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Industrial application of natural gas

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1. Introduction to General Aspects of Natural Gas Production and Consumption Worldwide and in Latin America

The world's natural gas reserves are concentrated in a small number of countries representing over 70% of total reserves. Distribution by country is shown below in figure 1.1.

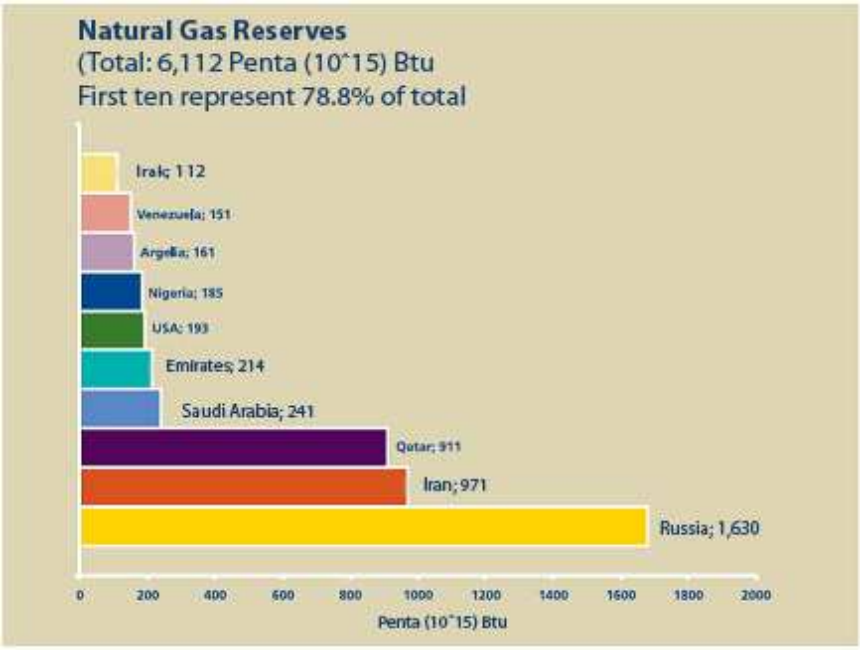

Fig. 1.1 Natural Gas Reserves. Reference (2)

Natural gas reserves are concentrated in the Middle East (40%), primarily Iran (16%) and Qatar (14%). After the Middle East, the world's largest reserves are located in Russia (27%); Africa (8%), above all Nigeria (3%) and Algeria (2.4%), and in the Asia-Pacific Region (8%).

In comparison with the regional distribution of oil reserves, natural gas reserves are more diversely distributed.
Major natural gas producing regions include North America (27%), led by the United States (19%); the Former Soviet Union (26%), where the world's largest production company is located, Russia (20% of total worldwide production in 2008); and the Asia-Pacific Region (13%).
The largest natural gas consumers are the United States and Russia (approximately 22% and 14%, respectively, of total worldwide consumption in 2008). They are followed by Canada, Japan, the United Kingdom, China and Germany, each representing nearly 3% of worldwide consumption.
In terms of the international gas trade, natural gas traded between different countries in 2008 represented over 26% of worldwide production and demonstrates significant potential for growth, particularly as regards LNG (liquefied natural gas). In 2008, 19% of the gas traded internationally was sold through pipelines and 7% as LNG. Japan and Spain are the two largest importers of liquefied natural gas.
As regards South America, the largest reserves are found in Venezuela, Bolivia, Columbia, Argentina and Peru, with a total of 6500 bcm. The countries with the highest consumption are Argentina and Brazil, with a total of 55 bcm/year.
The international natural gas trade in this region is carried out between countries which are interconnected via gas pipelines, such as Argentina with Bolivia, Chile and Uruguay and Bolivia with Brazil and Argentina. For geopolitical reasons and due to differing economic policies, a more universal natural gas transportation system which would allow gas to be traded throughout the continent has not been developed. Multiple ports with liquefied natural gas regasification terminals have been built to meet demand, reaching different regions of the world where it is injected into the local distribution networks of each country. Graph 1.2 shows gas pipelines and liquefied natural gas reception ports in the Southern Cone.

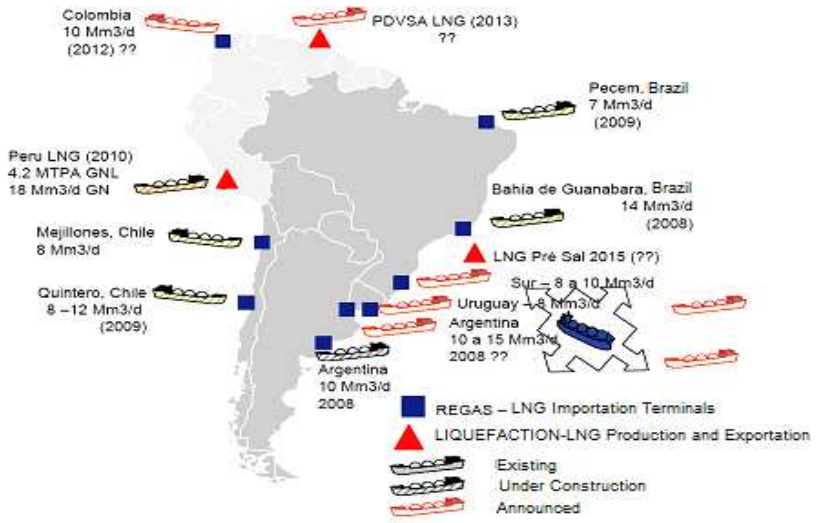

Fig. 1.2. Liquefied Natural Gas Reception Terminals in South America. Reference (3)

2. Properties of Natural Gas and their Impact on Industrial Applications

Natural gas is a fossil fuel found underground, generated by the decomposition of organic matter trapped between rocky strata of the Earth's crust. It is extracted from subterranean deposits of gas, oil and gas or condensate, so it may be obtained alone or together with oil.

2.1 Composition of Natural Gas

Natural gas is a fuel found in deposits in its gas phase. It is colorless and odorless, non-toxic, lighter than air and does not contain olefins (hydrocarbons produced during the process of destructive distillation or reforming). It is constituted primarily by methane (CH4), usually in a percentage of over 85% of volume. The remaining percentage is composed of higher order hydrocarbons such as paraffins or isoparaffins. It also contains water vapor at varying degrees of saturation, or condensed water. It may also contain carbon dioxide, nitrogen, hydrogen sulphide and helium, among others. Table 2.1 shows the typical composition of Argentine natural gas originating from the Northeast Basin.

If the gas contains enough carbon dioxide to cause its calorific value to fall below the values specified in sales contracts it must be subjected to a process to extract this element, in addition to hydrogen sulphide or other sulfur compounds causing it to be highly corrosive and inadmissible for certain industrial applications.

Once extracted, the gas is treated for the purpose of removing undesirable components such as water vapor, carbon dioxide, sulfur compounds, condensable hydrocarbons and solid and liquid particles. This process is known as "gas drying"; therefore, dry gas is gas which has been dehydrated and subjected to a process in which condensable hydrocarbons such as propane, butane pentanes and higher hydrocarbons have been extracted. The amounts which may be recovered from the abovementioned components depend on the original composition of the natural gas and the process used to dry it. Dry gases are also known as lean gases, and wet gases are also known as rich gases.

