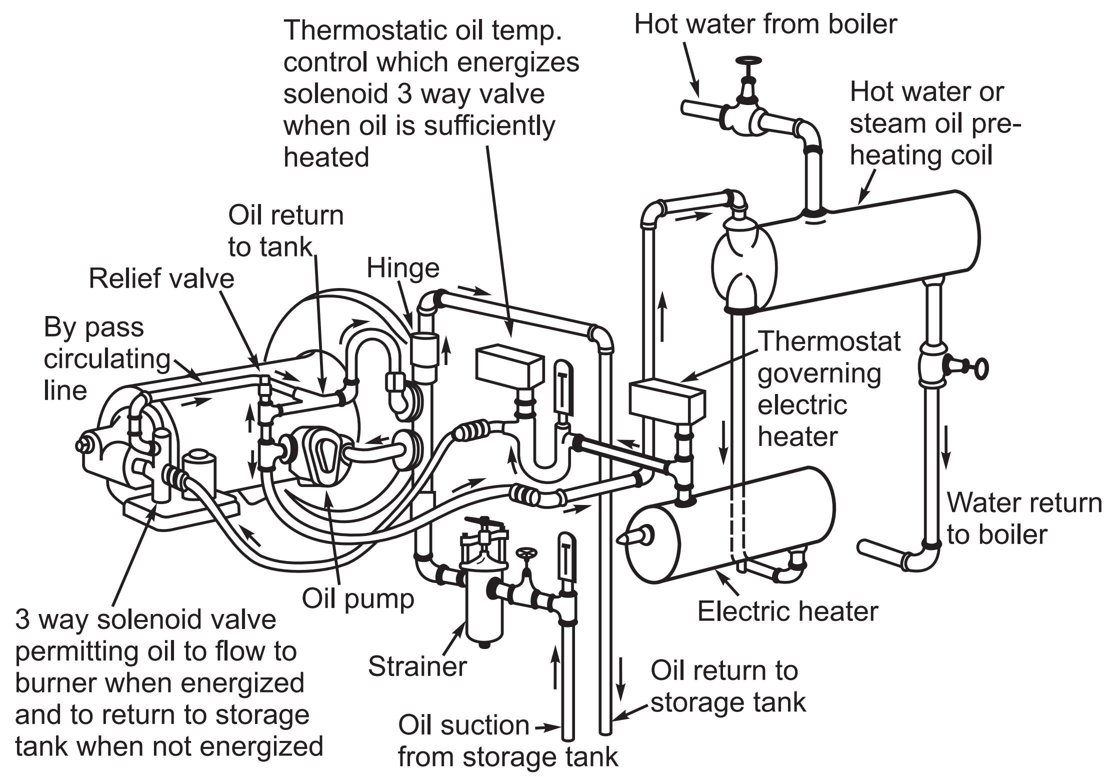

Fig. 11. Heavy fuel-oil heating system for horizontal rotary burner.

2.7.1 Tandem Valve

In the tandem valve system, air and oil valves with matched flow characteristics at a selected differential pressure are linked mechanically for consistent ratio control.

2.7.2 Volumetric

With volumetric control, either air or fuel is controlled by the output of some combustion variable such as temperature. The rate of the controlled flow is then transmitted to a ratio control device which causes the flow of the other fluid to respond to the first.

2.7.3 Pressure Balance

Pressure balance control utilizes the output pressure of the air control valve to control the output of an oil pressure regulator. Provided the regulator is adequately sized, this system provides excellent control.

2.7.4 Constant Flow Valve

In constant flow valve control systems, the flow rate regulated by the valve is a function of valve opening and pressure differential across the valve. If the differential is kept constant, the flow will be consistent since it will depend only on valve position. This type of control is good when using heavy, dirty oils since it is insensitive to partial plugging.

2.8 Oil Burners

The two types of oil-flame combustion are vaporization and atomization.

2.8.1 Vaporization

Light oils, Nos. 1 and 2, can be completely vaporized by heat, leaving little or no residue, and burned as gas. The flame is nonluminous, and blue or purple in color.

In some vaporizing burners, oil is exposed to the radiant heat of an oil-vapor flame burning above a thin layer of oil, or the oil is drawn into the burner by wicks where it is vaporized by the heat of the flame. In other types a separate vaporizer is used and the oil vapor produced is burned in regular gas burning equipment.

Vertical rotary vaporizing burner (Fig. 12). In the vertical rotary vaporizing burner, oil enters the burner by gravity through a constant-level device and flows through a hollow motor shaft to a rotating cup. The cup is equipped with tubes from which oil is thrown in drops to a metal or refractory groove near the edge of the firebox. The oil that collects in the groove is vaporized by the flame, and the vapors rise and burn above the metal or refractory ring at the sides of the firebox.

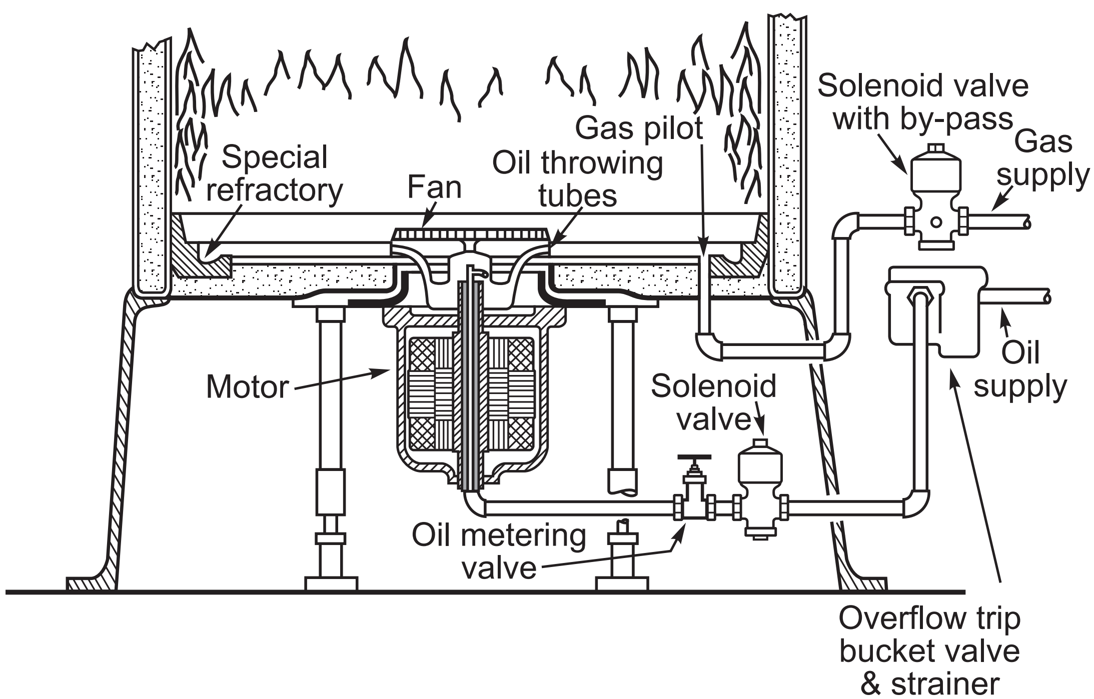

Fig. 12. Vertical rotary vaporizing burner.

Such burners usually operate intermittently under automatic control. The oil in the groove can be vaporized and ignited by gas pilots or by a special flaming-arc type of electric ignition.

Because of the intermittent operation, an explosion hazard exists during the starting period. The hazard is also present during the operating period, because of the possibility of a change in air adjustment which would smother the flame.

Oil Gasifiers. One type of oil gasifier vaporizes light oil with a self-contained heater and mixes the vapor with air to supply the burners as a substitute for gas in heat treating furnaces, some types of ovens, and other gas heated equipment.

An early design is shown in Fig. 13, where a constant level of oil is maintained in the bottom of a vaporizing chamber. Above this chamber is a mixing inspirator in which air at pressures up to 8 oz (3.5 kPa) (35 mbar) passes through a nozzle and venturi tube, creating a suction in the vaporizing chamber. The inspirator suction draws the hot products of combustion through the oil, vaporizing it. The vapor is drawn into the inspirator, mixed with air, and delivered to the burners.

