

- Power supply and arc management
- Mechanical systems such as charging devices, hydraulic systems, injection devices, etc.
- Charge balances
- Heat balances, thermal efficiency and productivity improvements.

19.3 PERFORMANCE ASSESSMENT OF EAF STEELMAKING

19.3.1 Key Process Performance Indices

Broadly speaking, prior to the 1990s, the tap-to-tap time in EAFs was 4–5 hours, electricity consumption was 650–800 kWh/tonne of liquid steel, electrode consumption around 4 kg/tls and refractory consumption 7–8 kg/tls. S. Kohle (1999) has summarised the data of some modern EAFs, in Japan and in other countries like Europe. Based on the data collected for 35 EAFs, statistical methods were employed to provide values of medians, which categorise the furnace performance into two separate groups, one lying below and the other above the median. Table 19.2 contains some salient data, in which DC arc furnaces are not included. The data for

Table 19.2 Comparison of performance of AC EAFs between 1990 and 1999 (values are medians)

Parameter		1990 Average	1999 Average	Japan	Other
Furnace tap weight	t	86	110	110	112
Transformer power	MVA	60	80	60	93
Specific power	kVA/t	590	758	581	863
Voltage	V	680	900	750	950
Current	kA	50	50	42	54
Total oxygen used	Nm ³ /t	24	30	31	28
Tap temperature	°C	1660	1635	1603	1639
Tap-to-tap time	min	105	70	63	78
Electrical energy consumed	kWh/t	450	392	367	416
Electrode consumption	kg/t	2.9	1.9	1.8	2.0
Refractory consumption	kg/t	6.9	3.1	3.4	2.9
Productivity	t/h	61	94	111	82

1990 were taken from a report prepared by the International Iron and Steel Institute, and the corresponding 1999 data collected from several sources. Significant improvements may be noted in all the key performance indices between 1990 and 1999. The data reveal that in this period:

- Tap-to-tap time decreased from 105 to 70 min
- Electrical energy consumption decreased from 450 to 392 kWh per tonne of steel
- Graphite electrode consumption decreased from 2.9 to 1.9 kg per tonne of steel
- Refractory consumption decreased from 6.9 to 3.1 kg per tonne of steel
- Productivity increased from 61 to 94 t/h.

19.3.2 Operating Costs

The relative operating costs are approximately as follows.

	Percentage of total cost
Charge scrap + DRI + other metallics	65
Other charge materials	5
Electric power	10
Electrodes + refractories + other consumables	10
Labour + miscellaneous	10

19.3.3 Steel Quality Control in EAF

Some features of refining in EAFs has been presented in Sections 19.2.3 and 19.2.4 under the heading GROUP 4. It has been noted that the extent of refining is less. The EAF is primarily a melting unit, and final refining including composition and temperature adjustment are carried out during secondary steelmaking. Under these circumstances, it is worth noting that for effective control on the quality of steel:

- Scrap should be low in tramp elements
- DRI/HBI should have low levels of phosphorus and sulphur.

Millman (1999) has reviewed the issue of steel quality in EAF steelmaking. Of all the residual elements, nitrogen is the most difficult to control in EAFs, and is a major limitation in the production of high-quality steels using the arc furnace route. Some nitrogen comes through the scrap, but the major amount absorbed by the molten steel bath comes from nitrogen in the furnace atmosphere. This situation is aggravated by the very high temperature in the arc zone which prompts dissociation of N₂ molecules.

The principal method for the prevention of nitrogen absorption is to maintain a foamy slag right through the heat, thereby shielding the metal bath from the arc zone. Nitrogen is also removed from the bath by the flushing action of the rising CO bubbles. Therefore, all steps that promote these two factors will tend to lower nitrogen in steel. Features like continuous charging of high percentages of DRI, extensive bottom argon injection, etc. are beneficial. However, even after incorporating them, the minimum nitrogen in EAF steel is about 40 ppm.

Hydrogen dissolved in steel also gets flushed out by the rising CO bubbles and typical tap hydrogen contents vary from 2 to 7 ppm. To arrive at lower hydrogen levels in the final product, it is necessary to take recourse to vacuum degassing during secondary steelmaking.