Component	Identification	Unit	Value
Methane	C_1	mol%	91.15
Ethane	C_2	mol%	5.56
Propane	C_3	mol%	0.16
Carbon Dioxide	CO_2	mol%	2.39
Nitrogen	N_2	mol%	0.72
Other		mol%	0.02
Water	H_2O	mg/Sm^3	14.59
Sulfuric Acid	H_2SO_4	mg/Sm^3	0.65
Total Sulfur	S	mg/Sm^3	1.13

Table 2.1, Typical Elemental Composition of Natural Gas

2.2 Elemental Analysis of Natural Gas

Elemental analysis of a fuel allows the elements composing to be identified, making it possible to determine the stoichiometric ratio as well as the products associated to the combustion process. Table 2.2 shows a comparison of the typical elemental analysis of the main fuels used in the industrial sector.

Fuel	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ashes
Natural Gas	76.0	23.2	0.0	0.8	0.0	0.0
Liquefied Petroleum Gas	81.0	19.0	0.0	0.0	0.0	0.0
Fuel Oil 6	86.6	10.6	0.4	0.1	2.0	0.1
Fuel Oil 5	86.1	12.0	0.1	0.1	1.7	0.0
Fuel Oil 2	86.3	13.1	0.0	0.0	0.6	0.0
Kerosene	85.9	13.6	0.0	0.0	0.2	0.0
Firewood	45.1	5.6	43.5	0.1	0.1	5.6
Sub-bituminous Coal	49.0	6.1	30.0	0.6	0.3	14.0
Bituminous Coal	72.2	5.6	11.8	1.3	1.7	7.4

Table 2.2. Typical Elemental Analysis of Industrial Fuels (% of mass)

2.3 Properties of Natural Gas

a) Density

Table 2.3 shows the absolute densities of different liquid and gas fuels.

Fuel	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ashes
Natural Gas	76.0	23.2	0.0	0.8	0.0	0.0
Liquefied Petroleum Gas	81.0	19.0	0.0	0.0	0.0	0.0
Fuel Oil 6	86.6	10.6	0.4	0.1	2.0	0.1
Fuel Oil 5	86.1	12.0	0.1	0.1	1.7	0.0
Fuel Oil 2	86.3	13.1	0.0	0.0	0.6	0.0
Kerosene	85.9	13.6	0.0	0.0	0.2	0.0
Firewood	45.1	5.6	43.5	0.1	0.1	5.6
Sub-bituminous Coal	49.0	6.1	30.0	0.6	0.3	14.0
Bituminous Coal	72.2	5.6	11.8	1.3	1.7	7.4

Table 2.3. Fuel Density

b) Heat Value of Natural Gas

The heat value of a fuel refers to the amount of energy released during complete combustion of one mass unit of the fuel, with the fuel and oxidant at a reference temperature and pressure. The properties of each fuel affect heat value in that the fewer inert elements the

gas contains, the greater its heta value will be. As can be observed in Table 2.2, natural gas is a fuel with a high carbon and hydrogen content, making it the fuel with the highest heat value after pure hydrogen. Figure 2.4 shows a comparison of the calorific value of different fuels.

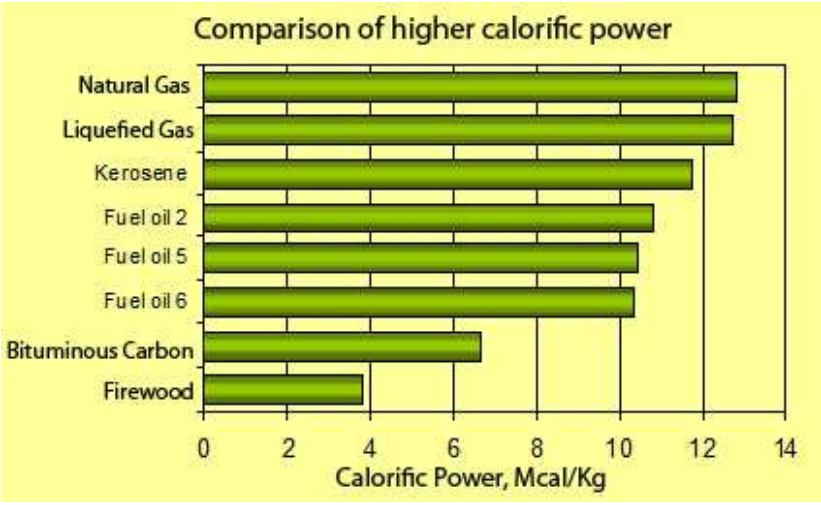

Fig. 2.4 Calorific value or Heat Value of different fuels.

However, the heat value of natural gas normally varies according to its content of inert elements or heavy hydrocarbons, resulting in lower or higher caloric value, respectively.

2.4 Interchangeability of fuel Gases

Two gases are considered interchangeable when, distributed under the same pressure, in the same network, feeding the same burners and without changes to regulation, they produce equivalent combustion results: calorific flow and flame behavior, regardless of the composition of the combustible gases.

The Wobbe index is the most frequently used indicator to establish criteria for the interchangeability of gases. It is defined as a quotient of the gross calorific value based on the square root of the relative density of the gas in relation to air under the same pressure and temperature conditions.

$W = PCS / \sqrt{d}$

Where:

GHV : gross heat value of fuel
d : relative density of gaseous fuel

When gases are interchanged, the value of the Wobbe index must be the same for both gases in order to ensure that the calorific value of the burner remains constant.

2.5 Characteristics of Natural Gas Combustion

Correct burning of natural gas requires the proper proportion of air and gas in order to achieve complete combustion. The stoichiometric amount of air needed for complete combustion is shown in Table 2.4 along with the amount of exhaust gases produced. In addition, characteristic combustion values of other fuels traditionally used in the industry are shown.

Fuel	A_e (a)	G_{ehe} (b)	G_{ese} (c)	G_{er} (d)	H_2O (e)	NHV (f)	W o (g)	Dv (h)	CO_2 (i)	E_a (j)
	Sm 3/kg				Kg/kg	Kcal/kg		[-]	%	
Natural Gas	12.9	14.2	11.6	14.5	2.09	11.500	14.846	0.6	12.2	2
Liquefied Petroleum Gas	12.2	13.3	11.2	13.5	1.71	11.400	8.875	1.65	13.5	2
Fuel oil 6	10.5	11.1	10.0	14.8	0.95	9.550	-	-	16.2	35
Fuel oil 5	10.9	11.5	10.2	14.8	1.08	9.900	-	-	15.7	30
Fuel oil 2	11.1	11.9	10.4	14.1	1.18	10.200	-	-	15.5	20
Kerosene	11.2	12.0	10.5	14.2	1.22	10.300	-	-	15.3	20
Firewood	4.0	4.7	4.0	8.7	0.50	3.500	-	-	20.9	100
Sub-bituminous Coal(m)	5.0	5.5	4.8	9.3	0.55	4.200	-	-	18.9	75
Bituminous Coal	7.6	8.0	7.3	13.6	0.50	6.200	-	-	18.4	75

Am 3: Volume measured in cubic meters under standard or normalized conditions

(a) Stoichiometric Air
(b) Wet Stoichiometric Exhaust Gasses
(c) Dry Stoichiometric Exhaust Gasses
(d) Real Exhaust Gasses considering characteristic operational air
(e) Mass of water generated per kg of burnt fuel
(f) NHV: Net Heat Value
(g) Wobbe Index
(h) Density relative to air
(i) Maximum or stoichiometric CO_2
(j) Excess of characteristic operational air
(k) Liquefied Petroleum gas (LPG) of the type that is commercialized in the Metropolitan Region of Chile
(l) San Pedro de Catamutún Carboniferous type (fuel analysis based on how it is received)

Table 2.4 Combustion Characteristic Values of Different Industrial Fuels

3. Characteristics of Natural Gas Flames and Combustion Products

The flame is the visible and calorific manifestation of the combustion process reaction. In practice, there are different types of flames which vary according to the mixture of fuel and oxidant. Given that the volume of air which participates in combustion is much greater than

that of combustible gas, it is ultimately control of air that which defines the shape and dimensions of the flame.

i) Without Prior Mixing (Diffusion).