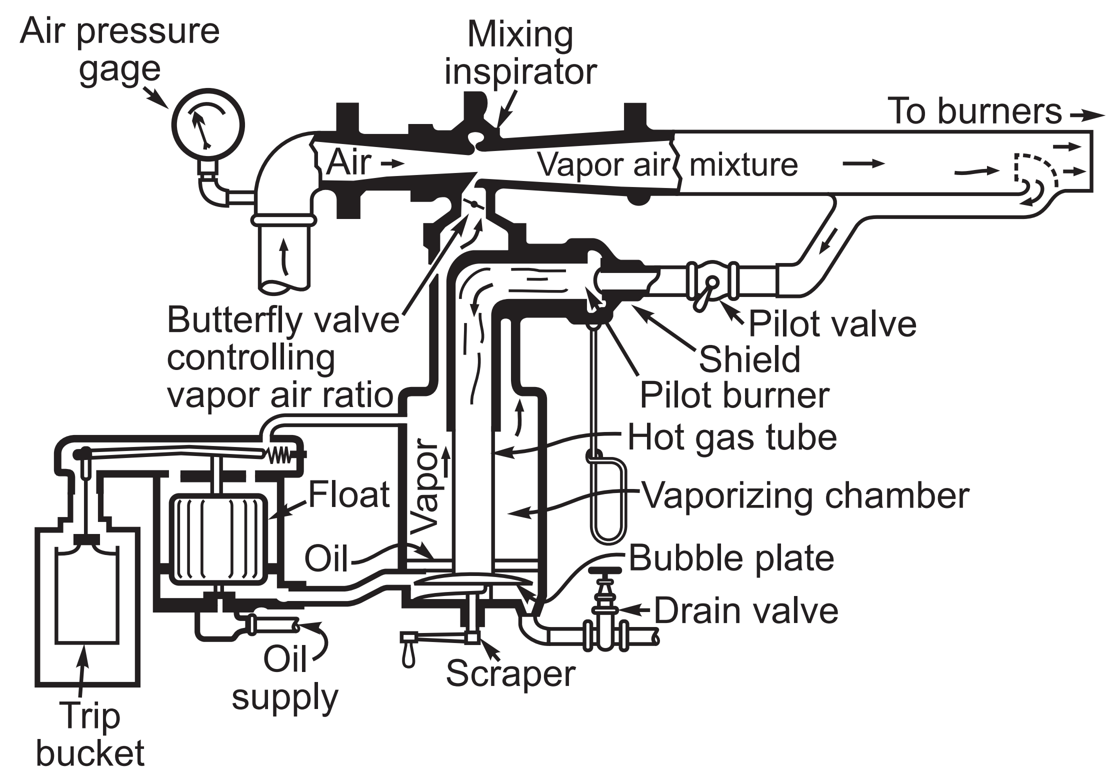

Fig. 13. Oil gasifier or vaporizer.

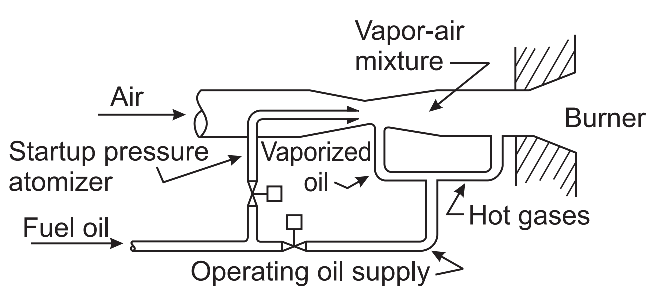

Fig. 14. Oil gasifier or vaporizer.

A current design (Fig. 14) starts with a pressure-atomizing oil nozzle which discharges with the combustion air into a venturi. After a brief interval the venturi assembly will draw hot gases back through the gasifier line. The operating oil supply valve is then opened, and oil is vaporized by the returned hot gases and drawn into the venturi. The atomizing nozzle is then shut down.

The heavier oils, Nos. 4, 5 and 6, cannot be satisfactorily burned in vaporizing burners because they break down into light oils and residual material when heated. Most of the latter is carbon which does not burn readily and eventually obstructs the burner.

2.8.2 Pressure (Mechanical Atomizing Burners)

In simple atomizing burners, oil is forced through a spray nozzle at high pressure and discharged as a fine mist. These burners are usually limited to light oil and have a tendency to clog because of the small port sizes used.

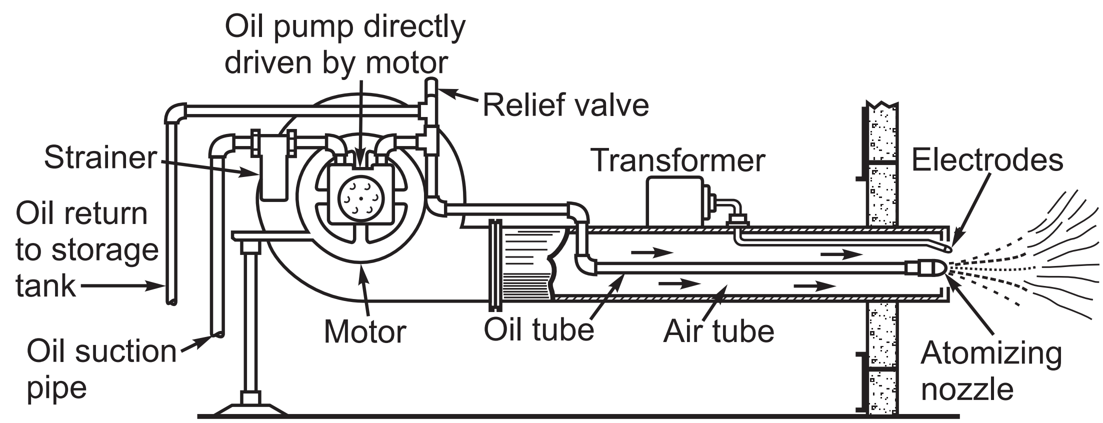

Fig. 15. Pressure atomizing or gun-type burner.

In a gun-type burner (Fig. 15), oil is drawn to the burner by a rotary pump and discharged through an atomizing nozzle at abut 100 psi (0.69 MPa) (6.9 bar). A relief valve regulates the pump discharge pressure by returning excess oil to the tank or pump suction.

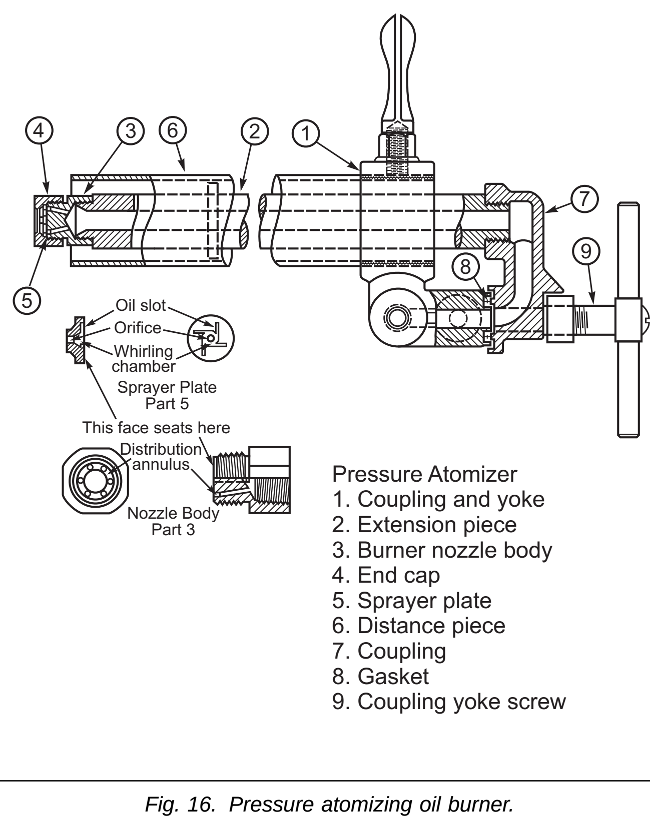

Fig. 16. Pressure atomizing oil burner.

In an industrial mechanical-type burner (Fig. 16), preheated oil at 150 to 300 psi (1.0 to 2.0 MPa) (10 to 20 bar) is discharged from the burner nozzle in a fine mist. Air enters through a register and mixes with the oil spray after passing a diffusing plate (Fig. 17).

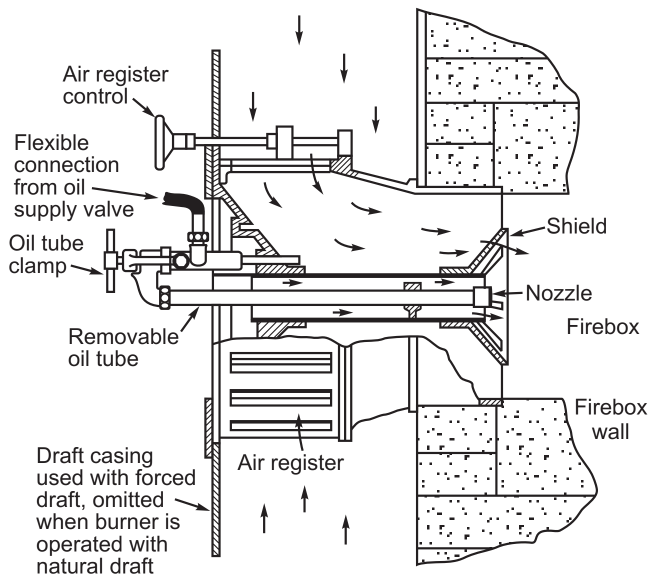

Fig. 17. Pressure atomizing oil burner and combustion air register.

