
Refrigeration, Heating & Air Conditioning

Gas Heat Fundamentals and Maintenance Procedures



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Bryan, Ohio 43506

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planned.*

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Contents

Cabinet	1
Temperature Treatment Section	1
Heat Sections	1
Cooling Section	3
Blower	3
Belt Drive Blower	3
Direct Drive Blower	3
Filter	3
Thermostat	3
Electrical System Components	4
Furnace Circuits	4
Blower Motors	4
Fan Control Switch	4
Downflow and Horizontal Units	5
Limit Control	6
Upper Limit Control	6
Additive Cooling Relay	7
24 Volt or Low Voltage Control Circuit	7
Transformer	7
Thermostat	7
Basic Maintenance Procedures	7
Maintenance Check Sheet	7
Maintenance Checksheet	8
Pre-Service Check	9
Thermostat	9
Blower Compartment Check	10
Nondisposable Slab (Polyurethane)	10
Disposable Slab (Fiberglass/Cardboard)	10
Direct Drive Blower	10
Post-Service Checks	12
Heat Section Checks	12

The Combustion Process

Servicing furnaces that use gas or oil as fuel is dependent upon understanding the combustion process. The shape, appearance and color of the flame tells a great deal about the condition of the components used to ignite and control the fuel. Often, minor adjustments will correct what might become a serious fault. Experience and knowledge gained through observation of different flames and their behavior will make the detection of potential trouble spots and their necessary correction much easier.

In order to produce combustion, three things are required:

1. **Fuel**—In the warm air heating business, this is normally natural gas, LP (Liquified Petroleum) gas or oil. (No combustion takes place in electric furnaces.)
2. **Heat**—Enough heat must be supplied to bring the fuel up to its ignition point; the temperature at which it will burn. This heat can be supplied by a previously lit small flame (a pilot) or an electric spark.
3. **Oxygen**—The combustion process consumes oxygen which is obtained from the surrounding air or air supplied to the combustion chamber by a small blower.

These three elements make up what is known as the “combustion triangle.” All must be present in order to have ignition and a flame. This can be demonstrated by inverting a glass over a lighted candle. The oxygen is consumed and the flame is smothered.

Measurement of heat: BTU (British Thermal Unit)

The amount of heat required to raise the temperature of 1 pound of water, 1 degree Fahrenheit.

Fuels are a form of energy. They follow the “Law of Conservation of Energy” which states that energy can neither be created nor destroyed but it can be converted into other forms of energy. When a fuel is burned, it is transformed into two other forms of energy—light and heat. This light and heat is flame.

There are two basic types of furnace flames: a “yellow flame” and a “blue flame.” They will be described and illustrated in terms of the light (appearance of the flame) and heat (temperature) produced.

Yellow Flames

The earliest gas burner was the open end of a gas pipe. The flame from this burner was bright yellow. Not only did the flame emit heat, but because of its luminous nature it also gave off light. The burner for this type of flame was commonly called a yellow or luminous flame burner. Examination of the yellow flame reveals a small blue area at the bottom of the flame near the opening (port) of the burner or pipe. The balance of the flame is a bright yellow.

Fuels are hydrocarbons (hydrogen and carbon atoms in varying combinations according to the fuel). When the fuel is ignited, the hydrogen burns with a bluish color. The remaining bright yellow luminous area of the flame is a characteristic of carbon at higher temperatures. The burning hydrogen at the base of the yellow flame heats the carbon particles until they glow and produce a large amount of light. This giving off of light is called **incandescence**. Since there is no oxygen within the flame, the carbon atoms complete their combustion only at the outer edges of the flame where combustion air is present.

Fuels are grouped according to their heat (BTU) content. When a specific quantity of a fuel is burned, only a certain number of BTU's will be generated. There are heat content values for natural gas, fuel oil, cherry wood or anything that can be used as a fuel.

Hydrogen burns at a fast rate because it combines easily with oxygen in the air. When hydrogen burns, it does not give off a large amount of heat. Carbon will burn at a rather slow rate but it gives off a tremendous amount of heat energy. Consequently, fuels that contain a lot of carbon atoms are also fuels with higher heat content values. The greater amount of carbon present in these fuels means a larger volume of combustion air is going to be needed for complete combustion of the fuel to take place.