This refers to a long but low-temperature flame. It is yellow in color, due mainly to the presence of free carbon which has reached only the temperature necessary to become incandescent without oxidizing. The fuel reaches only the first stages of oxidation, with low combustion and burning efficiencies, so it requires a longer reaction time in order to achieve complete combustion. It is appropriate for use in homes or larger combustion chambers.

ii) With Prior Mixing (Premixing).

Premixing improves the homogenization of the fuel and oxidant mixture in order to increase the amount of fuel burned, producing short flames of bluish color, at high temperature and with a highly defined geometry (Figure 3.3). If not enough oxidant is incorporated to ensure complete combustion, a second zone of colorless flame is produced, creating a plume which surrounds the blue flame.

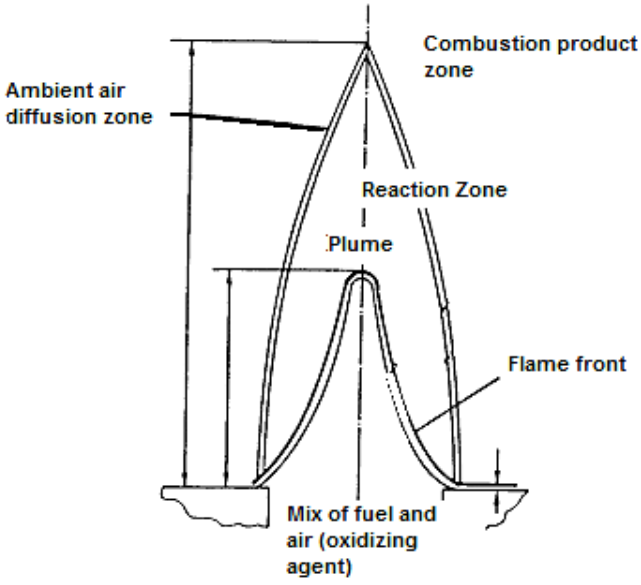

Fig. 3.3. Premixed Laminar Flame

a) Flame Temperature

Theoretical combustion temperature cannot be determined empirically, and corresponds to the temperature that would be reached by combustion products if the heat released during

stoichiometric combustion were used exclusively to heat them. This is known as adiabatic flame temperature. However, this situation never occurs in practice, due mainly to:

Heat transfer from combustion products to the surrounding environment.
Reduction of CO2 and H20 (vapor) in CO, H2 and O2, at temperatures above 1,700 ºC.

The adiabatic flame temperature of natural gas originating from Argentina is 2,020 ºC in the stoichiometric condition. This corresponds to 2,026 ºC for ethane and 2,059 ºC for propane. This natural gas temperature may increase if operating conditions are altered.

It is important to make the distinction between the adiabatic theoretical temperature of combustion and real flame temperature. The former is a set value (for specific combustion conditions) while the latter corresponds to the actual temperature reached during real combustion, which therefore will vary according to position.

Maximum flame temperature is reached in premixed combustion with air in excess of stoichiometric amounts. Usually, by pre-heating the mixture and/or air, flame temperature increases of 25 ºC to 40 ºC may be achieved. Figure 3.4 shows the temperature variation experienced by the mixture and combustion products as a function of distance from the burner head.

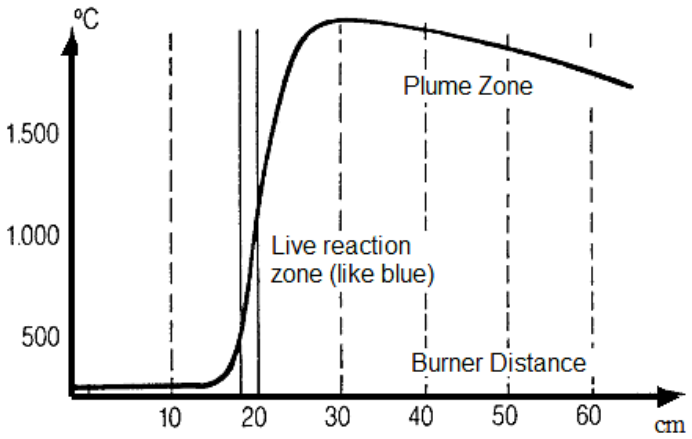

Fig. 3.4. Flame Temperature

b) Flame Speed

The flame front advances as the fuel mixture exits the burner head, producing combustion of the mixture. The reaction between the fuel and air may only occur at a certain speed. This speed depends on the reaction (chemical) and the degree of flame turbulence (physical). Thus, if the flame is turbulent, the mixture will burn more quickly. In addition, flame speed varies according to the fuel-to-oxidant ratio of the premixture known as the primary aeration rate.

Flame speed is an essential factor in proper combustion and better use of energy from fuel. Thus, it is necessary to have a stable flame front, achieved when the transport velocity of the reactants is equal to flame speed. If fuel is supplied at a higher speed than that of the flame, liftoff (movement forward) will occur. On the other hand, if the fuel is supplied at a lower speed than that of the flame, flashback (movement backward) will occur.

Other factors which also affect flame speed are the nature of the fuel, the presence of inert gases (nitrogen, carbon dioxide, etc.) and the temperature of the mixture (combustible gas – combustion air). Figure 3.5 shows flame speed for different combustible gases, as a function of the percentage of primary air in relation to theoretical air (stoichiometric air).

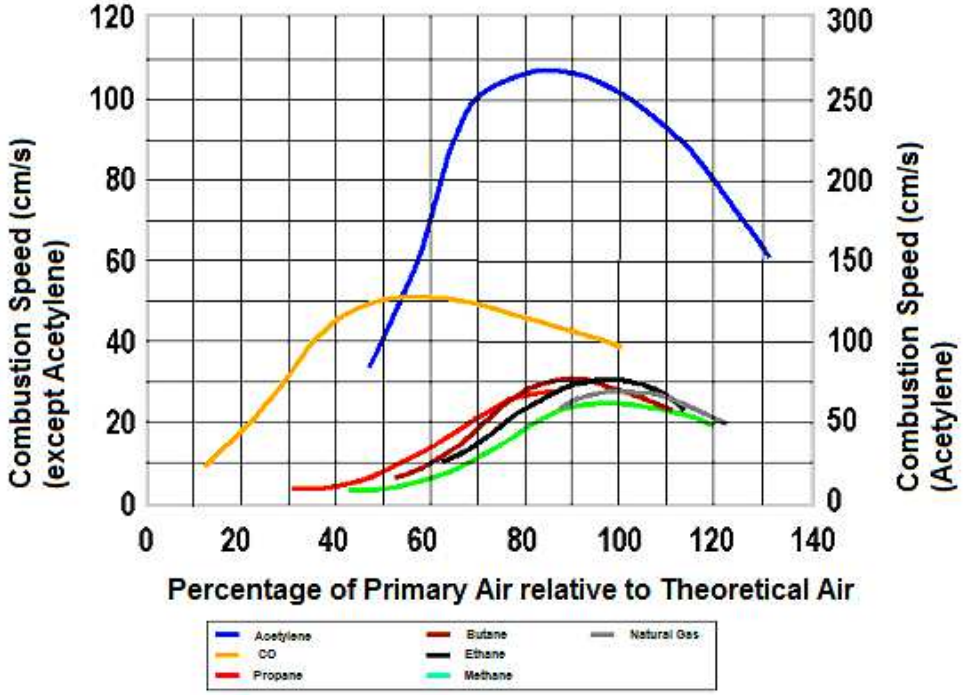

Fig. 3.5. Flame Speed [10]

c) Flame Stability

In order to keep the flame attached to the burner port, equilibrium must be reached between the exit velocity of the fuel-air mixture and flame propagation speed. Frequently, flame instability is the result of pressure variations in fuel supply to the burner or in combustion air:

Increase in fuel pressure. Generates increased pressure on the mixture and increased exit velocity, producing detachment of the flame or liftoff.