Mechanical atomizers are limited to less than a 2 to 1 turndown since a drop in pressure drastically affects the atomization.

2.8.3 Air Atomizing Burners

In the low-pressure air atomizing burner, oil at approximately 35 psi (0.24 MPa) (2.4 bar) is picked up by the air stream from a low-pressure blower system 16 to 32 oz. (13.8 to 27.6 kPa) (0.138 to 0.27 bar), and carried into the combustion chamber. In the medium-pressure type the atomizing air is proportional to the fuel flow rate.

This type of burner is extremely flexible since its spray angle can be readily changed. Maximum turndown ratio can be obtained by using a minimum airflow.

2.8.4 Steam Atomizing Burners (Fig. 18)

Steam atomizing burners resemble the low-pressure, air-atomizing type in method of operation. Oils up to No. 6 grade can be used and good atomization is obtained by the rapid expansion of steam as it leaves the nozzle. Air is supplied by natural or forced draft around the oil nozzle.

Orifice sizes are larger with this type burner so the plugging potential is greatly reduced. Approximately 1 to 2 lb/gal (120 to 240 kg/m^3) of steam are used to atomize light oil and 2 to 3 lb/gal (240 to 360 kg/m^3) for heavy oil.

2.8.5 Rotary Atomizing Burners

In the rotary atomizing burner, oil sprayed onto a spinning cup spreads out into a thin film by centrifugal force and breaks into fine drops as it leaves the edge of the cup. A high degree of atomization is afforded and the heaviest oils can be used.

There are three types of rotary atomizing burners. The *vertical rotary* atomizing burner resembles the vertical rotary vaporizing burner, but the motor is run at higher speeds. In *direct-driven, horizontal rotary* burners (Fig. 19), the spinning cup is either electric or steam-turbine driven. In *air driven, horizontal rotary* burners (Fig. 20), the cup may be driven by a separate fan-driven air turbine or a blower which is powered by its own motor.

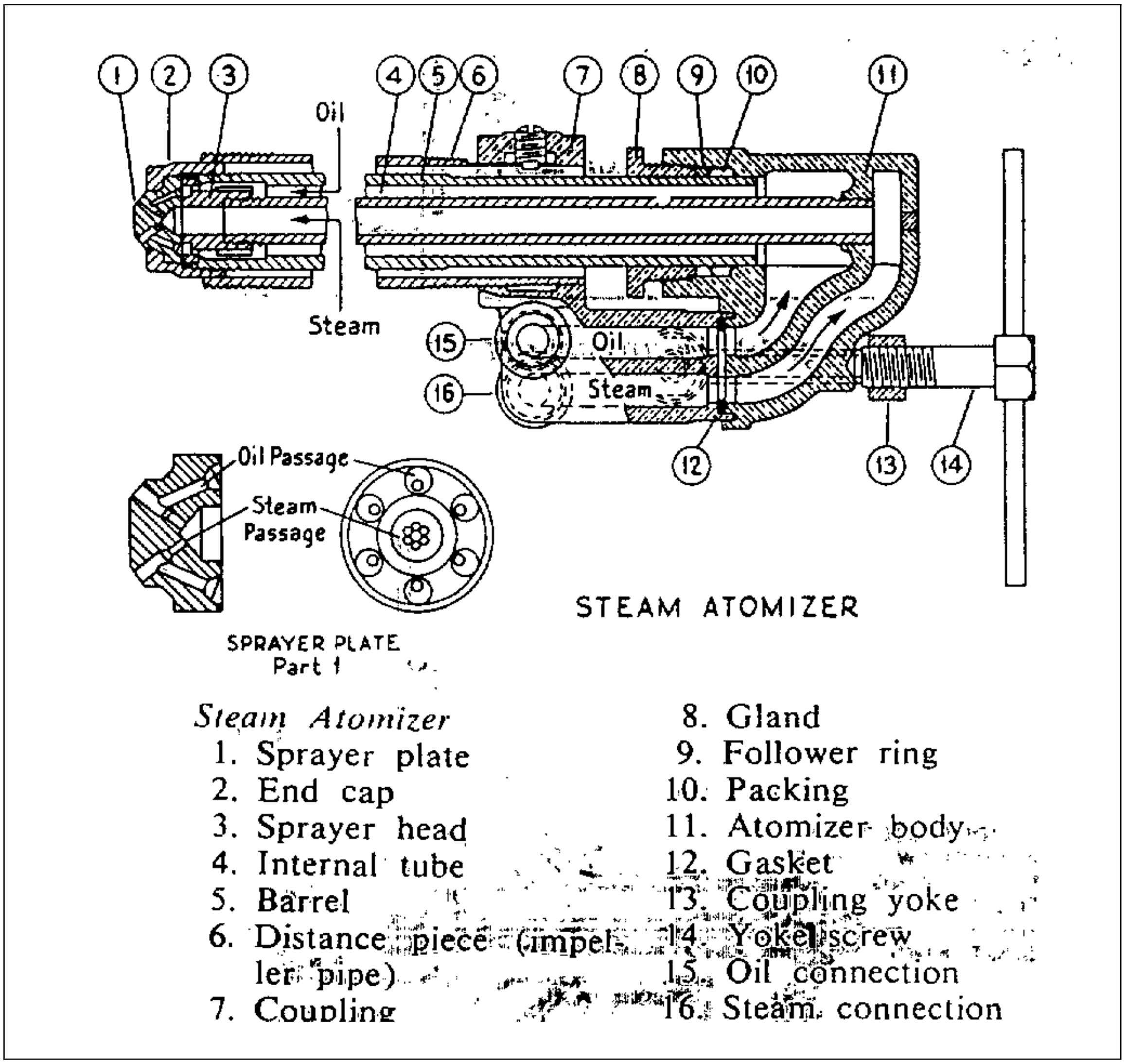

Fig. 18. Steam atomizing oil burner.

2.9 Combination Gas and Oil Burners

Because the availability of certain fuels varies, it is often advantageous to have burners equipped to fire either gas or oil.

Low-pressure air atomizing oil burners are most adaptable as combination burners since gas can be fed through the atomizing air ports. Burners can be run on ‘‘zero’’ or low pressure gas depending on the internal design.

Combination burners are usually the nozzle mix type with the gas in the center and air in the space around the gas tube. Either gas or atomizing air can be passed through the gas tube.

Special combination burners can be arranged as simultaneous gas-oil burners, as can most combination burners with separate connects for gas and atomizing air. An existing low-pressure air atomized burner can be made a simultaneous burner by (1) substituting gas for atomizing air, (2) mixing gas and atomizing air as they enter the burner, or (3) inserting an aspirator mixer in the main air line.

