Chapter 5

Production and Use of Industrial Gases for Iron and Steelmaking

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5.1 Industrial Gas Uses

5.1.1 Introduction

The iron and steel industry, one of the largest users of industrial gases, consumes substantial quantities of oxygen, nitrogen, argon, and hydrogen, and a small but growing amount of carbon dioxide (CO_2). Table 5.1 shows estimates of total consumption by the US industry for the most commonly used gases.

Table 5.1 Consumption of Industrial Gases by the United States Steel Industry

(Millions of Cubic Feet in Gaseous Form)

	1990	**1995**
Oxygen	199,420	288,105
Nitrogen	133,250	135,665
Argon	2,480	2,513
Hydrogen	830	940

Oxygen and nitrogen represent the largest volumes by far. Oxygen consumption has grown substantially in recent years while use of the other gases has remained relatively constant.

In order to provide a framework for reviewing the various uses of industrial gases, Table 5.2 summarizes the generic process functions they perform in iron and steelmaking operations.

Table 5.2 Industrial Gas Functions

Gas	Heating	Oxidation	Reduction	Stirring	Inerting	Injection
Oxygen	X	X				
Nitrogen	X (plasma)			X	X	X
Argon	X (plasma)			X	X	X
Hydrogen			X			
CO_2				X	X	X

Oxygen is used to provide process heat through various exothermic reactions which occur upon contact with hot metal and liquid steel and through combustion of fossil fuels. Injected oxygen also participates in the formation of carbon monoxide for the reduction of iron ore in the blast furnace and in some natural gas-based processes for producing direct reduced iron. Nitrogen, argon, and CO_2 are used for inerting vessels, equipment, and metal transfer streams in tapping and casting operations; to eliminate the formation of explosive mixtures in enclosed spaces; and to prevent undesirable reactions between iron and steel with oxygen and hydrogen in the surrounding atmosphere. Nitrogen and argon are also injected into molten iron and steel to provide metal stirring and slag/metal mixing, and as a carrier gas for powder injection. Additional uses for these gases include providing conditions which favor the oxidation of carbon instead of chromium in the argon oxygen decarburization (AOD) process for producing stainless and high alloy steels and as a coolant to protect oxygen injection tuyeres in various oxygen converters. The choice of gas for such inerting, stirring, injection, and steelmaking converter operations is dictated by overall cost and effect on metal chemistry and quality. Nitrogen is usually the gas of choice so long as its reactivity with molten metal and the associated increase in dissolved nitrogen or nitride formation is acceptable. Argon is used whenever a totally inert gas that does not affect metal chemistry is required. CO_2 does not result in increased nitrogen levels but can result in increased carbon, oxygen, and oxide inclusion content depending on the molten metal chemistry and extent of contact. A more detailed discussion of the use of each gas follows.

5.1.2 Oxygen Uses

The introduction of the basic oxygen furnace (BOF) for steelmaking in the 1950s also marked the genesis for tonnage supply of oxygen from on-site cryogenic air separation plants. Today, oxygen is the most widely used industrial gas due to its continued use in the BOF and its growing uses for enrichment in the blast furnace and providing supplemental chemical heat in electric arc furnace based steelmaking. Over 90% of this oxygen comes from plants that are owned and operated by industrial gas suppliers. Table 5.3 provides a summary of the more significant oxygen uses for the integrated and electric arc furnace industry segments.

Table 5.3 Oxygen Applications

	O_2 Consumption (millions of cu. ft.)		**Raw Steel Production** (thousands of net tons)		**Specific O_2 Consumption** (cf/ton* of steel)	
	1995	**1990**	**1995**	**1990**	**1995**	**1990**
Blast Furnace Enrichment	90,700	37,750	62,525	58,470	1450	645
Basic Oxygen Process	124,500	112,720	62,525	58,470	1990	1930
Electric Arc Furnaces	55,400	27,235	42,410	36,940	1305	735
Cutting, burning, etc.	17,520	15,890	104,930	95,410	165	165

*One ton equals 2000 pounds
Source: American Iron and Steel Institute, 1995 Annual Statistical Report

5.1.2.1 Blast Furnace

The use of significant quantities of oxygen for enrichment of the blast has become widespread. Table 5.3 shows that specific consumption rates have more than doubled over the last five years, and 40% of the total oxygen requirement of integrated steel mills is consumed in the blast furnace. This increase is a result of the desire for higher furnace productivity and the growth in powdered coal and natural gas injection as a means of reducing coke consumption and lowering production costs. Typical levels of enrichment are in the range of 3–8%, but enrichment levels as high as 12% have been used in furnaces using large amounts of coal or natural gas. Oxygen enrichment increases furnace productivity by reducing the blast volume and the associated pressure drop which allows a higher total oxygen throughput rate. It is also used to compensate for the reduction in raceway adiabatic flame temperature (RAFT) that results from the injection of powdered coal and natural gas into blast furnace tuyeres, thereby maintaining smooth furnace operation and the required hot metal temperature.

Oxygen is injected through spargers into the cold blast line between the blower and stoves. While process considerations would allow the use of relatively low purity oxygen for enrichment, the need to supply high purity oxygen for the BOF and to produce nitrogen and argon usually results in the use of standard 99.5% purity plants. However, the trend to very high rates of powdered coal and natural gas injection can easily result in the use of 300 to 1000 tons of oxygen per day in a single furnace. There have been a few recent installations of on-site cryogenic plants that are dedicated to the blast furnace thereby allowing optimization concerning product purity as well as plant integration and cogeneration schemes. The pressure required depends on the operating pressure of the blast furnaces and is usually about 60 psig.