Decrease in fuel pressure. Generates a decrease in the exit velocity of the mixture, which produces flashback. This phenomenon is especially relevant to premix burners.

Fluctuations in combustion air supply, producing oscillating flames which cause strong pressure vibrations in the combustion chamber.

d) Inflammability Limit

Inflammability is related to the chemical energy of a mixture of combustible air and the minimum ignition energy; if the former is lower than the latter, it is impossible to produce a flame. This leads to the definition of inflammability limits.

Thus, the lower limit corresponds to a lean mixture situation, in which there is not enough fuel to achieve minimum ignition energy. Conversely, the upper limit (rich mixture) applies when there is not enough air for the combustion reaction to take place. Inflammability limits of some gases are shown in Figure 3.6.

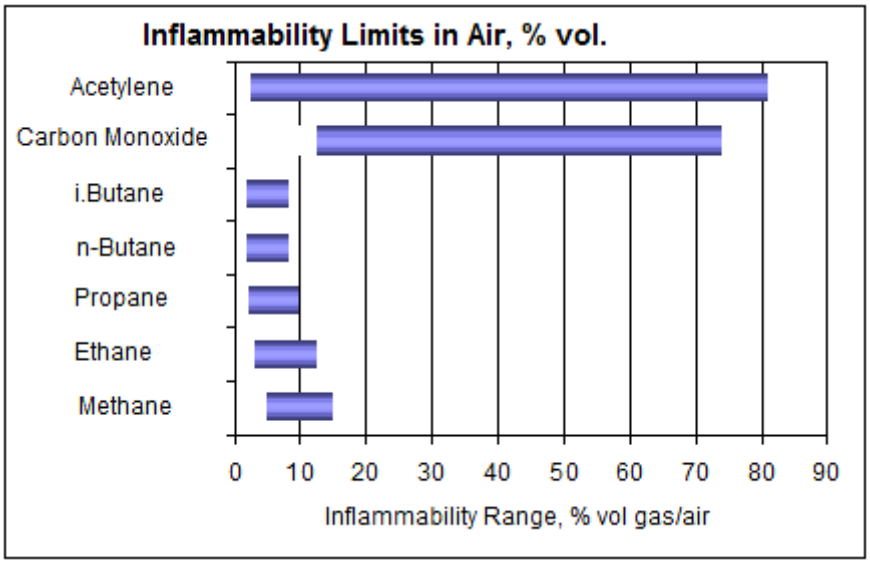

Fig. 3.6. Inflammability Limits of Combustible Gases

e) Flame Color

In complete combustion, the flame should exhibit a nearly transparent plume with a blue or blue-green cone in the middle, depending on the type of gas being burned (Figure 3.7). If combustion is incomplete the flame will be of a yellowish color, also depending on the environment in which the combustion reaction is produced.

Fig. 3.7. Color of a Natural Gas Flame

f) Flame Radiation

When the origin of the radiation is heat, energy is emitted only according to temperature and is known as thermal radiation. Radiation heat transfer occurs when energy is transported from one surface to another as electromagnetic waves, which propagate at the speed of light and do not require a physical medium to be transferred. Radiation heat transfer can be separated into:

Short-wavelength thermal radiation with wavelengths between 0.2 and 3 μm, characteristic of high-temperature radiation sources (T = 6000 ^{o}K) such as the sun or artificial lighting, and whose field includes part of ultraviolet radiation (λ<0.4 mm), all of the visible spectrum (0.4< λ <0.7 mm) and near infrared radiation (0.7< λ <3 mm), within which margin it emits 98% of energy.

Long-wavelength thermal radiation, also called irradiation, with wavelengths between 3 and 50mm, characteristic of ambient temperature radiation sources (T = 300^{o}K), such as environmental surfaces, and whose spectrum includes far infrared radiation, within which 97% of energy is emitted.

The radiation that can be produced by a flame depends on how luminous it is. An oil flame can radiate 3 to 4 times as much as a gas flame, due mainly to soot production in the flame which makes it luminescent. Although a gas flame may produce soot under certain conditions of mixing, the amount of radiation attained is still significantly lower than that of an oil flame.

However, given that the emissivity of gases from natural gas combustion is lower (Figure 3.8), the energy transferred in the radiative zone is also lower. Therefore, the gases that reach the convective zone have a lower temperature than the gases produced by the combustion of petroleum-derived fuels.

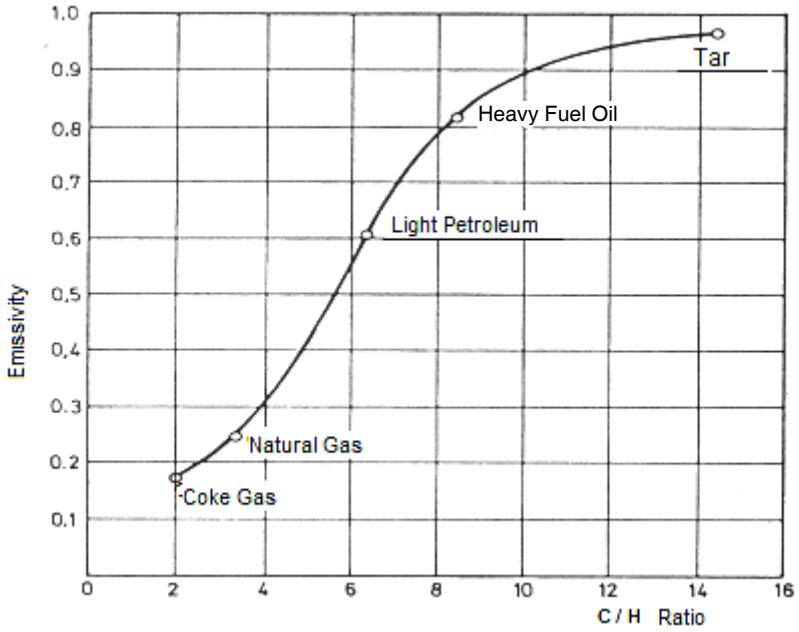

Fig. 3.8 Emissivity of Different Fuel Flames [1]

Thus, if heat transfer in the convective zone remains constant, the gases will exit through the stack at a higher temperature, which results in a loss of thermal efficiency of the equipment (as full use is not made of the energy contained in exhaust gases).

This is very important in terms of converting thermal equipment from oil to natural gas, for which purpose it is necessary to increase the convective heat transfer area. This shift in temperature profile must be taken into consideration for thermal equipment used for mineral fusion and cement furnaces.