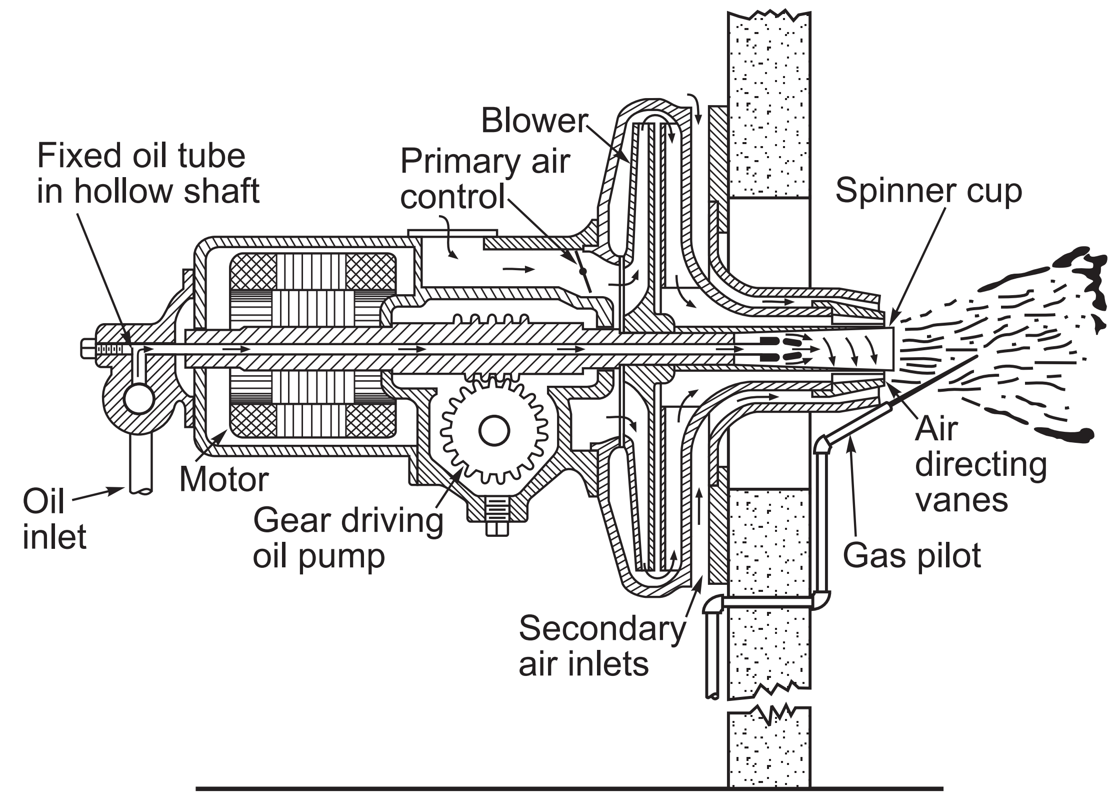

Fig. 19. Horizontal rotary burner.

2.10 Combustion Controls and Safeguards

2.10.1 Combustion Controls

Types

Manual-lighted types of heating equipment, gas-or oil-fired, such as a boiler or oven, are those in which fuel to the main burner(s) can be turned on only by hand and is manually or semiautomatically ignited under the supervision of the burner operator. (See Manual-Ignited Burner and Semiautomatic-Ignited Burner below.) Once ignited, firing of the main burner(s) may be high-low, modulated to off, or on-off.

Automatic-lighted gas- or oil-fired equipment is that in which fuel to the main burner(s) is turned on and ignited automatically. (See Automatic-Ignited Burner below.) Firing of the main burner(s) may be high-low, modulated to off, or on-off.

Ignition Methods

A manual-ignited burner is ignited by a portable gas or oil burner torch or by an oil soaked swab torch placed in proximity to the burner nozzle by the operator.

An automatic-ignited burner is ignited by direct electric ignition or by an electrically-ignited or continuous pilot.

A semiautomatic-ignited burner is also ignited by direct electric ignition or an electrically-ignited pilot, but the electric ignition is manually activated.

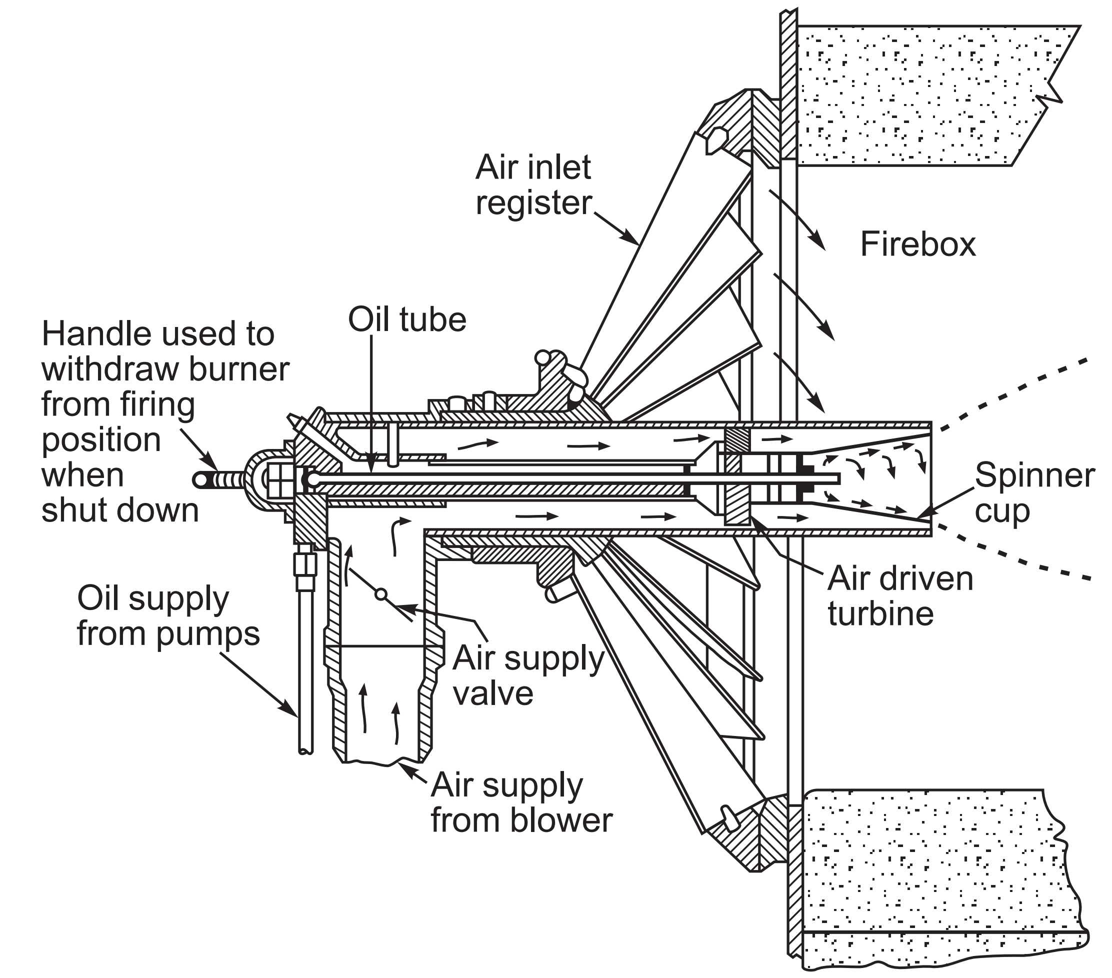

Fig. 20. Horizontal rotary burner with air-driven spinner cup.

Pilots

Pilots for automatic- and semiautomatic-ignited burners are of three types. A continuous pilot burns without turndown throughout the entire period that the heating equipment is in service, whether or not the main burner is firing. An intermittent pilot burns during light-off and while the main burner is firing, and shuts off with the main burner. An interrupted pilot burns during the pilot flame-establishing and/or trial-for-ignition periods, and cuts off (i.e. is interrupted) at the end of this period or during firing.

Safety Shutoff Valves

The safety shutoff valve is the master of all safety controls used to protect against explosion or fire which could result from accidental interruption of various operations. Hazardous interruptions would include failures involving the burner flame, fuel pressure, combustion-air pressure, exhaust or recirculation fans, temperature controls, or primary power.

An approved fuel safety shutoff valve is held open by electrical energy, pressure or both. It is self-closing within 5 seconds after the holding medium is cut off. Approved valves are available in manual or automatic opening types. Both can be opened only after the holding medium is applied and are so enclosed that they cannot be readily bypassed or blocked open. Blocking the valve’s operating handle does not prevent it from closing when the holding medium is cut off.

All approved fuel safety shutoff valves, except the direct-acting, packless solenoid type, have a mechanically actuated indicator to show whether the valve is open or shut. Some packless solenoid types have magnetically actuated position indicators.

2.10.2 Combustion Safeguards

The term *combustion safeguard* means a safety control that is directly responsive to flame properties. It senses the presence of flame and causes the fuel to be shut off if the flame fails. All approved combustion safeguards have a response time to flame failure of not more than 4 seconds. A flame-failure contact is wired into flame-failure alarm and signal circuits. Usually, there is a built-in, safe-start check that prevents lighting-off if the flame sensing relay is in the unsafe (flame present) position.

Programming combustion safeguards are composed of flame detecting and ignition timing assemblies, and one or more flame-sensing elements. The two assemblies are usually in the same enclosure and complement each other.

This device may be wired into a safety control circuit so that it also protects against explosions during lighting-off by automatically limiting the pilot-flame establishing and/or the trial-for-ignition periods. A programming combustionsafeguard may provide still other features such as timed preventilation and post-firing purge periods.

Approved programming combustion safeguards may be of either the recycling or non-recycling type. The difference is in whether or not they automatically make one attempt to reignite and prove a pilot flame before permitting the main fuel safety shutoff valve to reopen following an accidental flame failure during firing.

