**Fuel gases used in the steel industry**

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A fuel gas is a fuel that exists in gaseous form under ordinary conditions. Some of these gases contain hydrocarbons (such as methane or propane)， hydrogen (H2)， carbon monoxide (CO) or a mixture of these gases. These gases are a source of thermal energy that can be easily transferred and distributed directly from the source to the application via pipelines. Fuel gases are different from liquid and solid fuels， although some can be liquefied for easy storage or transport.

Fuel gases have different application areas in steel mills including (1) heat source (2) as a reducing agent， (3) power generation， and (4) cutting and welding applications. Fuel gases typically used in steel plants include (i) natural gas (NG)， (ii) liquefied petroleum gas (LPG)， (iii) by-product gases such as blast furnace (BF) gas， coke oven gas (COG) and converter gas， and (iv) acetylene. Figure 1 shows the types of fuel gases and their applications in steel plants.

Figure 1 Types of fuel gases and their application in steel plants

Natural gas

Natural gas is an environmentally friendly， non-renewable， gaseous fossil fuel extracted from the earth's deposits. It is a clean fuel with high efficiency. It is transported over great distances (up to 5，000 km) through a network of pipelines. It is usually supplied to consumers in the form of (i) pipeline natural gas (PNG)， (ii) compressed natural gas (CNG) and (iii) liquefied natural gas (LNG).

Natural gas supplied to consumers by pipeline is PNG， and the pipeline pressure at the consumer's end is usually less than 16 atmospheres. Compressed Natural Gas (CNG) is a form of natural gas that is compressed (200 atm to 250 atm) into a container.LNG is made by cooling natural gas to a temperature of -162 degrees Celsius. At this temperature， NG becomes a liquid and its volume is reduced by a factor of 600.

Natural gas is a mixture of hydrocarbons consisting primarily of methane (CH4)， usually more than 85% by volume. other hydrocarbons in NG include various higher alkanes in varying amounts， such as ethane， propane and butane. It also contains water vapor (H2O)， or condensate， in varying degrees of saturation. It may also contain some small percentages of nitrogen (N2)， carbon dioxide (CO2)， hydrogen sulfide (H2S)， and helium (He).

Natural gas is an odorless， colorless， tasteless and non-toxic gas. It is lighter than air and when mixed with the necessary amount of air and ignited， it produces a clean blue flame. It is considered to be one of the cleanest burning fuels. When burned， it produces mainly heat， carbon dioxide and water.

The amount of natural gas is measured in normal cubic meters (equivalent to 0 degrees Celsius and 1 atmosphere) or standard cubic feet (equivalent to 16 degrees Celsius and 14.73 pounds per square inch of absolute pressure). The higher calorific value of a cubic meter (Cum) of natural gas ranges from about 9，500 kcal to 10，000 kcal. Its density is about 0.85 kg/m3.

The main use of natural gas in the production of iron and steel is in ironmaking， where it is used as a reducing agent. The use of NG in gas-based direct reduced iron (DRI) production requires the conversion of NG into a usable reducing gas with a high H2 and CO content. More than 90% of DRI facilities worldwide use natural gas. For DRI production， it is reformed to produce reducing gas， which is then used for iron ore reduction. The main reforming reactions are (i) 2CH4 + O2 = 2CO + 4 H2， (ii) CH4 + H2O = CO + 3 H2， and (iii) CO2 + H2 = CO + H2O.

NG is injected into the spigot of the BF as an auxiliary fuel. It is injected together with a hot O2 enriched blast. The purpose of injecting NG as an auxiliary fuel is to reduce the specific consumption of coke. The coke replacement ratio achieved by injecting NG gas in the blast furnace is between 1.3 and 1.4. The NG injected into the BF supplies the furnace with reducing gases consisting of H2 and CO which move around the furnace shaft and participate in the reduction reaction of iron oxides.

Liquefied Petroleum Gas (LPG)

LPG is extracted from crude oil. the main components of LPG are hydrocarbons containing 3 or 4 carbon atoms. the normal components of LPG are propane (C3H8) and butane (C4H10). small proportions of other hydrocarbons may also be present in LPG.

LPG is a gas at atmospheric pressure and ambient temperature， but it can be liquefied when moderate pressure is applied or the temperature is sufficiently reduced. It can be easily condensed， packaged， stored and utilized， which makes it an ideal energy source for a wide range of applications. Typically， LPG is stored as a liquid under pressure in steel containers， cylinders or tanks.

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LPG is a colorless， odorless and non-toxic gas. It is highly flammable. The vapors of LPG are heavier than air， so any leaks will sink to the ground and accumulate in low-lying areas where they are difficult to dissipate. lpg expands rapidly when the temperature rises.

LPG is a colorless liquid that evaporates easily into a colorless， odorless gas. Often， malodorous ethanethiol is added to LPG as an odorant so that leaks can be easily detected. During a leak， the vaporization of the liquid cools the atmosphere and causes the water vapor in it to condense and form a wXITE mist so that the LPG leak can be seen.

When mixed with air， the gas can burn or explode when it encounters an ignition source. It is heavier than air， so it tends to sink toward the ground. lpg can flow far along the ground and can collect in drains， gutters and cellars.