4. Type of Burners Used in Industrial Equipment, Boilers and Furnaces

Proper fuel burning is necessarily connected to the technology designed and built in order to make better energetic use of the exothermal process produced.

4.1 Burner Definition and Functions

A burner is a set of mechanisms designed to allow for proper mixing of a fuel and an oxidant in order to produce a combustion chemical reaction with certain flame characteristics. For this reason, the functions of a burner are:

Allow for regulation of air and gas flows.
Ensure mass transfer or mixing of fuel (gas) with oxidant (air) in the correct ratio.

Carry out flame combustion with the dimensions and chemical and physical properties appropriate to the application, maintaining the heat transfer process.
Maintain flame stability.

The most frequently used oxidant is ambient air. However, depending on the application, it is possible to use hot air or oxygen-enriched air. Instead of air, it is also possible to use pure oxygen or combustion products with an elevated oxygen content. In order to make full use of the energy generated during the combustion process, the flame must be stable, without lifting off from the burner or flashing back. To prevent this from happening, there must be an equilibrium between the speed of flame propagation toward the unburned fuel and the exit velocity of this fuel.

Burners which operate using several different gases are called multi-gas, and those which operate using different types of fuel are called "mixed" or "dual", generally using a petroleum derivative (frequently diesel) as the second fuel. If the gas and the other fuel can be burned together, the burner employs what is known as simultaneous operation; if this is not the case, its operating method is known as alternating.

The combustion system used will depend on the type of application. The following are some examples of combustion systems:

Diffusion system, or separate delivery of air and gas.
Premix system, or external mixing of fuel and oxidant.
Atmospheric system, or air drawn into the burner by natural draft.
Forced system, or combustion air supplied by using an additional piece of equipment.

a) Diffusion System or Separate Delivery of Air and Gas

In this combustion system, mixing of fuel and oxidant is carried out in the burner itself, or as they flow toward the combustion chamber. The parameter that indicates the intensity of the mixture is the swirl number (Sx), corresponding to the ratio between the radial moment and the axial moment of the total flow in the burner.

Two types of burners use this combustion system:

When mixing is carried out in the burner head, the gas released into the combustion chamber already has the proper composition. The combustion reaction is quick, and the resulting flame is short and hot. This burner is characterized by a swirl number higher than one.

This system is characterized by generating high turbulence, which causes the reactants (gas and air) to mix quickly. This is induced using vanes or blades, which produce a rotating movement in the air current to encourage turbulence, as shown in Figure 4.1.

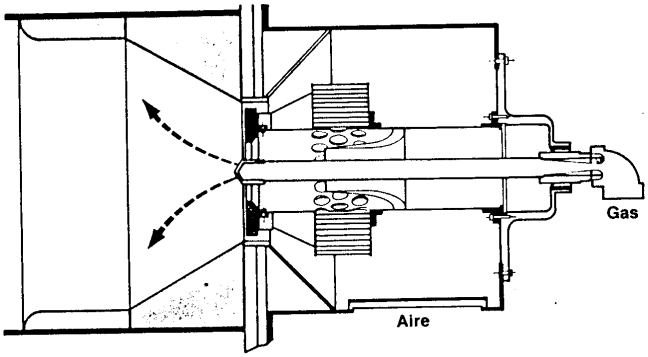

Fig. 4.1, Diffusion Burner with a Set Total Turbulence

In other burners, such as that shown in Figure 4.2, a plate is introduced into the path of air flow in order to stabilize it and encourage mixing with combustible gas.

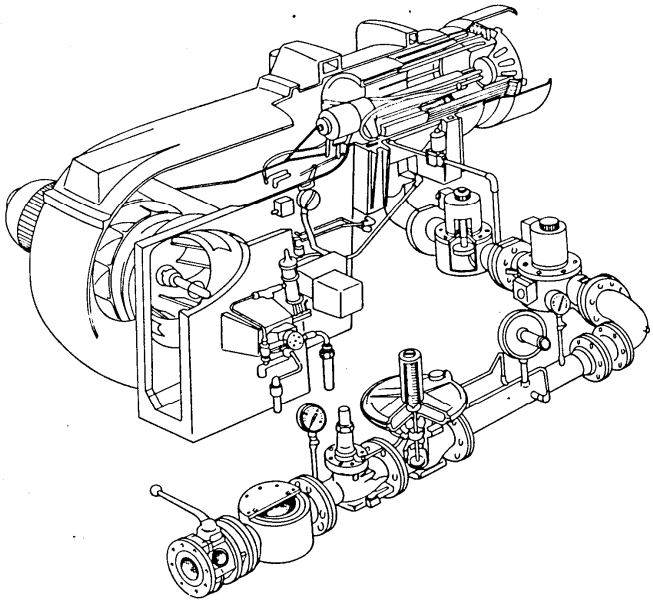

Fig. 4.2. Monoblock Burners with Gas Train and Regulation Unit

In other cases, such as in Figure 4.3, turbulence is not generated using vanes or mixing plates, but through use of converging or divergent flows.

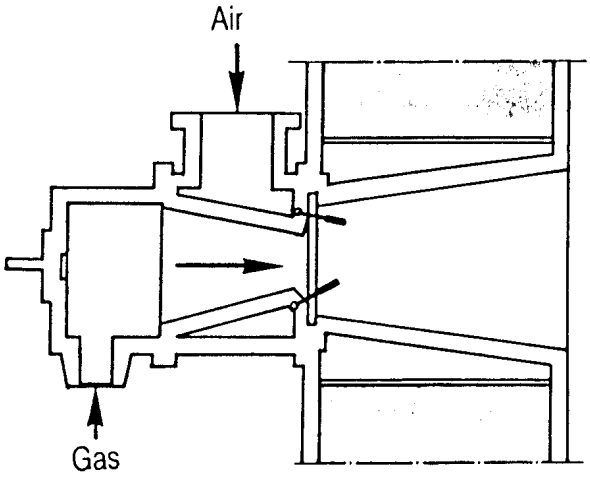

Fig. 4.3. Burner with Converging Air Current

In dysfunctional burners with a swirl number less than one, the flame obtained is long and very luminous due to the longer mixing time needed for fuel and oxidant.

In these low-turbulence burners, air and gas flows are mixed along the combustion chamber (Figure 4.4) and are used for processes in which heat transfer from the flame must be homogenously distributed throughout the space.

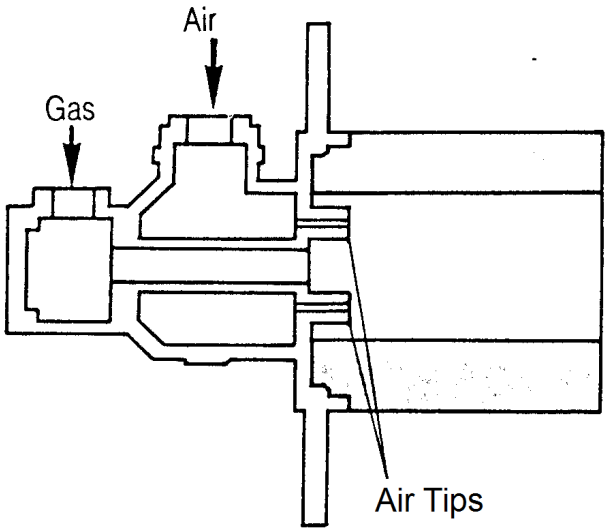

Fig. 4.4. Low-Turbulence Parallel Flow Burner

b) Premix System

In this system, a portion or all of the air required for complete combustion (known as primary air) is mixed with the gas upon entering the burner or immediately before. Thus, better mass transfer (intimate mixture) is achieved between fuel and the oxidant before reaching the burner through an elevated combustion speed and a high volumetric thermal load.