The non-recycling type causes all fuel to be shut off and the electric ignition deactiviated if (1) the pilot flame is not proved at the end of the pilot-flame establishing period, (2) the main flame is not established and proved at the end of the trial-for-ignition period, or (3) accidental flame failure occurs during firing. In all these events, the attention of an operator is required before the next pilot flame-establishing or trial-for-ignition periods can start.

The recycling type causes all fuel to be shut off and the electric ignition to be deactivated in the situations described in (1) and (2) above. And again, the attention of an operator is required before the next pilot-flame establishing or trial-for-ignition period can start. In the case of an accidental flame failure during firing, this device also causes the main fuel safety shutoff valve to close, but it automatically recycles. That is, it makes one attempt to reignite and prove the presence of the pilot flame before permitting the main fuel safety shutoff valve to be reopened. If the pilot is not ignited during this attempt, the safeguard causes the fuel to the pilot to be shut off and the electric ignition deactivated. The attention of an operator is required before the next pilot-flame establishing or trial-for-ignition periods can start.

Nonprogramming combustion safeguards, in their simplest form, are composed of a flame detecting assembly and one or more flame sensing elements. This safeguard operates similarly to that described above, but in the event of an accidental flame failure and consequential shutdown, the attention of an operator will be needed before the next pilot-flame establishing or trial-for-ignition periods can start. Because of this operating characteristic, a nonprogramming combustion safeguard is often further classified as nonrecycling.

Safe-start checks are incorporated in safety control circuits (usually built into the combustion safeguard) to prevent lighting-off if the flame sensing relay of the combustion safeguard is in the unsafe (flame present) position because of component failure within the combustion safeguard or the presence of actual or simulated flame.

A *safety shutdown* occurs when a safety interlocks(s) stops burner operation by shutting off all fuel and ignition energy to the furnace. It requires a manual re-start.

Flame supervision is the detection of the presence or absence of flame. A flame supervisory system performs three basic functions: (1) verifying the proper conditions for combustion, (2) providing sequence-controlled ignition, and (3) monitoring the presence of combustion.

Flame detectors normally operate on the principles of (a) temperature, (b) flame rod conductivity and (c) optical (radiant) energy.

The earliest developed flame detectors monitored the *temperature* of combustion products in the flue or flame. These methods delay one to three minutes before indicating flame failure. This is too long for safe operation of most burners, although it may be satisfactory for some pilots and small appliances.

The three types of temperature detectors are (1) bimetal element and switch, (2) bulb and capillary combination and switch, and (3) thermocouple and relay or solenoid.

The bimetal element consists of two dissimilar metals fastened together which provide motion to operate a switch when heated. This type of detector is usually placed in the flue.

Bulb and capillary detectors consist of a metal bulb connected to capillary tubing which operates a bellows controlling a switch. This type operates upon expansion or contraction of a fluid. It is usually used with small gas pilots.

A thermocouple consists of two wires of different metals fastened to form a junction. When placed in a flame, enough voltage is generated to initiate action to cause operation of a solenoid actuated fuel valve.

A *flame rod* depends upon the ability of a flame to conduct electricity. The rod acts as one electrode and the burner head or furnace walls as the ground electrode across which an alternating voltage is applied. Appreciable current will only flow between the two when the rod is negative and ground positive. The flame thus acts as a rectifier. This current then feeds an amplifier whose output signal is strong enough to hold open a fuel valve. Any current leakage causes an ac signal in the circuit and a subsequent shutdown.

Direct-currnt flame systems, which were the forerunners of flame-rectification ac systems, could not differentiate between flame and current leakage and, therefore, are no longer used.

For a flame rod to function properly, the rod must be properly located, the ground area a minimum of four to one, and the flame being monitored stable and in constant contact with the grounding area.

The use of flame rods is usually limited to the smaller gas flames, such as pilots, because of the rod's temperature limits. Rods are rarely used on oil burners because oil flames produce deposits on the rod which may prevent electrical conduction.

There are no performance requirements for flamerods. They are compatible with any brand of combustion safeguard.

Optical detectors sense the radiant energy produced by a flame. There are three types (Fig. 21).

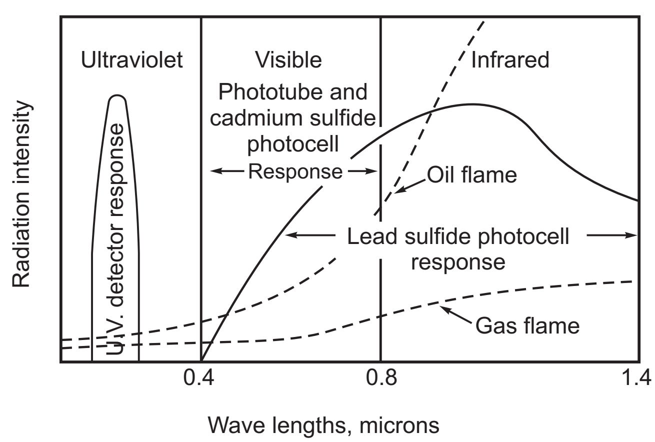

Fig. 21. Light wave leng;ths for optical detectors.

1. The visible-light rectifying phototube has a cathode containing cesium oxide which emits electrons in the presence of visible light and, therefore, causes a current flow. Since the control circuitry operates on rectified current only, it is protected from false signals due to short circuits.

Cadmium sulfide photocells are sensitive to radiation in the visible light spectrum. Their electrical resistance is inversely proportional to light intensity.

These detectors are used only on single burner, oil-fired installations since they cannot differentiate between the light of several burners. They are not used for gas flames because of the insufficient visible light emitted.

2. Infrared sensors contain lead sulfide which decreases in resistance when exposed to infrared radiation, permitting a current flow. A special amplifier used for this current responds only to the flickering of a flame and is not affected by refractory light.

Infrared sensors can be used on gas or oil flames, and are ideal for large oil burners.

3. An ultraviolet sensor has a cathode that emits electrons when it is exposed to ultraviolet light with a high potential applied across its electrodes. The electrons ionize the gas in the sensing tube, permitting a current flow.

Ultraviolet sensors can be used for gas and combination burners as well as multiple-burner installations and pulverized coal burners. Electric ignition sparks emit ultraviolet light. Therefore this type of sensor must be arranged to detect only the burner flame.

Some UV scanners have a self-checking feature. A shutter closes over the cell every six seconds for a fraction of a second. If the scanner does not sense a loss of flame during the check, the scanner will initiate a shutdown. UV scanner cells can fail in an unsafe manner and detect flame even when no flame is present, although this is very rare. Equipment that operates continuously for periods longer than a week normally uses this type of scanner (if using a UV scanner). The combustion safeguard does a safe-start check at each startup and, in effect, a scanner check also.

The *pilot-flame establishing period* is that interval of time during lighting-off when a safety control circuit permits the pilot fuel safety shutoff valve to remain open before the combustion safeguard is required to prove the presence of the pilot flame.

The *trial-for-ignition period* is that time during lighting-off when a safety control circuit permits the main burner fuel safety shutoff valve to remain open before the combustion safeguard is required to supervise the main burner flame alone.

2.10.3 Other Interlocks and Controls

High and low fuel, or *combustion air pressure switches* are pressure-actuated devices arranged to shut down the burner or prevent it from starting upon excessively high or low fuel or combustion air pressure.

A *low oil-temperature interlock* is a temperature actuated device arranged to shut down the burner or prevent it from starting when the oil temperature falls below the limit required to maintain the viscosity range recommended by the burner manufacturer.

An *atomizing-medium interlock* effects a safety shutdown if atomizing pressure and flow become inadequate, or the proper differential is not maintained between fuel and atomizing-medium pressures.

The *gas analyzer-type combustion control* continuously samples the gaseous products of combustion and indicates (and may record) the percent of combustibles and oxygen. It is important that a collection point(s) be located where the sample for the analyzer accurately represents the flue gas or atmosphere, and so that it indicates changes in gas concentration at the burners as promptly as possible.

The percent of combustibles indication is the safety control function of the equipment (Fig. 1). During a firing cycle a dangerous condition may result, for example, from a deficiency of air; such a deficiency would normally cause a gradual increase in the amount of combustibles in the products of incomplete combustion. The equipment provides an automatic warning signal at 1 percent and a danger signal at 2 percent combustibles. The 2 percent value is well below the danger level regardless of the kind of fuel. This equipment may also be used to detect a dangerous internal atmosphere at the time of burner light-off.

The percent of oxygen indication, when employed, provides information to judge efficiency of combustion. This makes possible more economical operation of burners.