Carbon Content	Fuel	Heat Content BTU's Vol.	Combustion Air
↓ Increasing ↑	1. Natural gas	1000 BTU Ft ³	10 Ft ³
	2. Propane gas	91,800 BTU gal	LP gas 18 Ft ³
	3. Butane gas	102,000 BTU gal	
	4. #2 fuel oil	140,000 BTU gal	215 Ft ³

The table shown above illustrates four fuels. They are listed by increasing carbon content. The chart correspondingly shows heat content values and combustion air requirements. These values assume the fuel is totally burned (compare combustion).

The two types of gas commonly used as a fuel are natural gas and LP. Most LP gas is a combination of Propane, Butane and Pentane. Products of combustion for LP gas are the same as natural gas, however, they vary in amounts.

For complete combustion, one cubic foot of natural gas requires ten cubic feet of air plus a flame for ignition. The products of combustion then would be one cubic foot of carbon dioxide (CO₂) and two cubic feet of water vapor, with approximately eight cubic feet of nitrogen. For complete combustion of LP, one cubic foot of LP gas requires 18 cubic feet of air plus a flame for ignition. These products of combustion would be 2 cubic feet carbon dioxide (CO₂) and 3 cubic feet of water vapor (H₂O), with 14 cubic feet nitrogen passing through the reaction unchanged. Heavier than air, LP is a very dense gas. Leaking LP gas has a tendency to drop to the floor. Because it has little odor and puddles near the floor. It is sometimes difficult to detect.

When a gas flame does not receive sufficient oxygen, the gas will not be completely burned (incomplete combustion). Incomplete combustion of gas results in the release of carbon dioxide (CO₂), water vapor (H₂O), aldehydes (acrid in odor and irritating to the eyes, nose and throat), and carbon monoxide (CO). Carbon monoxide is a deadly by-product of incomplete combustion.

Incomplete combustion occurs when a part of a yellow flame is cooled below its ignition temperature. Impingement on (touching) a cold surface such as the bottom of a cooking pot will cool the flame. When incomplete combustion results from impingement of the yellow flame upon a cool surface, the semi-solid carbon particles contained in the flame are cooled and will not burn completely. The black deposit on the bottom of the pan is called soot. Any time that soot is observed on or in fuel burner furnaces, it indicates incomplete combustion. This is caused by some part of the flame being chilled below its ignition temperature or lack of sufficient oxygen to insure complete combustion.

Remember that only carbon dioxide and water vapor (plus the nitrogen that passes through the flame unchanged) should be the

by-products of combustion. A yellow flame needs a large area in which to burn, therefore its use is restricted. Yellow flame burners are not used on modern gas-fired furnaces.

Gases			
Gas	BTU/CU FT.	Specific Gravity	Pressures
Natural	950 - 1,125	0.65	3-1/2" to 4" w.g.
Manufactured	500 - 550	0.45	1" to 2-1/2" w.g.
Mixed	700 - 900 to mixture	Varies according	3" to 3-1/2"

LPG			
Gas	BTU/CU FT.	Specific Gravity	Pressures
Butane	3,200	2.01	11" to 14"
Propane	2,500	1.52	11" to 14"

Blue Flames

In 1855, Robert Wilhelm Von Bunsen discovered that an entirely different combustion process resulted when part of the air required for combustion was mixed with the gas before igniting it. So significant was his discovery that the burner he designed was named in his honor and called the Bunsen Burner. Its main operating characteristic is that it mixes part of the air needed for combustion with the gas before ignition. The flame from the Bunsen Burner is altogether different from that of the yellow flame burner. It is blue, much smaller in size, higher in temperature, non-luminous and easily adjustable. Because of the color of the flame, the Bunsen Burner is called a Blue-Flame Burner.

The flame produced by the Bunsen Burner consists of several parts, the most prominent being the bright blue inner core. Around this cone is an outer mantle or shroud, much less brilliant but also blue.

In a laboratory-type Bunsen Burner, gas and air enter the burner tube at the bottom. The air that enters with the gas at the bottom is called **primary air**. This air can be metered to the burner in controlled amounts by a slide shutt at the base of the burner. Approximately 50% of the air necessary for combustion is mixed with the gas before the mixture is ignited at the burner port. The remainder of the air necessary for combustion is supplied from around the flame and is called **secondary air**.

With the addition of primary air to the combustion process, the resulting blue flame is smaller than a yellow flame. The blue flame is more concentrated (smaller and faster burning) and has a higher temperature than the yellow flame. The amount of heat (BTU's) produced by both flames will be equal if equal amounts of gas are burned.