It is not difficult to bring down phosphorus in steel to below 0.015% in EAFs, which is acceptable for most steel grades. However, sulphur cannot be reduced to very low levels directly in EAF steelmaking without sacrificing productivity and incurring high cost. Therefore, desulphurisation is often carried out during subsequent secondary steelmaking.

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20

Secondary Steelmaking

20.1 INTRODUCTION

Primary steelmaking is aimed at fast scrap melting and rapid refining. It is capable of refining at a macro level to arrive at broad steel specifications, but is not designed to meet the stringent demands on steel quality, and consistency of composition and temperature that is required for various grades of steel. In order to achieve such requirements, liquid steel from primary steelmaking units has to be further refined in the ladle after tapping. This is known as *Secondary Steelmaking*.

Secondary steelmaking has become an integral feature of virtually all modern steel plants. The advent of the continuous casting process, which requires stringent quality control is one of the main reasons for the growth of secondary steelmaking.

The harmful impurities in steel include: sulphur, phosphorus, oxygen, nitrogen and hydrogen. The latter three elements occupy interstitial sites in the iron lattice and hence, are known as *interstitials*. The principal effect of these impurities in steel is loss of ductility, lower impact strength and poorer corrosion resistance.

Oxygen and sulphur are also constituents of non-metallic particles in steel, known as *inclusions*. These particles are also harmful for steel properties and should be removed to as low levels as possible. Carbon is also present as an interstitial in the iron lattice as well as in the form of *Cementite* (Fe_3C). Unlike the other interstitials, some carbon is always required in steel and hence, the content of carbon forms a part of steel specifications. However, in recent times, in some special sophisticated grades like *Interstitial Free (IF) steels*, carbon is considered as an impurity and has to be removed to very low levels (*Ultra-low Carbon steels*).

Normally the temperature drop of molten steel during tapping from the primary steelmaking furnace is around 20–40°C. An additional temperature drop of about 30–50°C occurs during secondary steelmaking. Continuous casting involving pouring into a tundish causes additional drop of 10–15°C in liquid steel temperature. Therefore, provisions for heating and temperature adjustment are very desirable, which has led to the development of liquid steel treatment in ladles in special units, such as *Ladle Furnace (LF)*, *Vacuum Arc Degasser (VAD)*, *CAS-OB unit*, etc.

Table 20.1 presents a list of various secondary steelmaking units and their capabilities (Ghosh Ahindra 2001). Degassing refers to the removal of nitrogen and hydrogen from liquid steel. In common terminology, the abbreviations used and their full forms are:

- VD—vacuum degassing
- VOD—vacuum-oxygen decarburisation
- IGP—inert gas purging in a ladle through bottom porous and slit plugs; or, by lance immersed from the top, i.e. *Overhead Lance Purging* (OLP)
- IM—injection metallurgy, where some solid agents are injected into liquid steel in a ladle; or, nowadays also by wire feeding.

Table 20.1 Various secondary steelmaking processes and their capabilities

Item	Processes						
	VD	VOD	IGP	IM	VAD	LF	ASEA-SKF
Desulphurisation	minor	minor	minor	yes	yes	yes	yes
Deoxidation	yes	yes	yes	yes	yes	yes	yes
Decarburisation	minor	yes	no	no	no	no	yes
Heating	no/yes	yes*	no	no	yes	yes	yes
Alloying	minor	yes	minor	minor	yes	yes	yes
Degassing	yes	yes	no	no	yes	no	yes
Homogenisation	yes	yes	yes	yes	yes	yes	yes
Achieving more cleanliness (i.e. less inclusions)	yes	yes	yes	yes	yes	yes	yes
Inclusion modification	no	no	minor	yes	yes	yes	yes

* Chemical heating only

With the passage of time, customers are demanding higher quality steels, which requires:

- Lower impurity contents
- Better cleanliness (i.e. lower inclusion contents)
- Stringent quality control (i.e. less variation from heat-to-heat)
- Microalloying to impart superior properties
- Better surface quality and homogeneity in the cast product.

Figure 20.1 shows the trends in residuals attained so far as well as those projected for future in Japanese steel plants (Adachi 1990).