Automatic continuous gas analyzes, permanently mounted, use numerous analysis methods. The more common methods operate on the principles of catalytic combustion, thermal conductivity, the infrared spectrum, paramagnetism, electrochemistry, or chromatography. Many of these methods, including the Orsat method (gas absorption), also are used in portable equipment, and is standard equipment for most burner and heating services agencies.

To derive the full benefits of the equipment, each application must be individually engineered and inspected by the manufacturer of the device or an authorized representative.

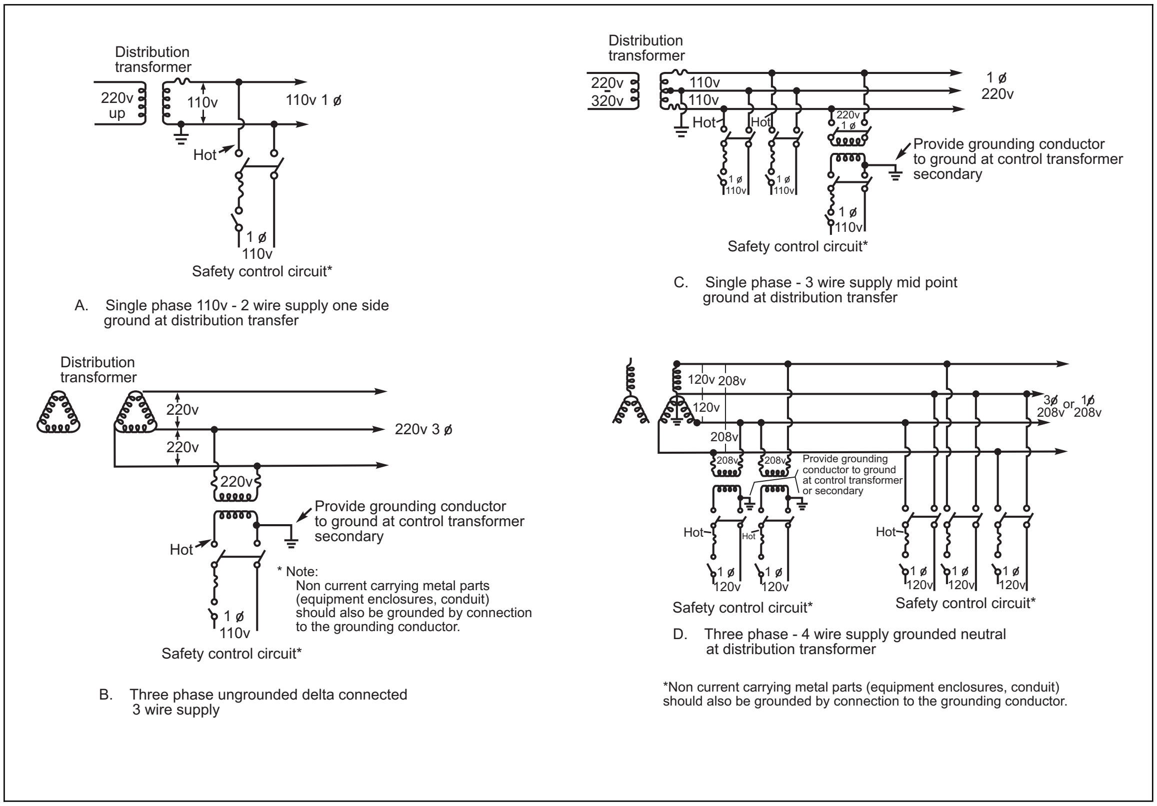

Fig. 22. Grounding of safety control circuits.

2.11 Safety-Control Circuit Wiring

Some safety control circuits are susceptible to malfunction. This is due to the use of an ungrounded circuit or installation of controls in the grounded conductor of a grounded circuit. The equipment will appear to function normally even though a fault may have occurred. The result of such a fault is the bypassing of an important safety function.

The diagrams in Fig. 22, A to D are typical of the power systems commonly available for supplying control circuits. They illustrate the proper method of grounding the circuit, which will prevent malfunction of the safety devices resulting from an accidental ground fault.

Ac and dc safety-control circuits should be two-wire, one side grounded, and preferably not over a nominal 120 volts. All safety control switching should be in the ungrounded conductor. Overcurrent protection should be provided as required by the National Electrical Code. In addition to circuit grounds, non-current carrying metal parts should also be grounded. This may be done by connecting the equipment enclosures and conduit to the grounding conductor.

Exception: In unusual cases where an ungrounded dc power supply cannot be avoided, all switching should be located in one conductor. Ground fault detection should also be provided (Fig. 23, A and B).

Wiring that is used for data transmission between electronic components such as PLCs, PCs, circuit interfaces, and transponders should be protected against noise caused by rf and electromagnetic interference. Use proper shielding and separation from higher voltage wires.

2.12 Maintenance Testing of Safety Controls

Safety controls, besides requiring regular maintenance in accordance with the manufacturer's instructions, should be inspected and tested periodically.

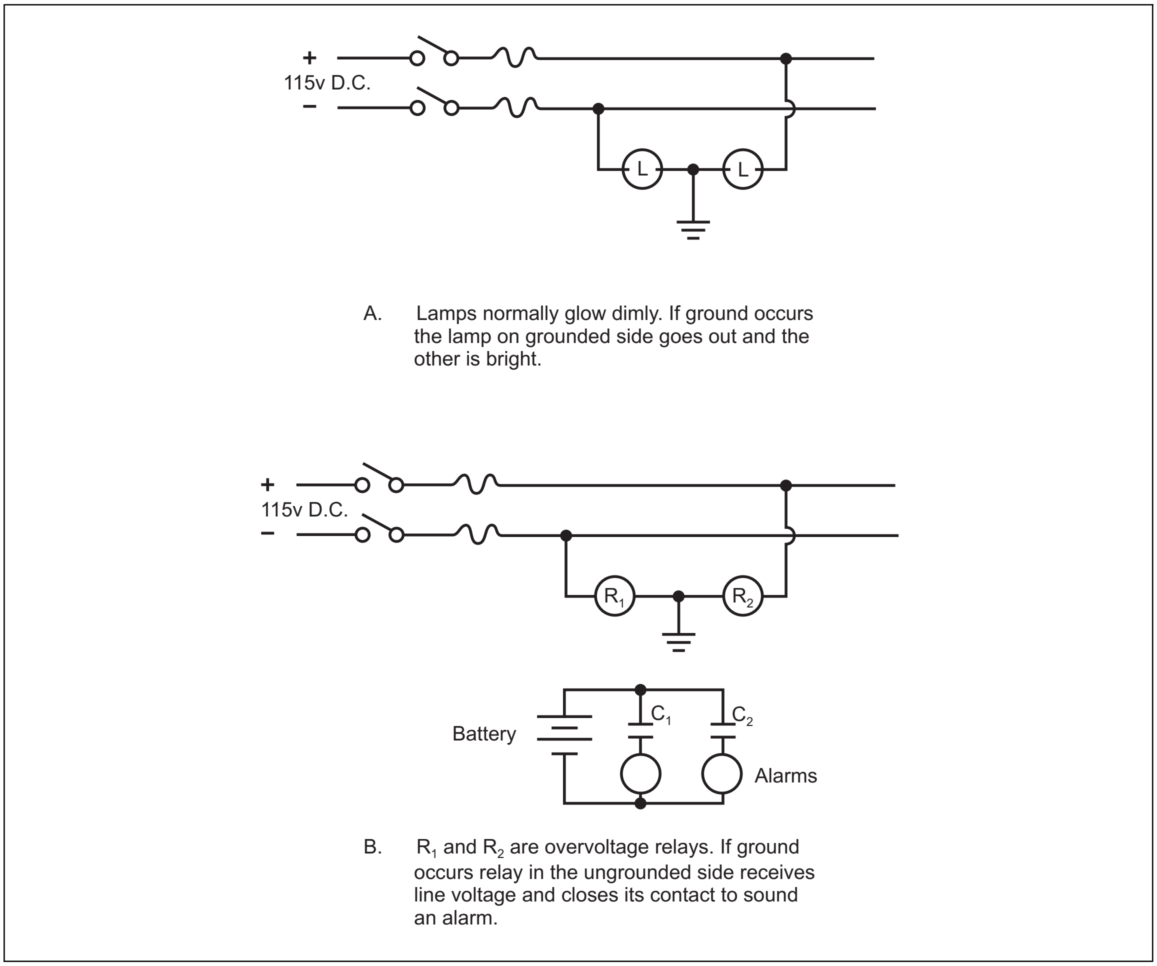

Fig. 23. Underground d-c power supply, with ground fault detection.