Combustion in a Bunsen Burner flame occurs in two distinct and well-defined zones. Oxygen, contained in the primary air, first combines with gas (hydrocarbons). The initial combustion of this mixture takes place on the extremely thin surface of the bright blue inner cone. The combustion process using primary air takes place only on the surface of the bright blue inner cone. The mixture of air and gas contained inside the bright blue cone is composed of unburned gas and primary air. The combustion process using secondary air takes place on the surface of the outer shroud. There is very little illumination from a blue flame. Absent in a correctly adjusted Bunsen Burner flame are the semi-solid carbon particles that are present in a yellow flame. Because there is enough oxygen present in the primary and secondary air to react with all of the

carbon contained in the gas, the carbon remains in a gaseous state throughout the combustion process.

If there is an insufficient amount of primary air to the Bunsen burner flame, there will not be enough oxygen available to react with all the carbon. Some of the carbon will form semi-solid particles. These carbon particles become incandescent and appear as a yellow tip on the outer cone of the blue flame. Complete restriction of the primary air in a Bunsen Burner will result in a yellow flame as described earlier.

1. **Excess supply of primary air.** When this occurs, the flame will be distorted and will lift away from the burner port. The flame will make a short blowing noise and could burn itself out.
2. **Lack of secondary air.** Even though the primary air adjustment is providing a sufficient amount of primary air, incomplete combustion will result from a lack of secondary air. This is because the outer shroud does not have enough oxygen to support combustion.
3. **Inner cone impingement on a cool surface.** If the bright blue inner cone impinges on a surface which is cooler than its ignition temperature, temperature is reduced, removing one of the basic requirements to support combustion—heat.

Impingement by the outer mantle of a blue flame on a surface cooler than its ignition temperature will not interfere with the combustion process of the fuel. This is because the heat from the inner cone maintains the temperature required for combustion and no semi-solid carbon particles are formed. Soot, aldehydes and carbon monoxide will not be produced by an impinged outer mantle of a blue flame. However, impingement of the blue flame should be avoided because a flame directly hitting a metal creates hot spots. These hot spots can result in weakened areas, sometimes called metal fatigue.

Blue flames are adaptable to many appliances such as stoves water heaters and gas furnaces.

The Products of Incomplete Combustion are as Follows:

1. Carbon Dioxide (CO₂)
2. Water Vapor (H₂O)
3. Carbon Monoxide (CO)
4. Aldehydes (irritates eyes, nose and throat)
5. Soot (unburned carbon)

The Products of Complete Combustion are as Follows:

1. Carbon Dioxide (CO₂)
2. Water Vapor (H₂O)
3. Nitrogen (that passes through the flame unchanged)

Air from Combustion and Ventilation

A supply of air is essential to a gas appliance. See Figure 1. Proper venting action cannot be maintained unless there is ample air at the draft hood. Normally, the air is supplied by infiltration through cracks around doors and windows. In some instances, especially in new houses of tight construction, it is necessary to provide special means for supplying air to the appliances.

Outside air openings or openings to ventilated areas are required when appliances are enclosed in a special room; in multi-story vent installations where the appliances are separated from living spaces; and in basementless homes where appliances are installed in a closet or small utility rooms.

For each 1,000 BTU of gas burned, there may be up to 30 cubic feet of air required for combustion air, draft hood dilution air and general ventilation of the space occupied by the appliance. Range hoods and exhaust fans further increase the need for air. Supplying the total air requirements for ventilation is as important as the venting system itself.

Make-up air to be removed from a dwelling by exhaust fans should not be drawn from the same space that the combustion air for an appliance is drawn. Return air, which is the air returning for reheating by a forced-air furnace after circulating through a house, should be isolated from the combustion air space as well. If not, in either of these two cases, the possible lowering of pressure in the combustion air space can cause the appliance draft to be disturbed.

Confined Spaces

A room in which appliances are installed must be considered as confined regardless of size if a source of air supply is not directly available. Figures 2, 3, 4, 5 and 6 represent different methods of supplying air to different situations of a confined space. The sizing and location recommendations shown in the figures are based on information contained in NFPA No. 54.

Figure 2—Providing all ventilation air from inside building

Of the two ventilating air openings shown in Figures 2 to 6, one opening should be located within 12 inches of the floor and the other within 12 inches of the ceiling. Even for short appliances, the space between the louvered areas should never be less than 3-1/2 feet. If connected with ducts, the cross-section area of the duct shall not be less than the free area of the louvered area.