This chapter will present a brief outline of secondary steelmaking. For detailed treatment of the subject, the readers may refer to (Ghosh Ahindra 2001).

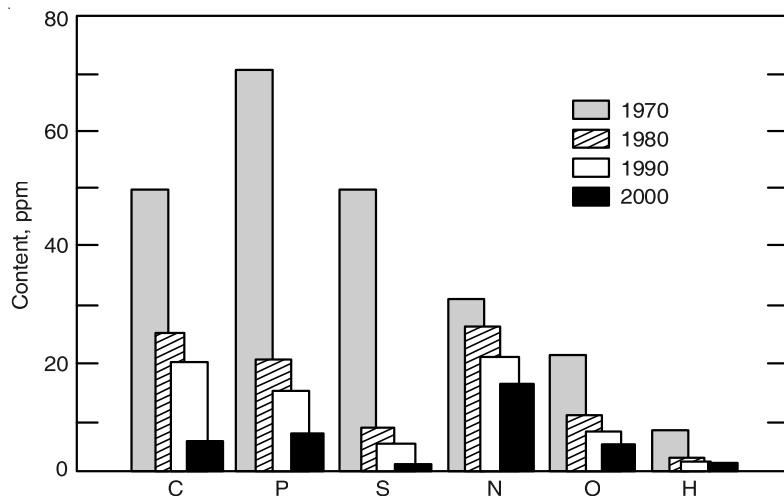


Figure 20.1 Minimum residual levels in steel in Japan.

20.2 INERT GAS PURGING (IGP)

This consists of purging molten steel by argon introduced from the bottom through porous bricks or slit plugs, fitted at the ladle bottom. Purging by argon through a top lance, which is immersed into the melt in an open ladle, is also practised. The primary objective is to stir the bath resulting in homogenisation of temperature and composition of the melt. It offers additional advantages of faster deoxidation and floatation of inclusions (i.e. superior cleanliness). All secondary steelmaking ladles, nowadays, have provision for gas purging.

Some typical designs of refractory purging plugs are shown in Figure 20.2. Over the last three decades, a large number of investigations have been carried out on fluid flow, mixing and mass transfer during gas purging. Fundamental studies have been conducted in *Water Models* at room temperature, in which the vessel used is a transparent perspex model. Water is used to simulate liquid metal. Figure 20.3 presents a sketch of typical water model. The rising gas bubbles create a central two-phase gas-liquid region, known as the *Plume*. The upward motion in the plume causes *recirculatory flow* in the rest of the liquid.

Chapter 4, Section 4.5.4 has very briefly touched on the mixing and the approximate relationship between mixing time and *specific stirring power*, which has been dealt with further in Chapter 17, Section 17.5. For bottom gas flow

$$t_{\text{mix}} \propto Q^{-m} \propto P^{-m} \quad (20.1)$$

where m is a fraction, Q is the specific bottom gas flow rate (say, in $\text{Nm}^3 \cdot \text{s}^{-1}$ per tonne of liquid steel) and P is the specific stirring power (say, in watts/tonne of steel). The mixing time (t_{mix}) is normally taken for a *degree of mixing* of 0.95, i.e. 95% of perfect mixing.

P is related to Q by the equation:

$$P = \frac{340QT}{M} \ln \left(1 + \frac{0.707H}{P_0} \right) \quad (20.2)$$

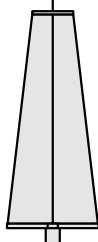
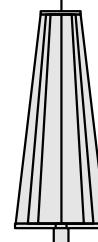
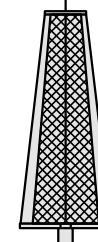
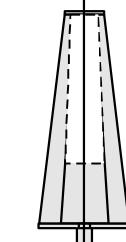
Porous plug	Single component plugs			Multi component plugs	
	Slot plug	Labyrinth plug	Star plug	Segment plug	Hybrid plug
					
Random pore structure	Separated slots	Crosslinked channels	Continuous slot	Random and directed pore structure	
High porosity					
Pressed		Cast			Pressed and cast

Figure 20.2 Different types of purging plugs.