Fuel safety shutoff valves, combustion safeguards, temperature-limit switches, fan interlocks or other safety controls may malfunction without the operator's knowledge unless the faulty controls cause nuisance shutdowns. In some cases, operators concerned primarily with production may bypass a faulty safety control without reporting the trouble.

Tests should be made by personnel who are competent, well trained, and familiar with the equipment and the specific functions of the various safety controls. It is usually better to have personnel from the mechanical or electrical maintenance departments rather than the regular operators make inspections and tests, although in smaller plants it may be necessary to use the operators. In larger plants, several people should be trained so that competent personnel will always be available when tests are due. The inspection reports should go to the management executive, whose responsibility includes both safety and production. Arrangements should be made to insure coordination between operating and inspecting personnel. In many cases tests can be made during nonoperating periods. Upon completion of the tests, covers of all safety controls should be properly sealed in place to minimize tampering.

The following inspection and testing program should be conducted for all fuel fired heating equipment:

2.12.1 Fuel Safety Shutoff Valves

With burners firing, trip each safety shutoff valve by cutting off its holding medium (electricity, pressure or both) to determine whether it closes tightly within the normal time. See that covers on main safety shutoff valves are properly installed and sealed in place whenever possible. See Tightness Test Methods.

2.12.2 Combustion Safeguards

With burners firing, institute flame failure by closing burner valves, or simulate failure by disconnecting or shielding the flame sensor and measure the failure response time (time between detecting flame absence and shutting safety shutoff valve). This determines whether the combustion safeguard operates properly within the proper time. Inspect flame sensing devices for needed replacement or cleaning. Also check the installation dates on electronic vacuum tubes to assure the replacement program is being followed.

2.12.3 Time Delay Switches

Note the time setting of each time-delay switch, and measure the actual delay period it is providing. Check whether the time-delay interlock is working. For example, check purge timers; the safety shutoff valve should be prevented from opening before the end of the preventilation period.

2.12.4 Fan-Failure Interlocks

Start each fan and note whether the fan interlock contact closes. Stop the fan and note whether the contact opens.

2.12.5 Temperature and Pressure Supervising Switches

Observe the set cut-in and cut-out position of each switch. For low pressure switches, turn the supervised pressure medium off and on, and observe whether the load contact opens and closes properly. For high temperature or high pressure switches, adjust the switch setting down until the load contact opens. For low temperature switches adjust the switch setting upwards until the load contact opens. Caution: The switch must be reset to the proper operational setting.

For fan failure interlocks and temperature and pressure supervisory switches, the switch-interlock should be tested to verify that the safety shutoff valve will close when the unsafe simulated or actual temperatures or pressures are detected.

Additional interlocks and safety devices provided on various types of heating equipment such as conveyor failure interlocks, explosion venting latches, and automatic fire checks should also be inspected and tested periodically.

2.12.6 Gas Safety Shutoff Valves—Tightness Test Methods

2.12.6.1. Single Safety Shutoff Valve (Fig. 24)

Trip safety shutoff valve closed and observe that valve indicator shows it closed.

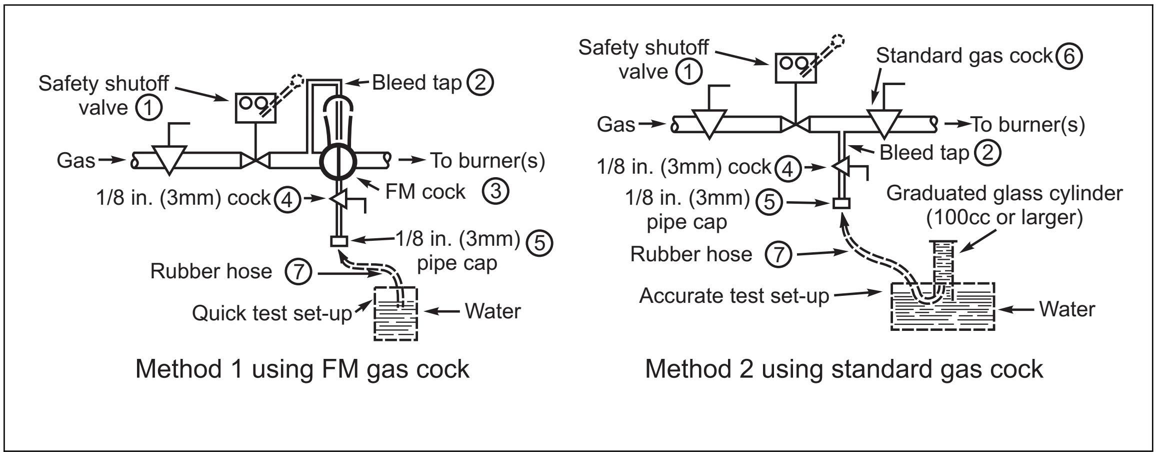

Fig. 24. Two acceptable methods for maintaining periodic tightness checks for gas safety shutoff valves.

Close FM cock 3 (method 1) or standard gas cock 6 (method 2).

Remove pipe cap 5 and attach rubber hose 7 to outlet of bleed tap 2.

Open cock 4 so as to vent any gas trapped in piping between valve 1 and cock 3 (method 1) or between valve 1 and cock 6 (method 2). Then hold outlet end of hose just barely under the surface of some water in a small container (can, bottle, etc.), and observe if bubbles appear. If no bubbling occurs, safety shutoff valve may be reported bubble-tight.

If bubbling occurs and continues at a rate of more than one bubble per second through a ¼ inch (6 mm) tube, the safety shutoff valve should be immediately cleaned and overhauled or replaced. However, it may be desirable to accurately measure the leakage rate beforehand: (a) fill a graduated glass cylinder with water and invert it in a large container of water; (b) insert end of hose in end of cylinder, and measure time interval required (seconds) to displace any given number of cubic centimeters of water displaced by seconds required; (c) if leakage rate exceeds 400 cm^3/hr, which corresponds to 0.014 ft^3/hr, valve should be immediately cleaned and overhauled or replaced. Repeat the test after installing the new or overhauled valve.

Important: At newly installed equipment, if this test discloses that the valve has leakage, it may indicate that fuel gas piping was not properly cleaned out so as to be free of weld particles, pipe chips, etc. Have pipeline and valve cleaned and then repeat test.

2.12.6.2 Dual Safety Shutoff Valves and Vent Assembly

The following additional methods for checking tightness will sometimes be found. Fig. 25 and 26 illustrate two acceptable arrangements. Each uses two safety shutoff valves in series with a vent line between. The vent line is controlled by a normally open (energize-to-close) valve.

At least one of the safety shutoff valves should be FM Approved.

Refer to Fig. 25.

1. Open manual cock C and, following normal start-up procedure, light burner.

2. With burner operating, push ''dead-man'' switch and hold. (This powers vent valve, directly holding the vent valve closed as long as the ''dead-man'' switch is held.) Note: This test may be invalid if the vent valve leaks or is not shut.

3. While holding the ''dead-man'' switch, rapidly close manual cock D. Safety shutoff valves will promptly close when loss of flame is detected by combustion safeguard. (If no combustion safeguard is provided, manually close the manually reset safety shutoff valve.)

4. Open manual cock D (to vent trapped pressure between second safety shutoff valve and manual cock D) and immediately reclose.

5. Open test valve at leak test tap B and observe for bubbles in water cup. (Bubbles observed will indicate that trapped pressure between the safety shutoff valves is leaking through the second safety shutoff valve.)

6. Once the condition of the second safety shutoff valve has been determined, release the ''dead-man'' switch and close test valve on leak test tap B. (Releasing the ''dead-man'' switch permits the vent valve to open releasing any remaining trapped pressure.)

7. Open test tap A and again push ''dead-man'' switch and hold, observing the water cup for bubbles. (This test may require more time as it will be necessary for any possible leakage to fill the manifold between the safety shut-off valves before leakage will be detected by the presence of bubbles in the water cup.)

Bubbles observed in the water test for either test tap A or B indicates that the safety shutoff valves are not bubble-tight and maintenance is indicated as needed.

Refer to Fig. 26.

1. Shut off power to combustion control panel. This will close valve #1 and valve #2 and open the vent valve.

2. Test valve #1 for tightness. Shut off lubricated plug cock No. 1, remove plug from ⅛-inch (3-mm) test connection, and open pet cock to bleed the line between main valve No. 1 and lubricated plug cock No. 1. Make bubble test.