Figure 3—Providing all ventilation air from outside building

Figure 4—Providing all ventilation air from ventilated attic

Figure 5—Providing ventilation air from crawl space with air outlet into attic

Figure 6—Providing ventilation air from inside; dilution air from outside

Figure 7—Furnace located in a confined space

Basic Gas Heating Units

In this next section, the student will be exposed to the basic component parts of a gas fired heating unit. Below you will see a gas fired furnace that has been “cutaway” to reveal the basic

component parts. These components will be discussed individually and in relation to the whole unit.

Design of Heat Exchangers

In a gas furnace, combustion takes place inside a heat exchanger. Air passing over the outside surfaces of the heat exchanger absorbs heat from the flame. Most heat exchangers are usually made of cold rolled steel, although some are made of cast iron. Sometimes a heat exchanger will have a vitreous enamel coat to protect it from toxic elements in the air. The water vapor that is a product of combustion can chemically react with these elements producing acids that attack and corrode the metal. Halogenated propellants in aerosol cans are an example of this. The shape of a heat exchanger is designed so that in normal operation, expansion and contraction of the metal will not cause fatigue of the steel, which could result in a rupture or crack.

Oblique design of the exchanger tubes causes the hot gases inside the heat exchanger to turbinate, changing direction and velocity seven times, providing faster and more efficient heat transfer to system air.

Dovetailing and scientifically spacing of exchanger tubes assures maximum delivery of conditioned air to living spaces, summer or winter.

The heat exchanger is usually divided into several sections (clam shells) to gain more heating surface. At the bottom of the heat exchanger is a cavity designed to accept burners. As the gas is burned in the heat exchanger, the products of combustion go up through the inside shell, collect at the top and are directed toward the vent. Air from the conditioned space is circulated over the heat exchanger. As it wipes across the surface, it is heated and delivered back to the conditioned space to warm the room. Most gas furnaces are designed to have somewhere between 45° and 100° temperature rise of the air that crosses the heat exchanger. If air enters the furnace at approximately 69°F, it could leave the furnace at approximately 160°F.

Design of Burners

As was noted, gas burners fit into the cavity at the bottom of the heat exchanger. The number of burners will vary according to the size of the furnace. There are many different styles and shapes of burners. The burner pictured has one row of continuous ports and is called an atmospheric gas burner. A mixture of both air and gas enters the burner, mixes and is ignited on the surface of the ports.

In order to burn gas completely, it is necessary to supply primary air and secondary air. Primary air is that air which is sucked into the venturi tube (see drawing) as a result of the aspirating (suction) of the jet of gas as it shoots across through the throat of the venturi (see drawing). None of the normal atmospheric type gas burners get sufficient primary air for complete combustion. Some additional air is needed. Secondary air is that additional air needed for combustion which comes in around the outside ports. The primary air is mixed thoroughly with the gas inside the burner head, so the gas-air mix that is delivered out the ports is well mixed. Primary air starts moving into the burner the instant the gas is turned on. Secondary air is brought in by draft through the heat exchanger.

Draft is the movement of air and combustion by-products through the heat exchanger and up and out the chimney. It is not fully established in a gas furnace until the heat exchanger gets hot. In a gas furnace, there is a back draft diverter which completely breaks chimney draft at the vent outlet from the furnace (see drawing). The draft in a gas furnace is the function of the chimney temperature.

The above has been a description for those furnaces using natural gas. There are slight changes to adapt a furnace to use LP gas. This will primarily be in the orifice size. Kits are available to make this kind of changeover.

Main Gas Valve

Most modern furnaces today use a **combination gas valve** and pressure regulator but at this point only the main gas valve portion will be described. The function of the main gas valve is to control the flow of gas into the burners of the furnace. The automatic valve is opened and closed by the thermostat to allow gas to flow into the burners.

The valve contains a valve disc which seats on a valve seat and this is attached to an iron core plunger which is spring loaded to keep the valve disc on the valve seat. A coil with insulated wire is wound into a cylinder shape and placed at the end of the valve plunger. When current is applied to this coil, there is a magnetic field created inside of the coil which attracts the iron core plunger, overcoming the spring tension and lifting the plunger upward into the magnetic field. This action lifts the valve disc off the valve seat allowing gas to flow to the burners. When the holding coil is deenergized electrically and there is no further magnetic field, the spring forces the plunger down, sealing the valve disc to the valve seat. This effectively stops the gas flow to the burners and shuts them off.

