

## Chapter 13

# Alternative Oxygen Steelmaking Processes

*R. J. Fruehan*, Professor, Carnegie Mellon University

*C. L. Nassaralla*, Assistant Professor, Michigan Technological University

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### 13.1 Introduction

Virtually all of the steel in the United States and the world is produced either in an oxygen steel-making converter such as a BOF, LD, OBM (Q-BOP) etc. or an electric arc furnace (EAF). The only exception are the few remaining open hearth shops and a negligible amount in other processes such as the Energy Optimizing Furnace (EOF). This is understandable since much of the steel-making capacity was built or rebuilt from 1955 to 1975; the BOF and EAF were the best technologies available at the time and were compatible with large blast furnace production and relatively inexpensive scrap. However, these conditions are changing. It may be possible to produce iron economically on a small scale, 0.5 million tons per year, in new processes such as COREX and bath smelting. Steelmakers desire more flexibility to use scrap and hot metal and other forms of iron such as direct reduced iron (DRI) and iron carbide. Therefore, it is of value to re-examine steelmaking options.

There is currently a large amount of development work related to the electric arc furnace including scrap preheating, continuous melting and the use of fossil fuels and hot metal. These are discussed in detail in Chapter 10. In particular electric arc furnaces will use more oxygen to oxidize carbon and for post-combusting CO to CO<sub>2</sub>. The EAF will act more like a BOF using fossil fuel such as carbon in iron or in direct reduced (DRI) products. They will also use more virgin (non scrap) iron such as DRI and liquid hot metal. The alternative steelmaking processes examined in this chapter are those using no electrical energy.

Many alternative oxygen steelmaking processes were being developed in the 1970s such as IRSID continuous steelmaking, WORCRA and the Bethlehem continuous process. However, these never were commercialized, in part because most companies invested in conventional oxygen steelmaking and no new capacity was required. In recent years, other processes have been developed or proposed such as the EOF, the AISI continuous process, iron carbide continuous processes and IFCON. In this chapter, the general principles of process types are examined, selected steelmaking processes are technically evaluated and an economic analysis of selected processes is made. This has been the subject of a 1998 publication and much of this chapter comes from that publication.<sup>1</sup>

### 13.2 General Principles and Process Types

The steelmaking processes considered in this chapter can be classified into two general types: batch and continuous. The continuous processes can be classified as a continuous stirred tank reactor (CSTR) or plug flow reactors (PFR). The process types are shown in Fig. 13.1 along with their characteristics with regards to concentration and reaction rates.

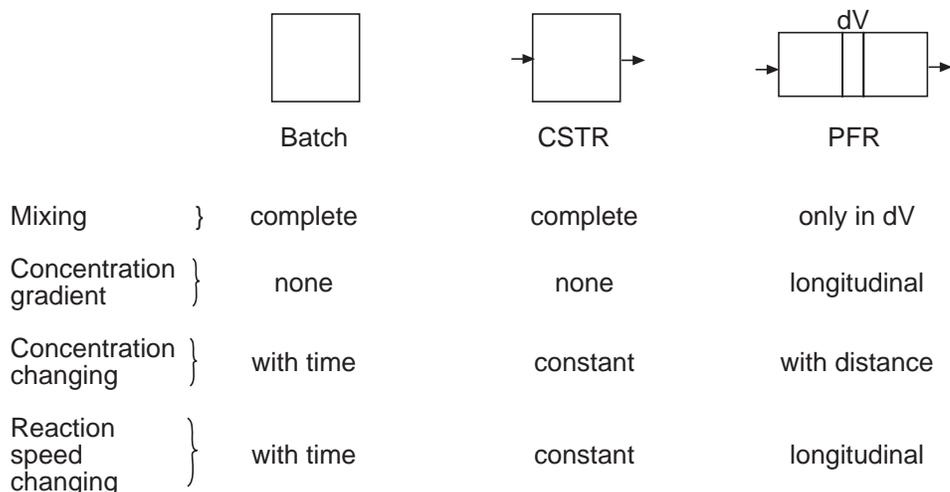


Fig. 13.1 Classification of steelmaking process types and their characteristics.

