Dynamic Modeling of Oxygen Steelmaking Process: A Multi-Zone Kinetic Approach

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INTRODUCTION

The primary aim of a BOF (basic oxygen furnace) process is to refine the impurities like C, Si, Mn, P and S from the hot metal and to achieve the optimal temperature of the liquid steel for further downstream treatment. The refining process involves oxidation of these impurities to their respective oxides and is removed by either slag or gas phase. The oxidizing refining reactions are complex in nature as it involves with multi-component and multiple phases exhibiting temperature more than 1600 deg C. In addition, due to injections of supersonic oxygen jet into the liquid steel, the liquid metal undergoes highly turbulent fluid flow and the reactor is sub-divided into several reaction zones. The physicochemical properties in the reactions zones are different from each other and are transient in nature during the blowing process. For example, the region at which the oxygen jet impacts on the bath surface is known as 'hot spot', experiences temperature as high as 2000 deg C, which is 500 to 800 deg C higher than the molten bath temperature. This temperature gradient can make a marked difference in kinetics and thermodynamic equilibrium nature of reaction parameters in different regions of the converter.

Similarly, due to the interaction of high-speed gas jet with the iron bath, a large number of metal fragments are ejected into the slag phase. It is observed that these metal fractions undergo a large proportion of refining by circulating through the emulsion phase. This is called the emulsion zone theory of the metal refining. [1, 2]The theory became clear when the researchers found the evidence of droplet swelling due to the formation of CO gas. [3] Brooks *et al.*[4] by analysis of the experimental results of Fruehan and coworkers, mathematically showed that the bloating of drops can increase their residence time up to ~60s as compared to the fraction of a second when there is no decrease in density in the case of non-bloating drops. This mathematical formulation led the foundation of "bloated droplet theory' and it opened a window for modeling of refining in emulsion zone by simulating the reaction kinetics of individual metal droplets. Though the importance of emulsion on refining in BOF was realized in the early development of the steelmaking process, but a mathematical treatment to quantify the proportion of refining by emulsion was first developed by Dogan *et al.* [5] for modeling of decarburization in an industrial converter. The authors estimated that emulsion zone contributes about 60% of the decarburization in a BOF converter.

Over the last decade due to a large increase in computing capacity, researchers have been engaged in developing dynamic models considering the fundamental understanding of BOF process.[6-9] Realizing that the steelmaking reactions rarely attains equilibrium during the blowing operation, the principle of kinetics has appealed to many workers. However, many of these kinetic models were based on single zone theory represented by a first order rate equation.[7, 9] The biggest challenge in this approach is to quantify the rate parameters, especially the slag-metal interfacial area that is no doubt a strong function of dynamic process conditions, varies from heat to heat and process to process. The inability to quantify the total reaction area means that kinetic models often rely on some fitting parameters, which is specific to particular plant conditions.[7, 10, 11]

The various reactions taking place in different regions of the BOF converter is illustrated in Fig. 1. As can be seen from the figure, the physicochemical characteristics of reaction interfaces vary significantly across different regions of the converter. For example, the reaction at jet impact region occurs at gas/liquid interface whereas reaction between the metal drop and slag takes in the region above the melt phase. The kinetic rate parameters, which are a strong function of interfacial area and