Design of Pilot Burners

A pilot flame which burns consistently is used to ignite the flame on the main burners. A pilot is nothing more than a miniature gas burner. It also uses primary and secondary air for combustion. In order for one pilot to ignite several burners, a cross-over igniter is used. This is nothing more than a piece of metal used as a bridge between the burners. As gas comes out of the main burners, a portion of it flows through the slot of the igniter until it comes in contact with the pilot light. The alignment of the cross-over igniter is critical. A mispositioned burner can cause noisy, delayed ignition.

If for some reason the pilot light was extinguished and the burner ignition could not take place, raw gas could collect in the furnace to the extent that it would cause an explosion if and when it was finally ignited. Therefore, there must be a means of detecting when the pilot light is or is not lighted. This is accomplished by means of a thermocouple which is installed so the pilot flame constantly keeps the end of the thermocouple hot. Heat from the pilot flame on the thermocouple actually generates a minute amount of electricity measured in millivolts. This small amount of electricity is enough to hold open a small pilot valve which permits the gas to enter the burners. If the pilot flame goes out, the pilot valve closes stopping the flow of gas to the burners. The electrical operation of this safety device will be discussed later.

Pilot Safety Device Circuit

The ignition pilot is installed near the burners in the heating unit for the purpose of providing a safe means of igniting the gas at the burners. The ignition pilot is constantly supplied gas from the combination gas valve and once lit, should be on all the time. It is obvious that it is absolutely necessary that the pilot light be on before the main burners are fed gas from the main gas valve. This is accomplished by the **pilot safety device circuit** which is a millivoltage power supply. Therefore, the other very important function of the standing ignition pilot flame is to produce heat energy that is converted into a very small amount of electrical energy. The device used to make this conversion is called a **thermocouple**.

The thermocouple is made by two wires of dissimilar metal that are welded together at their ends, making **junctions**. By heating only one of the junctions with a flame while the other junction remains cool, a very small electric voltage is generated and a small current will flow through the connected wires (conductors).

The junction that is heated is the **hot-junction** and the other junction is the **cold junction**. The amount of voltage generated by the thermocouple depends on the **temperature difference** between the **hot** and **cold** junctions, and will vary as the temperature difference varies.

Note that the cold junctions are connected to a load by conductors, thus we have a **complete electrical circuit** (a source of electrical energy; a conductor from source to load; a conductor from load back to the source). The thermocouple converts **heat** energy into **electrical** energy in millivolts. **Milli** means one-thousandth ($1/1000$). Millivolt means $1/1000$ of one volt, i.e., 3 millivolts - $3/1000$ - .003 volts.

Refer to thermocouple electrical drawing and note the parts that make up the thermocouple. Metals "A" and "B" are welded together forming the hot junction. The **inner conductor** is a wire that leads to one side of the load connection end of the thermocouple. Over the entire length of the inner conductor is an insulator. Its purpose is to keep the inner and outer conductors separated (prevents short-circuiting). The **outer conductor** in the form of a tube that surrounds the insulation and inner conductor, it too leads to the remaining side of the load connection end of the thermocouple.

In order for the thermocouple to properly generate electricity the pilot flame must envelop the **hot junction tip** from $3/8"$ to $1/2"$. When the pilot flame is not burning or is misapplied, the generation of electricity will be insufficient or will stop. By electrically connecting the load connection end of the thermocouple to an electro-magnet (similar to that used to operate the automatic main gas valve) which is powered by millivoltage, an automatic main gas valve can be "opened" and "closed". This automatic gas valve is the safety shut-off mechanism of the combination gas valve.

The drawing shows the safety shut-off in the "closed" position. The safety is located upstream of the automatic main gas valve. When the electro-magnet is de-energized, the closing-spring forces the valve disc to "seat", preventing gas flow into the remainder of the combination gas valve parts.

The electro-magnet is energized which means that it is "safe" to let gas flow to the burners in that the pilot flame is burning properly. Therefore, the gas will be safely ignited. In order to light the pilot,

push in and hold down the depression plunger while igniting the pilot flame with match. Continue to hold down the plunger until the thermocouple hot-junction generates sufficient millivoltage, the safety will be held open. Release depression plunger and the electro-magnet will hold the valve “open”.