By performing a simple mass balance in a reactor, one can see that the degree of dispersion in the system defines the type of reactor where the process takes place. The contributions to backmixing of fluid flowing in the x direction can be described by the following equation<sup>2</sup>:

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} \quad (13.2.1)$$

where the parameter D is called the longitudinal dispersion coefficient, which characterizes the degree of backmixing during flow. Equation 13.2.1 can be written in a dimensionless form where  $z = (ut + x)/L$  and  $\Theta = t/t = tu/L$

$$\frac{\partial C}{\partial \Theta} = \left( \frac{D}{uL} \right) \frac{\partial^2 C}{\partial z^2} - \frac{\partial C}{\partial z} \quad (13.2.2)$$

where the dimensionless group  $(D/uL)$  is the inverse of Peclet number, and measures the extent of longitudinal dispersion. The Peclet number represents the ratio of material transferred by bulk flow to material transport by Eddy diffusion. L is the length of the reactor and u is the velocity in the direction of the flow. Therefore,

$$\frac{D}{uL} \rightarrow 0 \quad \text{negligible dispersion, (PFR)}$$

$$\frac{D}{uL} \rightarrow \infty \quad \text{large dispersion, (CSTR)}$$

It means that when the diffusion, plus convection inside the vessel, is small the reactor approaches an ideal plug flow reactor. On the other hand, when the diffusion and convection are large, the reactor approaches a continuous stirred tank reactor.

Szekely<sup>3</sup> has shown that for values of  $(D/uL)$  greater than 0.2 there would be extensive dispersion. He further concluded that furnaces of more than 100 meters in length may be required for minimal dispersion. Measurements of the  $(D/uL)$  from an actual operation of the WORCRA furnace give value of 0.1 indicating shorter furnaces may be satisfactory<sup>4</sup>. For plug flow Taylor<sup>8</sup> has shown that the length to width ratio,  $L/W$ , should be around 50 for this type of reactor to be a PFR. For highly

stirred steelmaking systems it is difficult to maintain a PFR. The closest such reactor in steelmaking is a continuous casting tundish. Even for a tundish where turbulence is kept to a minimum it deviates significantly from a perfect PFR. In some PFR steelmaking processes, such as WORCRA, the slag runs counter-current to the metal. This has advantages when refining hot metal with high phosphorus contents. A further discussion of trough concurrent and counter-current steelmaking is given by G. Brooks *et al*<sup>5</sup>.

The normal oxygen steelmaking processes, the EAF, and the EOF are batch processes. The AISI and IRSID processes are CSTR while the WORCRA, Bethlehem and the initial Iron Carbide processes should approach plug flow reactors; these processes are discussed later.

In steelmaking, the primary reaction is decarburization. At high carbon contents the rate is simply controlled by the oxygen input rate<sup>6</sup>. Below a critical carbon content, typically about 0.3% C for normal OSM, the rate is controlled by mass transfer of carbon, is first order with respect to carbon, and given by:

$$\frac{d\%C}{dt} = -k [\%C - \%C^e] \quad (13.2.3)$$

where %C and %C<sub>e</sub> are the carbon content and the equilibrium content with the slag respectively and k is the overall decarburization rate constant given by:

$$K = \frac{Amp}{W} \quad (13.2.4)$$

where

- A = reaction surface area
- m = mass transfer coefficient
- ρ = density of steel
- W = weight of steel

It has been shown that for a CSTR the steady state or tap carbon content, %C<sub>t</sub>, is given by<sup>7</sup>:

$$\%C_t = \frac{F [\%C_o]}{F + k} \quad (13.2.5)$$

where, F is the specific feed or production rate which is the production rate divided by the weight of steel in the vessel and %C<sub>o</sub> is the initial carbon content.

In attempting to partially convert a reactor with intense stirring into one with concentration differences like a PFR, barriers are sometimes installed with a small opening for metal flow as shown schematically in Fig. 13.2. In this case, the tap carbon content is given by:

$$\%C_t = \frac{(F + \beta) \%C_I}{F + \beta + k} \quad (13.2.6)$$

where β is the backmixing flow rate through the opening and %C<sub>I</sub> is the carbon content of steel in Reactor I. In this case the W used in computing F is that of Reactor II.