LPG in liquid form has a specific gravity of 0.51 to 0.58 at 15 degrees Celsius (water = 1). The specific gravity of gaseous LPG is 1.52 to 2.01 (air = 1). The boiling point of LPG is between -42 degrees Celsius and 0 degrees Celsius. The physical state of LPG is a gas at 15 degrees Celsius and at a pressure of 1 kg/cm2.

The calorific value (CV) of LPG is about 11，000 kcal/kg or about 22，500 kcal/cm3. Because its boiling point is lower than room temperature， LPG evaporates rapidly at normal temperatures and pressures. The ratio of the volume of vaporized gas to that of liquefied gas varies depending on composition， pressure and temperature， but is usually about 250:1. The solubility of LPG in water is less than 200 ppm (parts per million) at 20 degrees C. LPG is soluble in organic solvents such as alcohol.

The vapor pressure of LPG is 5.3 kg/cm2 to 15.6 kg/cm2 at 40 degrees C. The pressure in the LPG storage vessel is equal to the vapor pressure corresponding to the temperature of LPG in the storage vessel. The vapor pressure depends on the temperature as well as the mixing ratio of hydrocarbons. Any further expansion of the liquid in the full liquid state， the pressure in the storage vessel rises， by about 14 to 15 kg/cm2 per degree Celsius， which clearly explains the dangerous situation that can occur due to overfilling of the storage vessel.

The flash point of LPG is -104.4 degrees Celsius. Propane has an auto-ignition temperature of 46.1 °C and butane has an auto-ignition temperature of 405 °C， so LPG does not ignite on its own at normal temperatures. lPG is highly flammable with a lower explosive limit (LEL) of 1.9 % and an upper explosive limit (UEL) of 9.5 %. This explosion range is much narrower than that of other common gaseous fuels. This indicates the risk of accumulation of LPG vapors in low-lying areas in the event of a leak or spill. It is explosively sensitive to static electricity.

In steel mills， LPG is used as a fuel， or by mixing with BF gas with low CV， for gas cutting of steel and other metals， and in gas torches for continuous casting machines. It is stored in pressure vessels. These vessels are spherical or cylindrical horizontal vessels (Figure 2).LPG vessels have pressure relief valves so that they vent LPG to the atmosphere when subjected to an external heating source.

Figure 2 Storage tanks for liquefied petroleum gas

By-product gases

During the steel production process in an integrated steel plant， three types of by-product gases are produced， which are classified as fuel gases because they have a comparable calorific value. These gases are (i) blast furnace (BF) gas， (ii) coke oven (CO) gas， and (iii) converter gas.

Blast Furnace Gas - Blast Furnace Gas is a gaseous by-product produced during the production of hot metal (liquid iron) in a blast furnace. It has a very high density of about 1.25 kg/m3 at a temperature of 0 degrees Celsius and 1 atmosphere pressure. This density is the highest of all gaseous fuels. Because its density is higher than that of air， it settles to the bottom in the event of a leak.

The four main components of BF gas are N2， CO， CO2， and H2. the percentages of these components in BF gas are typically: N2-40% to 60%， CO-20% to 28%， CO2-17% to 25%， and H2-1% to 7%. CH4 can also be present in BF gas up to 0.2 %. The BF gas may also contain some hydrocyanic acid (HCN) and cyanide (CN2)， which are formed by the reaction of N2 in the hot air and carbon in the coke. The reaction is catalyzed by alkali oxides. These gases are highly toxic. The H2 content of the gas varies depending on the type and amount of fuel injected into the BF.

The total amount of CO and CO2 in the BF gas at the top of the BF is about 40 to 45% of the total gas by volume. the CO/CO2 ratio can vary from 1.25:1 to 2.5:1. The high ratio of CO in the gas makes BF gas dangerous. the CV of BF gas varies， but is usually low， between 650 kcal/N cum and 900 kcal/N cum， and depends on the CO content of the gas. Therefore， BF gas is often enriched by COG or NG before use.

The main characteristics of BF gas are: (i) it is almost a colorless gas (slightly wXITE)， usually odorless， but sometimes with a slight sulfur odor; (ii) low CV value; (iii) low theoretical flame temperature of about 1455 degrees C; (iv) low flame spread， usually lower than any other common gaseous fuel; (v) it does not glow when it burns. (vi) an auto-ignition point of about 630 degrees C， (vii) an LEL of 27% and a UEL of 75% in an air mixture at normal temperature and pressure， (viii) flammable， can form explosive mixtures with air， and is readily ignited by static electricity， and (ix) stable chemical stability under normal storage and handling conditions.

In steel mills， BF gas is usually used with CO gas or converter gas or a mixture of both. The blended gas is used as fuel in various furnaces in steel mills. BF gas without mixing and preheating is used in BF furnaces， sintering plants， soak pits， normalizing and annealing furnaces， foundry core furnaces， gas engines for blowing， boilers for power generation， and gas turbines for power generation.