Three types of burners may be identified according to how premixing is carried out:

i) Enclosed Burners with a Mixture of Air and Gas

Air and gas are channeled by pressure through separate tubes with simultaneously controlled progressive regulation valves. The two streams may be unified in a mixing chamber or in the tube itself leading to the burner, as shown in Figure 4.5.

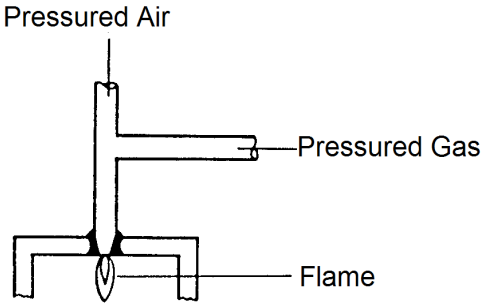

Fig. 4.5. Diagram of Enclosed Burner with a Mixture of Air and Gas

ii) Atmospheric System

An atmospheric burner (Figure 4.6) is comprised by:

A gas and air mixer which uses the kinetic energy of a stream of gas supplied by an injector to suction ambient air and create an inflammable mixture.
A burner head which ensures stable combustion of the air and gas mixture.

These types of mixers may be configured for a unit power of up to 1,000 kW. However, they are designed for unit powers of 30 to 300 kW. Their main advantage is their simplicity and low cost. This type of burner is used when mixing pressures approximate atmospheric pressure and when it is not necessary to obtain the amount of theoretical air in the premixture, as the quantity of air taken in by the gas is not enough to produce complete combustion. The remaining air, known as secondary air, is obtained by diffusion of the ambient air surrounding the flame.

Gas regulation is achieved by varying the pressure in the injector (progressively opening and closing the gas valve). Air is regulated (with gas at a constant pressure) by:

Movement of the injector nozzle in relation to the venturi.
Varying the air entry section by obstructing the orifices where air enters, or by using threaded plates, a moveable ring or a sliding hood.
Constricting the throat of the venturi (not recommended).

Fig. 4.6 Atmospheric Burners

Atmospheric burners (mixing by atmospheric induction) are virtually the only type used in household applications.

In industrial applications, for feeding enclosed areas such as combustion chambers and furnaces, among others, the air for the mixture is obtained by using special atmospheric induction mixers, with high injection pressure and double induction (Figure 4.7). This improves feed and supplies a combustible mixture which is nearly stoichiometric.

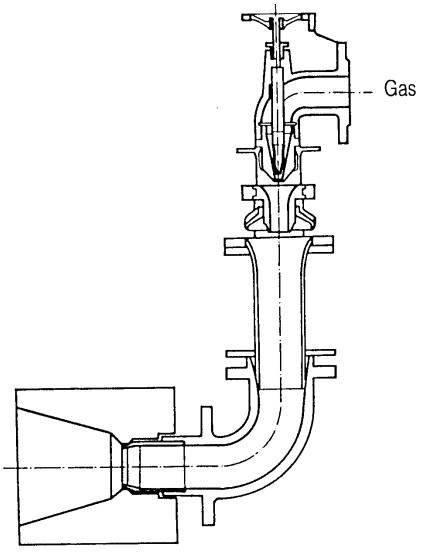

Fig. 4.7. Burner with Pressurized Gas and Double Atmospheric Induction

4.2 Auxiliary Components of Burners

The usage conditions of gas burner equipment make ignition, control and safety devices necessary. These auxiliary components are described as follows.

4.2.1 Ignition Systems

Different systems are used to ignite the combustible mix. The simplest of these consists of a pilot light ignited next to the main burner, which causes combustion when the gas exits the burner. The pilot light, which remains lit while the burner is used, fulfills the functions of initiating combustion of the gas exiting the main burner and preventing liftoff in the main burner once combustion has begun. In order to ignite the pilot light, burners employ several systems such as:

Piezoelectric System (Figure 4.8). This is the most commonly used system in household and low-power burners. It's based on the property had by some materials, such as quartz crystals, of being able to generate an electric potential difference upon being subjected to stress. This potential difference is transferred to two electrodes and produces one or more sparks, which ignite the combustible mixture. Generally, one electrode consists of the mass of the apparatus itself, and the other of a spark plug located near the pilot burner.

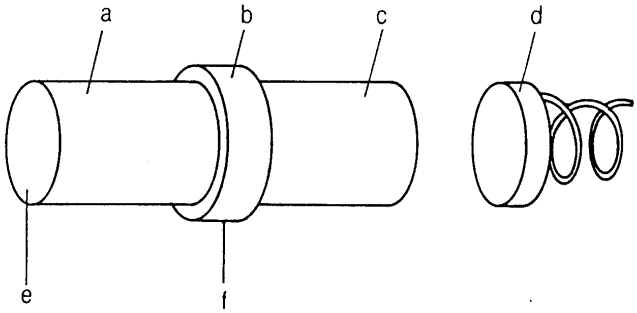

Fig. 4.8. Diagram of a Piezoelectric System

This system consists of a hammer activated manually or by a lever, in which a metal mass (d) strikes two quartz crystals (a and c) with a copper contact between them (b), producing a potential difference between points e and f.
The main advantages of this system are:

It does not require an electrical energy supply.
The energy source does not have to be renewed.
It is a simple system which ignites any type of commercial gas.
It can be automated so that the hammer is activated by a lever.

Electrical Resistance System. This system is based on heat production in an electrical resistor, increasing the temperature enough to ignite the combustible mixture. For this purpose, the resistor must be located near the gas exit port of the pilot light.

Voltage is low (from 2 to 12 V) and obtained from the network via a transformer or batteries. Thus, temperatures of between 700 and 800 °C are reached in the resistor. This procedure offers excellent possibilities for remote ignition.

This ignition device can work directly on the main burner (without a pilot light) as long as there is a flame detection system or device in place.

High Voltage Spark System. This system is essentially used for:

Lighting mixed gas and oil burners (Figure 4.9), whether simultaneous or alternating

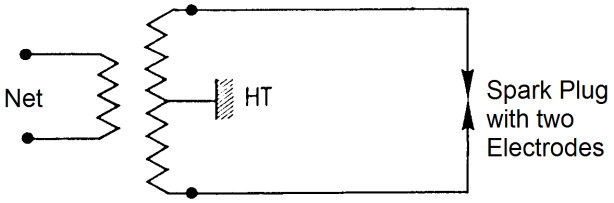

Fig. 4.9. Electrical Diagram for a Spark Plug with two Electrodes.

The no-load voltage is approximately 9,000 V. For a 50,000 Ohm resistor, the voltage should be close to 1,000 V.

Gas ignition only (Figure 4.10)

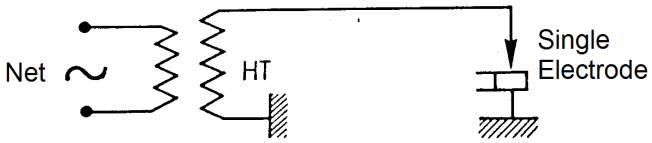

Fig. 4.10. Electrical Diagram for a Spark Plug with a Single Electrode

Automatic Ignition. This type of system, which can operate without a pilot light, consists of the following components:

Ignition device, usually with electrical sparks.
Quick response flame detector, such as those which use flame ionization or a UV photoelectric cell.
Appropriate control components in the event the ignition spark is absent or not produced within a few seconds, blocking the system and shutting off gas flow to the burner.