The electric main gas valve cannot be opened unless the gas pilot is lit and the flame sufficient to light the main burner. The pilot sensor or thermocouple proves both the existence of the pilot flame and its size.

Bard provides 100% safety shut-off on both their natural and LP gas furnaces. Liquefied Petroleum gas (LP) requires 100% safety shut-off and even though it is not required by code on natural gas units, Bard believes it is an extra safety feature. On an LP unit, when the pilot flame goes out the pilot valve must close, preventing any pilot gas from entering the heat exchanger. The reason is that LP gas is heavier than air and unlike natural gas, will not dissipate up the flue. Instead it will puddle in the bottom of the heat exchanger causing a hazardous condition when an attempt to relight the pilot is made.

Electronic Pilot Ignition Systems

The electronic pilot ignition system (sometimes called an intermittent ignition device) is designed for use in standard residential-sized gas furnaces. This system has several energy conservation features. Gas is saved because the electronic pilot ignition eliminates the continuous pilot burner flame. The pilot flame is ignited by electric spark and burns only when there is a call for heat. This ignition system also ranks high in convenience and reliability. If the pilot flame should be blown out, the pilot will automatically relight if the call for heat still exists.

Standard intermittent ignition system components include the Intermittent Pilot Module and Intermittent Pilot Dual Valve Combination Gas Control.

Intermittent Pilot Control Module

The control module contains the electronic components of the system, and also serves as a central wiring panel for the external controls. When powered by a 24V, 50/60HZ transformer and controlled by a suitable thermostat or controller, it performs the following functions.

1. Performs a safe-start check by checking for a false flame condition on startup.
2. Generates a potential of 30,000V (open circuit) for spark ignition of the pilot burner.
3. Opens the pilot valve.
4. Discontinue ignition spark when the pilot flame is established. The control module provides safety lockout if the pilot fails to ignite within the pilot flame-establishing period.
5. After proof-of-pilot flame, opens the main valve.
6. On a power loss, shuts down. When power is restored, it will begin a new startup.
7. On a loss of flame, the main gas is shut off and starts trial for pilot ignition.

Pilot Burner Igniter-Sensor

The pilot burner igniter-sensors consist of a pilot burner, ceramic insulator, combination spark electrode/flame rod, and a ground strap. Flame sensing and pilot ignition functions use a single rod. The ground strap extends over the tip of the insulator rod, forming the spark gap. The end of the rod is positioned in the pilot flame, with the pilot burner target and ground strap serving as a ground area.

When the burner is lit, the flame is detected through the principle of flame rectification. Flame rectification is a process of converting alternating current (ac) into direct current (dc). A voltage is applied to the flame rod. When the burner ignites, the gas molecules between the flame rod and ground become ionized, and are able to conduct an electrical current.

Current through the flame flows mostly in one direction because of the size difference between the electrode and ground areas. The overall result is a pulsating direct current. The flame monitoring circuit in the module will only respond to this dc current to prove the presence of the flame.

Functions and Operation

The control module performs the following basic functions. Opening and closing the first (pilot) operator, providing a spark for igniting the pilot, sensing the pilot flame, shutting off the spark, and opening and closing the second (main) operator. These functions occur in 2 stages.

First Stage—Trial for Pilot Ignition

On every call for heat (system start), the module performs an internal safe start check. A system start is prevented if the check shows that a flame simulating condition is present.

During a normal start, the module opens the first operator in the gas control. This allows gas to flow to the pilot burner. Simultaneously, the electronic spark generator in the module produces a 30,000 volt spark pulse output (open circuit). This voltage produces a spark at the pilot burner igniter-sensor rod, igniting the gas flowing around the electrode.

If the pilot flame is not detected during the trial for pilot ignition, the module will continue trying for pilot ignition until a flame is established. The module contains a safety lockout timer to limit the trial for pilot ignition period.

Second Stage—Main Burner Operation

When the pilot flame is established, a flame rectification circuit is completed to the burner ground. The module flame sensing circuit detects the flame current and shuts the spark generator off. At the same time, the second operator (main) is opened in the gas control, allowing gas flow to the main burner. The pilot flame ignites the main burner conventionally. On the module, the flame current also holds the safety lockout timer in the reset, or normal, operating condition.

Safety Lockout Timer

The safety lockout timer circuit starts timing the moment the trial for pilot ignition starts. When the timing period runs out, the trial for pilot ignition ends, and the control module goes into lockout.