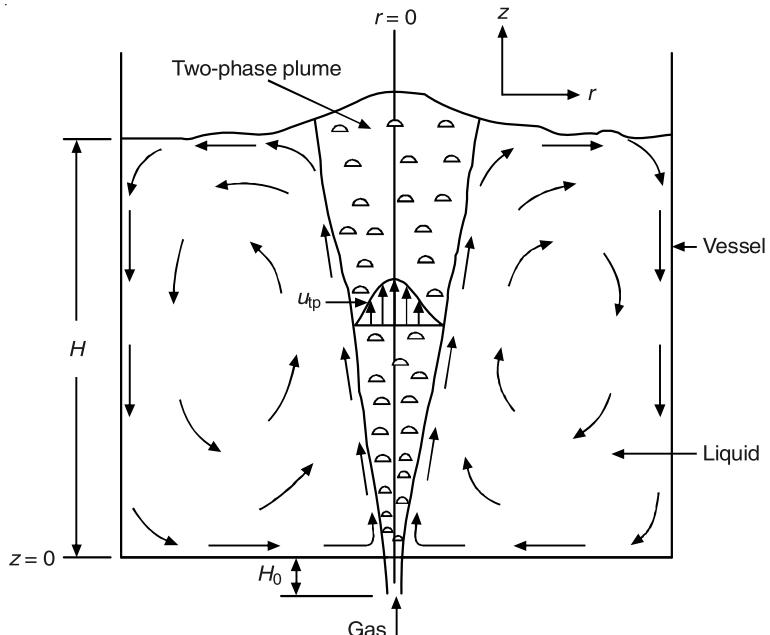


Figure 20.3 Schematic representation of the situation in a gas-stirred ladle.

where T is the temperature of the bath in kelvin, M is the mass of steel in tonne, H is the bath height in metre and P_0 is the atmospheric pressure in bar.

Figure 20.4 presents some t_{mix} vs. Q curves from a water model experiment (Mietz and Oeters, 1988). t_{mix} is determined by injecting a tracer (KCl solution is commonly used) into water as a pulse and then measuring the concentration of the tracer at some other appropriately selected location.

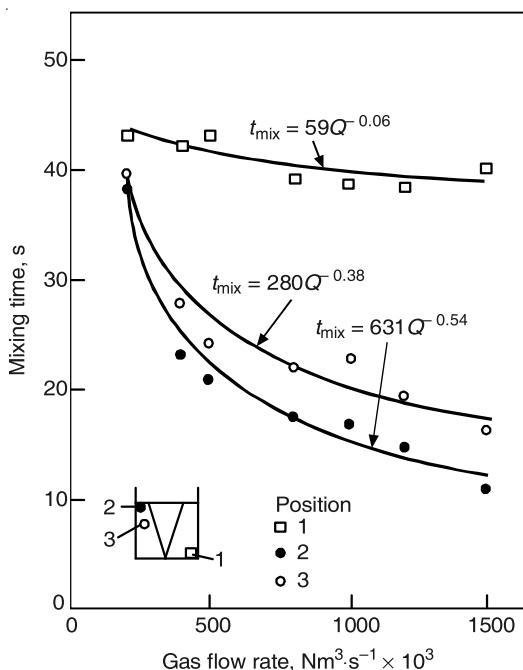


Figure 20.4 Mixing time vs. gas flow rate (centric nozzle, tracer addition in dead zone); 1, 2, 3 are locations of concentration measurements.

Figure 20.4 shows that t_{mix} in a large-size vessel depends on the location of the concentration measurement. In steelmaking ladles, the purging plug is eccentrically located at half radius at the bottom. Small ladles are fitted with one plug while large ladles have two plugs (Mazumdar and Guthrie, 1995).

EXAMPLE 20.1

- Calculate the specific stirring power (P) in watts/tonne of steel due to gas purging through bottom tuyere in a ladle. Given that $Q = 0.1 \text{ Nm}^3/\text{min/t}$, $T = 1900 \text{ K}$, $H = 1 \text{ m}$.
- If the mixing time for the above condition is 60 s, what would be its value if Q is doubled? Assume $m = 1/2$.