When the system is connected, the combustion chamber is initially swept with pressurized air to eliminate any potential unburned gas. Subsequently, the gas valve automatically opens and a stream of sparks is produced on the ignition electrode, initiating gas combustion.

If the gas fails to exit the burner, the sparks don't ignite the gas or the spark regeneration system fails, the system will be blocked within a few seconds.

If the burner ignites, this is detected by the ionization electrode, and the gas flow to the burner is automatically kept open and spark production is stopped.

4.2.2 Flame Safety Systems

The flame safety system is made up of a set of components that provide for safe control of burner operation which is appropriate to the application. Its main functions are to:

Provide a safe method for lighting and shutting off the burner (manual or automatic).
Light the burner in the proper order and supervise the flame during the operation.
Protect the system against excessive pressure or temperature.
Control burning capacity.
Maintain the burner ready for operation during the periods when it's turned off.

In order to fulfill these functions, the flame safety system has a programmer, a flame detector, limit and safety controls, operating condition controls, fuel valves and burner power control. The programmer, also called an ignition programmer, coordinates overall operation. In addition to verifying signals from the other components, it must also verify that its own operation is taking place properly. Flame detectors can be classified into three general types:

Thermal. Thermal detectors consist of components which detect the temperature of combustion gases using a thermocouple or a bimetallic strip. Their use is increasingly less common, given their slow response time and unreliability, and they are limited to small burners.
Flame rectification. Flame rectification detectors use the ionization produced by the flame to rectify an alternating current. Despite being simple and reliable, they cannot be used for oil flames, as they can be dirtied by drops of fuel, or in high temperature applications, as they burn too quickly.
Radiation. Radiation detectors are the most versatile, but also the most expensive. Some radiation detectors are sensitive to ultraviolet radiation.

Flame safety systems or flame detectors are devices which automatically interrupt gas supply when ignition has not occurred after a certain period of time, or in the event of accidental extinction of the flame during burner operation. To fulfill this purpose, they detect a distinctive characteristic of the flame such as its temperature, light emitted or its electrical properties. Flame safety devices may consist of:

Complete or total safety: when the safety device cuts off the gas flow to the main burner and the pilot. Simple safety is when gas flow to the pilot is maintained.
Positive safety: when a failure in the safety device produces the same result (gas flow cutoff) as the function of the device itself.

4.2.3 Flashback Protection Systems

In inflammable gas mixtures, the flame propagates from the point of ignition to the rest of the mixture. This phenomenon is known as deflagration, and the velocity of flame propagation or deflagration is about 10cm/sec or even 1m/sec. In some cases, due to low gas or air pressure, fluid at higher pressure flows into the piping with lower pressure fluid. Devices are used to avoid this problem and avoid flashback, fulfilling the following functions (Figure 4.11):

Closing the combustible mixture tube by means of a check valve that closes as a result of the back pressure produced by the downward-flowing gas in combustion.
Stopping the flame front by means of a fine wire mesh for detaining and cooling the flame.
Breakage of a membrane calibrated according to pressure increase, allowing the combustion products which caused the pressure surge to be released into the atmosphere.

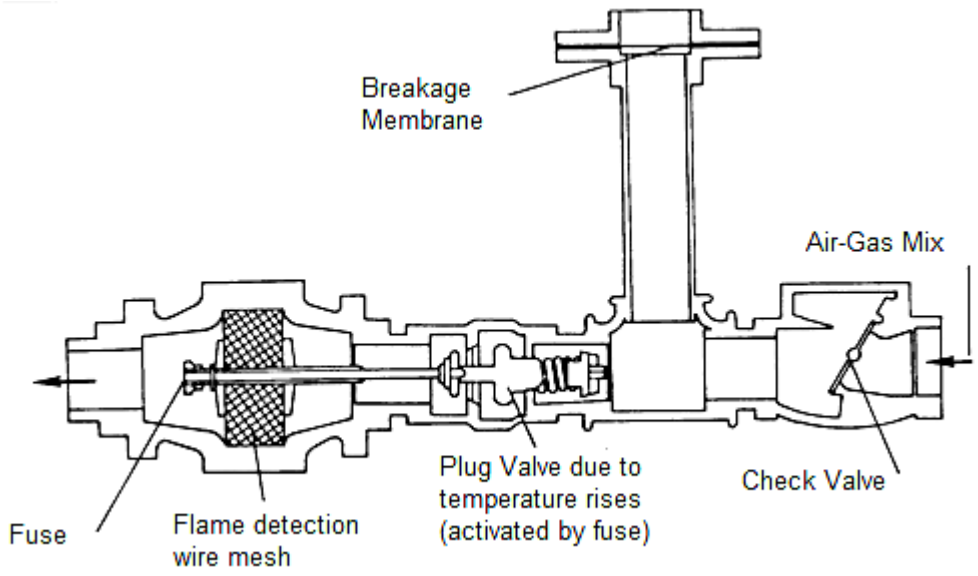

Fig. 4.11. Burner with Flashback Protection and Anti-Explosion Device

Other devices also include a broken membrane detector, which sends a cutoff signal to the main gas flow valve.

4.2.4 Practical Safety Aspects

The following should be considered among the important safety aspects of natural gas use:

Natural gas is lighter than air.
The enclosed spaces where natural gas is used require ventilation.
Flame color is transparent, which complicates visibility in some environments. Thus, burners must be handled with caution.

Gases must be completely swept from the furnace before lighting the burner. Thus, it must be ventilated with air prior to opening the gas flow and ignition. Sweeping time for gas is longer than that required for liquid fuels.
Pressure detection valves and systems must be in place to prevent pressure surges.
Natural gas contains odorizers that permit its detection without instruments and ensure that the operator does not breathe it in. In some cases involving circuit leakage, the operator may lose their sensitivity to the odor; thus, leakage and odor detectors are recommended.
Equipment maintenance must to be performed as indicated in the manual, with the recommended frequency.

5. Process Boiler Applications

Industrial processes requiring vapor are a very important area of natural gas use in practically every country. It's important to consider the characteristics of demand for vapor in processes, as seasonable variability is considerable. Many batch processes require vapor for specific periods of time, after which demand ceases or decreases to a minimal level. This is known as variable vapor demand, and it results in very irregular operation for the boiler, which must transition from zero production, or standby, to maximum production within a short time period. Thus, the efficiency of vapor generation is an average of the efficiencies attained at each demand level, from zero efficiency to the boiler maximum, in the range of 85% to 95% according to design and fuel used. Boilers which use natural gas provide the best efficiencies under these variable demand operating conditions, given that combustion may be efficiently regulated within a wide range of required calorific values. In addition, as natural gas combustion does not result in the generation of particles, heat transfer areas of the boiler remain clean for long periods of operation. This means that the equipment is available for longer periods of time, with less potential for impairing production due to lack of vapor.
The primary characteristics of boilers designed to burn natural gas are that they have a large area for heat transfer by convection and a smaller furnace than boilers using liquid fuels.
Boilers designed to burn combustible liquids have larger furnaces due to the fact that radiation from these fuel flames contains soot particles which emit radiant heat, which is used to generate vapor on the furnace walls. Generally, it is estimated that 50% of the heat required is provided in the furnace by flame radiation, and the other 50% in convection areas (tube bundle). It's very important to consider this situation when boiler fuel is changed. In the case of changing from liquid fuel to natural gas, vapor production will be reduced to maintain efficiency or efficiency will be reduced to maintain vapor production. One way to reduce this impact is to install heat exchangers on the boiler exhaust outlet for preheating boiler feed water.