### 13.3 Specific Alternative Steelmaking Processes

In this section, selected alternative steelmaking processes will be reviewed. A brief description, current status and an evaluation of the processes is given. The technical evaluation addresses issues such as productivity, yield and refining capability. First batch processes are discussed followed by CSTR and PFR. The processes considered are summarized in Table 13.1 with respect to type, typical charge make-up and current status.

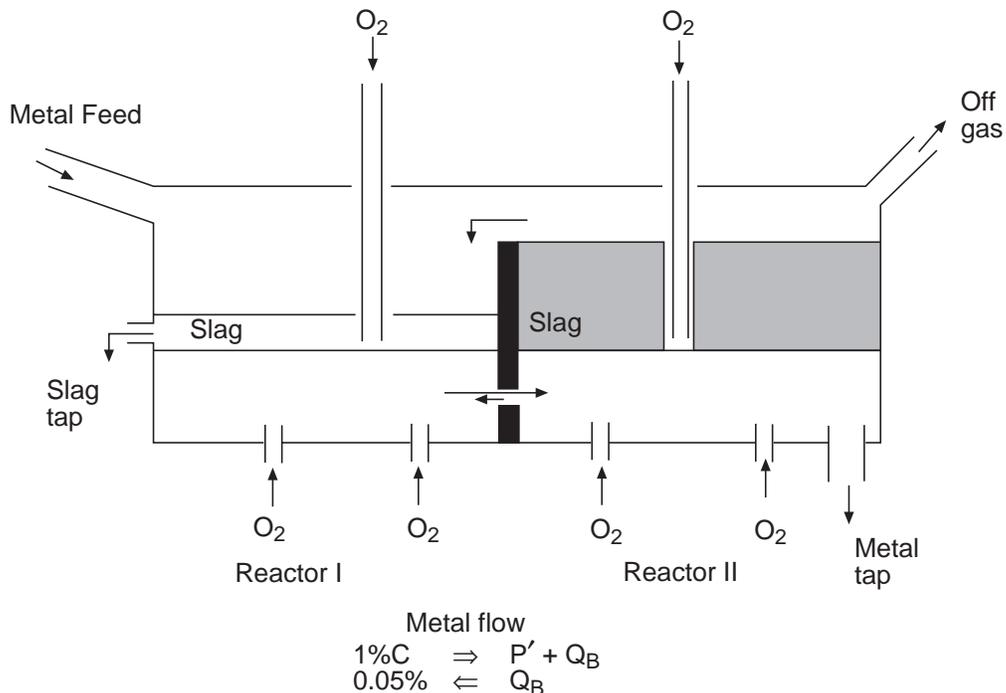


Fig. 13.2 Schematic diagram of a trough process with a barrier.

Table 13.1 Classification and Status of Steelmaking Processes.

Process	Type	Typical Charge	Current Status
BOF	batch	80% hot metal 20% scrap	65% of world production
EAF	batch	70–100% scrap 0–30% other	35% of world production
EOF (Brazil)	batch	50% hot metal 50% scrap	commercial
IRSID (France)	CSTR*	80% hot metal	pilot plant in 1970s
AISI (U.S.)	CSTR	hot metal	pilot plant in 1980s
WORCA (Australia)	PFR**	hot metal	pilot plant in 1970s
Bethlehem (U.S.)	PFR	hot metal	pilot plant in 1970s
NRIM (Japan)	PFR	hot metal	pilot plant in 1970s
COSMOS (U.S.)	PFR	hot metal	pilot scale in 1980s
IFCON (South Africa)	PFR	ore, coal	pilot plant in 1990s
Carbide to steel	CSTR; PFR	iron carbide	concept

\* CSTR = continuous stirred tank reactor; \*\* PFR = plug flow reactor.

### 13.3.1 Energy Optimizing Furnace (EOF)

The EOF is essentially a batch oxygen steelmaking process with high post-combustion, with coal additions and extensive scrap preheating; a schematic diagram is shown in Fig. 13.3.<sup>9</sup> The process theoretically can charge up to 100% scrap, but typically 40–60% scrap is used. Hot metal is charged into the vessel followed by scrap from the lower preheating chamber. In some cases, a second scrap charge is added about five minutes into the blow. The scrap is preheated in a series of preheat chambers to about 800 to 1200°C. For a 50/50 scrap to hot metal mix about 70 m<sup>3</sup>/ton of