Coke Oven Gas - COG is produced during the carbonization of coking coal in the by-product coke oven cell. The raw COG from the cell is purified in the by-product plant， which includes tar， ammonia， and benzyl alcohol， to produce clean COG. The major components of clean COG are H2 (42% to 65%)， CH4 (17% to 34%)， CO (4.6% to 7.5%)， and hydrocarbons (CmHn). It also contains inert gases， such as N2 (1.2 % to 18 %) and CO2 (0.2 % to 3.2 %). A small amount of oxygen (O2) is also present in the gas.

Clean COG is a colorless gas with the odor of hydrogen sulfide and hydrocarbons. It has an LEL of 4.4 % and a UEL of 34 %. Its vapor density is 0.36 (air = 1). At standard temperature and pressure， the density of COG ranges from 0.45 kg/volume to 0.50 kg/volume. the CV of COG ranges from 4，000 kcal/N cum to 4，600 kcal/N cum.

COG has a theoretical flame temperature of 1，982 degrees C. Its flame propagation speed brings its actual flame temperature close to its theoretical flame temperature. When exposed to high concentrations， COG acts as a simple asphyxiant. It replaces oxygen and causes rapid asphyxiation by exhibiting symptoms of oxygen deprivation.

Clean COG is commonly used for coke oven battery heating， heating of other furnaces and power generation. It can be used this way or mixed with BF gas and/or converter gas and then used as fuel in the furnace. In some steel plants， COG injection into BF has been successfully tried. COG is also used to produce DRI， which can replace NG.

Converter gas - During the steelmaking process in an alkaline oxygen furnace (BOF)， a large amount of CO-rich gas is produced at a temperature of about 950 degrees C. This gas mixture is known as converter gas or BOF gas. Converter gas is also referred to as LD gas.

The main components of converter gas are CO， CO2， O2 and N2. Compositionally， it is similar to BF gas， but the proportion of N2 in it is lower. The composition of converter gas is: CO between 58% and 70%， CO2 between 15% and 20%， N2 between 12% and 20%， H2 between 0.9% and 1%， and O2 between 0.1% and 0.3%. The density of converter gas is 0.865 kg/m3.

In the converter steelmaking process， the converter gas produced is about 75 to 95 liters per ton of crude steel. The CV of converter gas varies in the range of 1，600 kcal/Num to 2，400 kcal/Num. It is a function of the air ratio. The lower the air ratio， the higher the CV， because the proportion of N2 in the gas is reduced. A lower air ratio also means a lower specific yield of the gas.

Converter gas is highly toxic and explosive and requires highly rigorous handling during recovery. It cannot be detected by odor. It easily forms explosive mixtures with air and is easily ignited by static electricity. It is a chemical asphyxiant. It displaces oxygen and causes rapid asphyxiation by exhibiting symptoms of oxygen deprivation.

Converter gas is usually mixed with BF gas in different proportions and the mixture is used for heating in various furnaces.

Acetylene

Acetylene is a compound with the chemical formula C2H2. It is an unsaturated hydrocarbon and the simplest of the alkynes. An acetylene molecule consists of two carbon atoms and two H2 atoms. These two carbon atoms are held together by a so-called three-carbon bond. This bond is useful because it stores a large amount of energy， which can be released as heat during combustion. However， the three-carbon bond is unstable， making acetylene gas very sensitive to conditions such as overpressure， overtemperature， electrostatic or mechanical shock.

Acetylene is a flammable， colorless and odorless gas. Its molar mass is 26.04 g/mol. It is unstable in its pure form and is therefore usually treated as a solution. Pure acetylene is odorless， but commercial grades of acetylene usually have a distinct garlic odor due to the presence of impurities. At atmospheric pressure， acetylene cannot exist as a liquid and has no melting point. The gross and net calorific values of acetylene gas are 11，932 kcal/kg (13，980 kcal/year cumulative) and 11，514 kcal/kg (13，490 kcal/year cumulative)， respectively.

Acetylene has a density of 1.11 kg/L and a specific gravity of 0.91 (air = 1) at 1 atmosphere and 15 degrees Celsius. It is lighter than air， so it does not accumulate at low levels， where it would be potentially dangerous. The boiling point of the gas is minus 84.7 degrees Celsius and the melting point is minus 80.75 degrees Celsius. The adiabatic flame temperature (AFT) in air at atmospheric pressure is 2，534 degrees Celsius. The upper limit can reach 100 percent. It has a solubility in water of 1.2 g/l.

According to the chemical reaction CaC2 + 2H2O = Ca(OH)2 + C2H2， acetylene is produced by the hydrolysis of calcium carbide. Today， acetylene is mainly produced by partial combustion of CH4 or occurs as a by-product of the ethylene stream during the cracking of hydrocarbons.

Due to its unstable nature， acetylene needs to be stored under special conditions. This is achieved by dissolving acetylene in liquid acetone. The liquid acetone is then stored in acetylene bottles， which in turn are filled with a porous (sponge-like) cement material.

Acetylene is used for oxyacetylene gas cutting and welding in steel mills， and also for flame cutting in continuous casting machines. It is also sometimes used for carburizing steel， flame heating， flame planing， flame hardening， flame cleaning， flame straightening， thermal spraying， spot heating， brazing， texturing and profile cutting， and carbon coating.