6. Drying Furnace Applications

Given that its combustion produces very clean gases, natural gas is an optimal fuel for drying processes. This characteristic allows for direct application of hot gases in order to evaporate water from products which need drying, without introducing any type of residue which might alter the composition of the product and impair its quality.

Some examples of where this concept is applied are drying processes involving fish flour, mineral salts, agricultural grains, mineral concentrate, etc. Applying this process, known as direct drying, is more efficient and requires less capital and maintenance costs than indirect drying, which generally uses vapor as a heat transport fluid to heat the walls separating the vapor chamber from the products to be dried.
Experience indicates that fuel savings in the range of 15% to 30% may be obtained over indirect drying when the direct drying process is used.

7. Copper Pyrometallurgy Applications

The use of natural gas in copper pyrometallurgy processes can be divided into its application as a fuel and its application as a product employed in the metal purification process.

Fig. 7.1 Photo of Burners Installed in P&S Furnace

Its use as a fuel takes place in the burners used in the different furnaces involved in the process. Its primary function is to maintain the metal in its liquid state, which requires a temperature of over 1200 ºC while copper purification processes are carried out. Just as in Pierce Smith converters, a significant portion of the sulfur and iron contained in the metal is eliminated as air is forced through the liquid metal bath. This process generates heat from the burning of sulfur; however, thermal equilibrium must be maintained with burners, given that as the sulfur is eliminated, its heat contribution diminishes. In these furnaces, it has been proven that the use of natural gas results in a longer service life for refractory mantles, which protect furnace walls by reducing the quantity of soot (carbon) affecting refractory materials and maintaining uniform heat distribution throughout the furnace walls. Figure 7.1 shows the installation of two burners in the mouth of one of these furnaces, in which the color and transparency of the flame and the lack of radiant elements can be noted.
Upon increasing the service life of the furnace, two significant effects are produced:

Maintenance periods are lengthened, resulting in greater productivity.
Maintenance costs for refractory mantles are reduced.

Experience has shown that maintenance periods are extended by up to 50% and even longer in some cases, which signifies an increase in smelting production.
In addition, savings on maintenance of refractory components can amount to several hundred thousand dollars per year.

The next step in copper purification is known as fire refining. In this process, the remaining small amounts of sulfur must be eliminated, so the liquid metal is over-oxidized by injecting air into it until the sulfur is eliminated. However, this leads to oxidation of the metal, which must be treated with a reducing substance which deoxidizes the oxidized metal. During this phase of the process, natural gas is employed as a highly efficient reducing element, as it does not contain sulfur and has a low carbon content (the lowest of all fossil fuels). Experience has shown that black smoke emissions are eliminated during reduction when natural gas is used for this purpose instead of oil.
Finally, natural gas is also used in the burners which maintain the copper in a reductive environment during the process of casting the anodes, the end product of smelting.
Figure 4.6 shows an atmospheric burner used in the casting area of a smelter.

8. Environmental Aspects

All fuels, and particularly those of fossil origin, impact the environment to some degree. This impact is a product not only of their use (combustion processes), but also of extraction processes, as well as construction and operation of the infrastructure needed to make fuel available to consumers.

Most of the installations and infrastructure required for natural gas (gas pipelines and distribution networks, for example) are underground, so they don't substantially affect the esthetic value of the landscape.

Of all the fossil fuels, natural gas today is the cleanest, pollutes the least and has the lowest carbon content. This originates in the molecular composition of its principal component

(methane, CH4), which has four hydrogen atoms for each carbon atom. Natural gas combustion produces 50% to 70% of the carbon oxides produced by other fuels; as a result of its lower carbon dioxide emissions, natural gas contributes to reducing the greenhouse effect.

In addition, its sulfur content is virtually non-existent, so its combustion does not contribute to the generation of acid waste. Under normal conditions of regulation and operation, natural gas combustion does not generate black smoke, ash, slag or other solid waste.

Natural gas combustion generally produces more nitrogen oxides than other fuels. This characteristic has spurred the development of low NOx burners, in which flame temperature is reduced using secondary and tertiary burning techniques, thus preventing formation of these oxides.

9. Economic Aspects of Using Natural Gas as an Industrial Fuel

Natural gas offers some very attractive advantages when it comes to making an economic assessment of its use in industrial processes. These aspects are:

Natural gas does not require additional expense for transportation within the factory; all that's needed is a distribution network and pressure regulation systems for equipment. It should be taken into account that liquid fuels require pumps for transport, implying additional electricity use.
Unlike liquid fuels, natural gas doesn't require storage tanks.
Temperature doesn't have to be controlled, as it does with residual fuels, so additional heating expenses are made unnecessary.
No storage cost is incurred, as natural gas is piped in by the supplier according to demand.
Lower maintenance costs for equipment using natural gas and lower costs for the equipment required when other fuels are used.
Lower costs for meeting local atmospheric emissions standards due to lower costs of treating the gases emitted into the environment.

All of these aspects must be considered when comparative calculations are made of the costs of useful energy supplied by different fuels.
In industry, energy contributions of natural gas are measured based on different physical units of measurement. As this often generates confusion, Table 9.1 provides cost equivalency values based on commonly used physical units.

	US$ / Sm3	US$ / MMBtu	US$ / kJ	US$ / kcal	US$ / kWh
US$ / Sm3	1	28.571	2.719 e-5	1.136 e-4	9.779 e-2
US$ / MMBtu	3.5 e-2	1	9.479 e-7	3.968 e-6	3.421 e-3
US$ / kJ	36,784	1,055,000	1	4.1868	3,600
US$ / kcal	8,800	252,000	0.239	1	859.84
US$ / kWh	10.226	293.07	2.778 e-4	1.163 e-3	1

Table 9.1 Natural Gas Equivalencies in US$, based on Net Calorific Value

Supply contracts may establish certain conditions regarding how gas is delivered. One of the conditions which may create a negative impression is take or pay on an amount of gas. This condition makes paying for gas mandatory under all circumstances, so the manner in which it is proposed must be considered very carefully.

10. Referring

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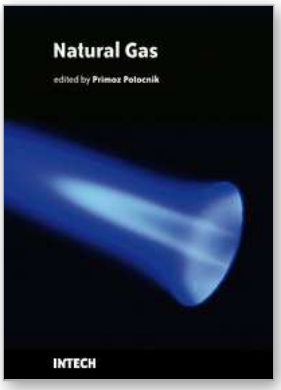
3. www.GasEnergy.com.br



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The contributions in this book present an overview of cutting edge research on natural gas which is a vital component of world's supply of energy. Natural gas is a combustible mixture of hydrocarbon gases, primarily methane but also heavier gaseous hydrocarbons such as ethane, propane and butane. Unlike other fossil fuels, natural gas is clean burning and emits lower levels of potentially harmful by-products into the air. Therefore, it is considered as one of the cleanest, safest, and most useful of all energy sources applied in variety of residential, commercial and industrial fields. The book is organized in 25 chapters that cover various aspects of natural gas research: technology, applications, forecasting, numerical simulations, transport and risk assessment.

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