3. Close valve in test connection, replace plug, and open lubricated plug cock No. 1.

4. Close supervisory cock. This will open main valve No. 1 and close vent valve. Main valve No. 2 will remain closed.

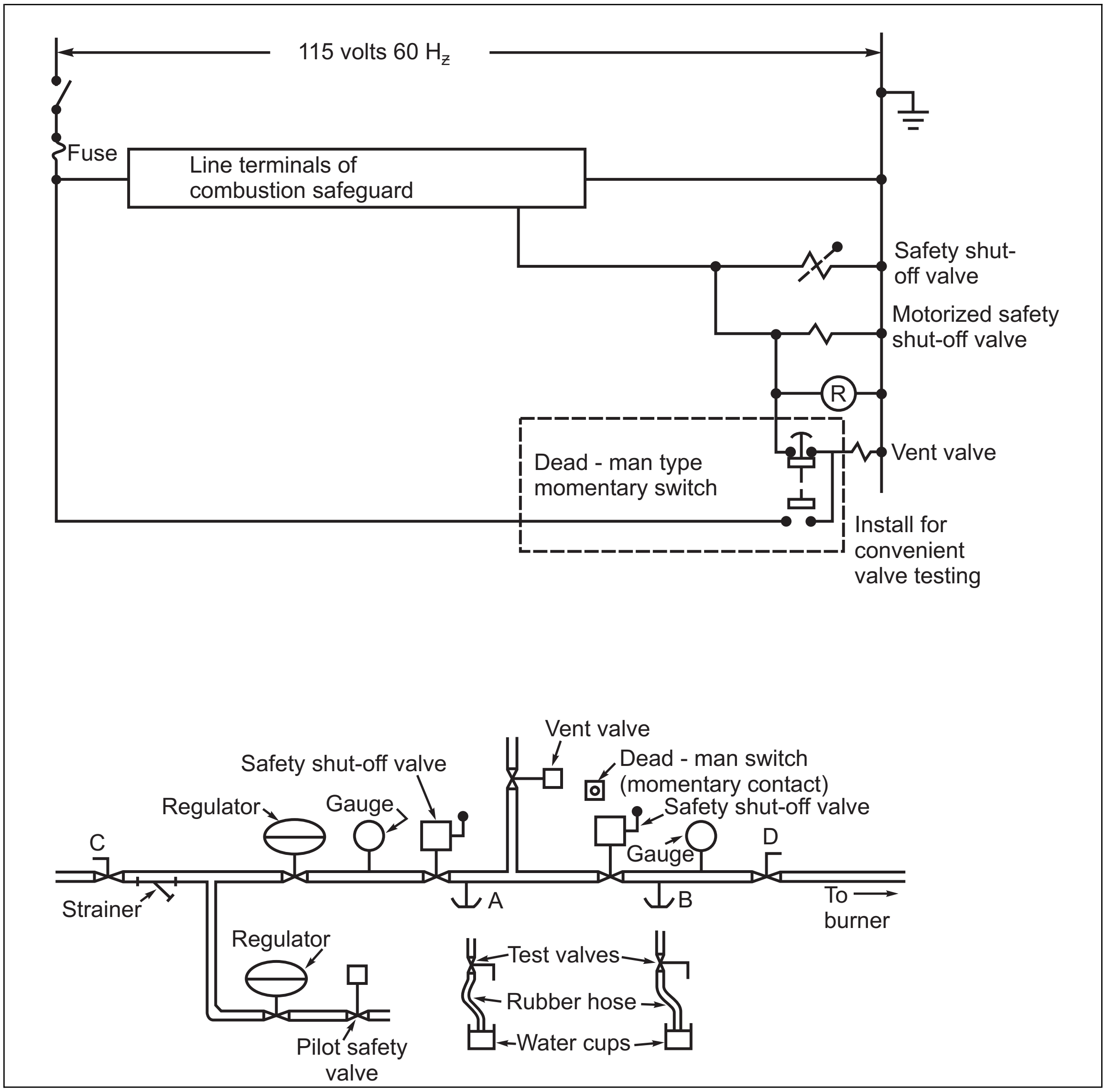

Fig. 25. Acceptable arrangements for checking tightness, where two safety shutoff valves are installed. In this arrangement, a deadman-type momentary switch is used on the vent valve.

5. Test main valve No. 2 for tightness. Shut off lubricated plug cock No. 2, remove plug at test connection, and open valve to bleed line between main valve No. 2 and lubricated plug cock No. 2. Make bubble test.

6. Close valve in test connection, replace plug, and open lubricated plug cock No. 2.

7. Test vent valve for tightness. Remove plug at test connection and open valve to bleed line between vent valve and supervisory cock. Make bubble test.

8. Close valve in test connection and replace plug.

9. Open supervisory cock. Control panel can now be energized to resume normal operation.

Combustion controls and safeguards, burners, and fuel air mixers are defined and described in several NFPA standards, such as No. 85 B, D, and E *Boiler-Furnaces* and No. 86 A, B, C and D *Ovens and Furnaces*. There is no known conflict with these standards.

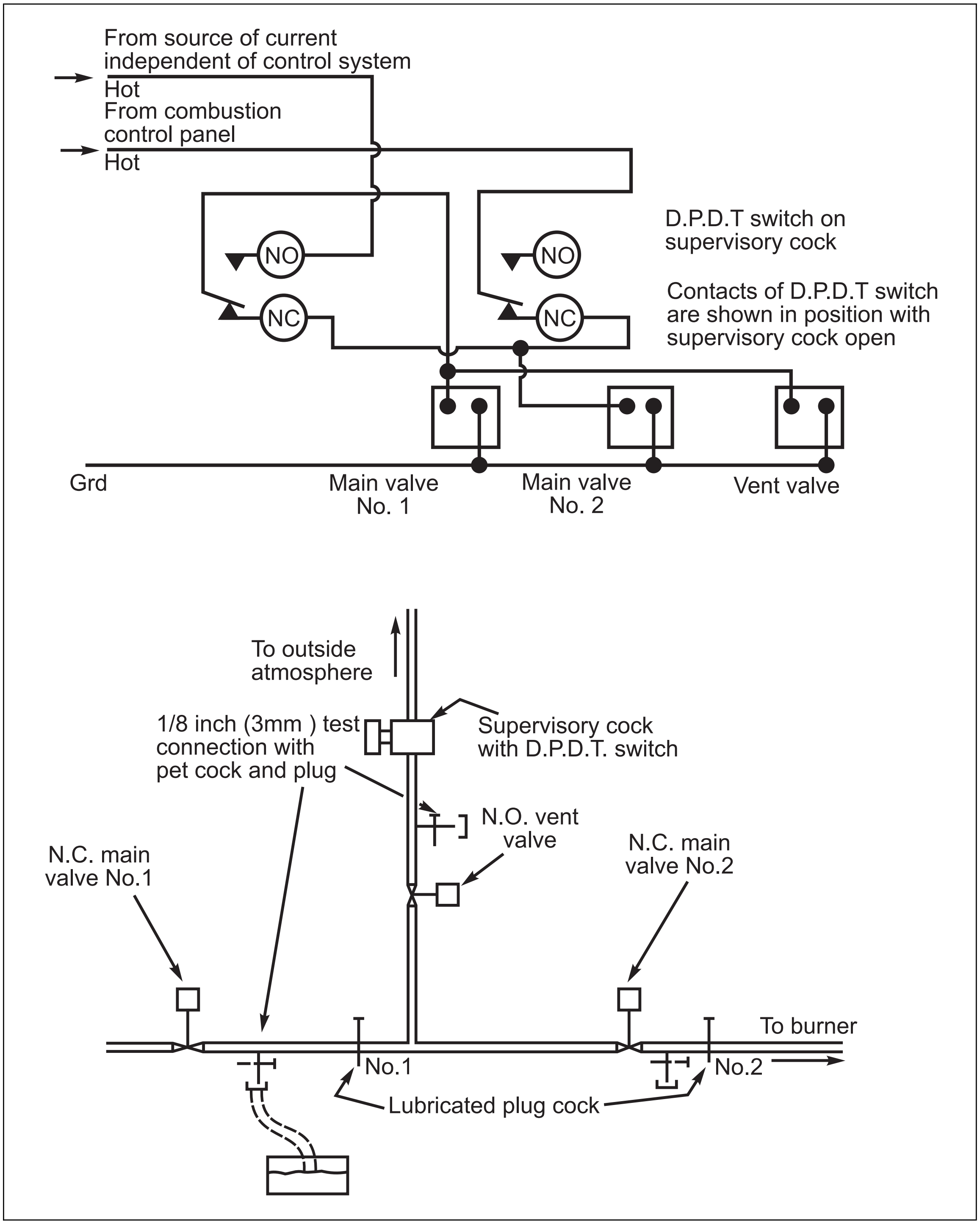

Fig. 26. Acceptable arrangement for checking tightness, where two safety shutoff valves are installed. In this arrangement, an electricalsupervisory cock is used on the vent line.