5.1.2.2 Basic Oxygen Furnace (BOF)

Oxygen is used primarily for decarburization and conversion of blast furnace hot metal to liquid steel in the BOF. This accounts for 55% of the total oxygen consumption in integrated steel mills. The heat which results from the exothermic reactions of oxygen with silicon and carbon in the hot metal and the post combustion of a portion (about 10–15%) of the carbon monoxide (CO) which is generated in the converter is sufficient to melt scrap in quantities that amount to about 25% of the total vessel charge weight. A supply system capable of providing high flow rates of up to 30,000 scfm at nominal pressures of around 250 psig for about 20 minutes is required. High purity (99.5% oxygen content) is required to achieve required low steel nitrogen contents and to maximize vessel productivity and scrap melting capability. In most vessels, all of the oxygen is injected through a water cooled top lance with tips that have four or five nozzles which generate supersonic jets that impinge on the molten bath surface. Recently, lances which also have a number of secondary subsonic oxygen nozzles have been introduced to increase the degree of CO post combustion in order to control skull formation and increase scrap melting capability. There are also several modifications to the BOF such as the K-BOP and OBM for which some or nearly all of the required oxygen is injected through hydrocarbon shrouded tuyeres located in the bottom of the converter.

5.1.2.3 Electric Arc Furnace (EAF)

Table 5.3 also shows that the total consumption of oxygen in electric arc furnaces has also more than doubled in the last five years, and that much of this increase is due to a 75% increase in specific oxygen consumption during this time period. Typical uses for oxygen in the EAF include oxy-fuel burners for scrap heating and melting; high velocity lancing for localized scrap melting, steel decarburization, slag foaming; and sub-sonic injection for post combustion of carbon monoxide. Recent trends to use more supplemental chemical energy to increase furnace productivity and reduce melting time and electric power consumption, scrap pre-heating, and the growing use of high carbon content materials such as direct reduced iron (DRI), pig iron, iron carbide, and hot metal have all contributed to this significant increase in specific oxygen consumption over the past five years. Oxygen derived chemical energy can provide 30% or more of the total energy required to make steel in a modern high productivity EAF.

The equipment used to deliver the oxygen includes water cooled burners located on furnace walls, slag doors, and pre-heat shafts to provide direct flame impingement on cold scrap; water cooled or consumable lances which are positioned through the slag door or sidewall for scrap cutting, bath decarburization, and slag foaming; and door and sidewall lances or wall mounted nozzles for post combustion.

Growth in the rate of steel production and in specific oxygen consumption at many EAF based mills have combined to increase oxygen use to levels that make an on-site plant an increasingly typical mode of supply. Cryogenic, vacuum pressure swing adsorption (VPSA), and pressure swing adsorption (PSA) type plants are all used depending on the total industrial gas requirement of the plant and surrounding local market, purity requirement, use pattern, power rate, etc. Oxygen purity is usually in the range of 90–99.5%, and supply pressure is usually in the range of 150–250 psig.

5.1.2.4 Cutting and Burning

High purity (above 98%) oxygen is also used extensively throughout integrated and EAF based mills for steel cutting and burning as well as general lancing requirements. Significant uses in this category include automatic cut-off torches on continuous casters, periodic lancing to remove skulls from the mouths of vessels and ladles, and cutting of crops, skulls, and other forms of mill scrap into pieces that can be readily fed to the BOF or EAF.

5.1.2.5 Steel Reheating

Oxygen is also sometimes used for enrichment or with oxy-fuel burners in steel reheat furnaces. Benefits associated with the use of oxy-fuel burners include a 25–60% reduction in fuel consumption and associated sulfur dioxide (SO_2) and CO_2 emissions, increased furnace productivity, up to 90% reduction in nitrous oxide (NOx) emissions, and elimination of recuperators.

5.1.3 Nitrogen Uses

Table 5.4 identifies the common uses for nitrogen in both integrated and EAF plants.

Table 5.4 Nitrogen Applications

Integrated Plants[1]	EAF Plants[2]
Inerting of coal grinding and storage equipment	EAF stirring
Inerting of blast furnace charging equipment	Injecting powder for steel desulfurization
Injecting powder for hot metal desulfurization	Ladle stirring
BOF slag splashing	AOD refining
BOF stirring	Caster inerting
Annealing atmospheres	Tundish stirring
Controlling Zn thickness on hot dipped galvanizing lines	Annealing atmospheres
Instrumentation and control equipment	Instrumentation and control equipment

[1]In 1995, US plants consumed 130 billion cubic feet to produce 62.5 million tons of raw steel which is an average consumption of 2,085 scf/ton.

[2]In 1995, US plants consumed 5.2 billion cubic feet to produce 42.4 million tons of raw steel which is an average consumption of 122 scf/ton.

As noted, both overall consumption and intensity of use are considerably higher at integrated plants. Nitrogen purity for most applications is typically 99.999%. Occasionally, nitrogen with a nominal purity of around 97–99% may be used for inerting to prevent explosive mixtures in confined spaces. High purity nitrogen containing 5–10% hydrogen is used to provide a protective reducing atmosphere in batch and continuous type bright annealing furnaces for carbon steel grades.

5.1.3.1 Integrated Plants

Traditional uses of nitrogen in integrated plants include purging and inerting of blast furnace raw material charging equipment to prevent reactions of air with furnace offgas; injecting lime, lime-magnesium mixtures, or other reagents in powder form through refractory coated lances to desulfurize hot metal in torpedo cars and ladles; injection through bottom tuyeres to provide stirring and slag/metal mixing during the initial period of refining in the BOF which improves yield, reduces slag iron oxide (FeO) content, and lowers metal oxygen content; as the inert component with