Original Article

Slag Splashing: simulation and analysis of the slags conditions

Inamara Amanda Souza Santos a, *, Vanessa Rodrigues de Medeiros Santos b, Willian dos Reis Lima b, c, Aline Lime da Silva b, Breno Totti Maia d, José Roberto de Oliveira a

a Instituto Federal do Espírito Santo (IFES), Vitória, ES, Brazil
b Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, MG, Brazil
c Lumar Metals Research, Santana do Paraíso, MG, Brazil

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ABSTRACT

The successful application of the repair and prevention of LD converters refractories technique called Slag Splashing requires a close control of the slag physicochemical properties (basicity, viscosity and surface tension), as well as suitable selection of operational parameters and geometric configurations. In this paper, a Slag Splashing process cold simulation is carried out, focusing on a case study of an LD converter from Ternium Brasil Company, located in Rio de Janeiro. The cold physical simulation showed the effect of solids fraction and viscosity on slag projection intensity, evidencing how the coating is affected. Finally, computational thermodynamics shows the evolution of the phases and viscosity during N2 blowing, allowing correlating results of the cold model with industrial practice.

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1. Introduction

The wear of the refractory working lining of an oxygen converter is explained by means of a combination of thermal, chemical and mechanical factors [1,2]. Aiming at reducing the wear, with the benefit of increasing the useful life of the converters, one of the most used techniques of maintenance and repair of the refractory working line consists in the projection of slag towards the hot face of the converter via nitrogen blowing lance — a technique known as Slag Splashing. For achieving an effective process, many variables should be controlled, including those related to the physicochemical properties of the slag (basicity, viscosity and surface tension), as well as the selection of suitable operational parameters (lance height, nitrogen flowrate, static or moving lance) and geometric configurations (number of lance holes, hole angle, the converter dimensions).

In this context, several studies have been carried out to improve the understanding of the effect of these variables [3–5]. Finally, the importance of controlling the viscosity of the slag is emphasized. From visual observation during Slag Splashing practice, one can easily verify that more viscous slags do not have the same intensity of projection in comparison with more fluidic slags. According to Garg and Peaslee
[5], despite of the higher intensity of projection, very fluidic slags are not interesting, since they do not adhere to the wall. According to Auad [6], determining the effective viscosity of slag is a complex task and there is a need for more assertive models for its prediction; there is an optimal range of effective viscosity that will account for part of the success of Slag Splashing.

In this context, the present work has the following objectives: (1) perform cold physical simulation in a 1/10 scale converter model, evaluating the influence of the effective viscosity on the intensity and projection height of the slag; (2) perform thermodynamic simulations aiming at establishing comparisons between viscosities from cold model and actual LD slags, evaluating the possibility of transposition of the laboratory physical model results to the steelmaking industry.

2. Methodology

2.1. Cold physical simulation of the Slag Splashing technique

A physical model of a Ternium Brazil LD converter (340 tons), in a scale of 1:10, was built. During laboratorial tests, air is employed for simulating N₂ blow. The following operating conditions were adopted: air flow rate of 120 m³/h, blowing time of 1 min, with a bath-lance distance (DBL) of 400 mm. The physical model used is outlined in Fig. 1.

According to Maia et al. [7], by similarity, one can simulate molten slags. In the present study, the effect of solids fraction is included in physical model for evaluating effective viscosity. Polypropylene particles have been previously used in cold experiments for investigating inclusions removal in steelmaking ladle. Based on this fact, such a material was also chosen to simulate solids fraction and viscosity variation of the slag. The density of polypropylene particles is measured by means of Archimedes method; from this value, the number of particles that must be added to the soybean oil can be calculated in order to obtain the desired solids fraction of the system. All viscosities were measured in a Brookfield viscometer at room temperature, and the values were compared with effective viscosity predicted by thermodynamic simulation along with Einstein–Roscoe equation, considering slag composition and temperature from industrial practice.

2.2. Thermodynamic simulation and viscosity determination

In order to estimate the effective viscosity of the slag at a given operating temperature, essentially three steps are followed:

(a) From composition of the slag, considering a slag composition from industrial practice, thermodynamic equilibrium calculation is performed in the Equilib module of FactSage software version 7.1. In this way, phases and their respective compositions are determined. Therefore, the fraction of solids in equilibrium with the liquid phase of the slag can be known. The databases used are: FToxid-SLAGA (liquid phase of the slag), FToxid-MeO (solid solution describing Magnesium–Wüstite phase, (Mg, Mn, Fe)O) and FToxid-bC2SA (solid solution which describes the calcium silicate phase, (Ca, Mg, Fe, Mn)₂SiO₄).

(b) Determination of liquid phase viscosity of the slag using the Viscosity module and Melts database.

(c) Determination of effective viscosity from Einstein–Roscoe equation (Eq. (1)), where solids fraction, \( f \), is obtained from step (a). It is worth mentioning that Eq. (1) relies on the original consideration of spherical particles, where \( \eta \) stands for the viscosity of liquid phase, and \( \eta_0 \) corresponds to the effective viscosity, including solid particles.

\[
\eta = \eta_0 (1 - 1.35f)^{-2.5}
\]  

(1)

3. Results and discussion

3.1. Physical cold simulation: influence of effective viscosity on slag projection

In Fig. 2(a), it is observed that, for slag with 10% solids fraction, the projection is concentrated in the upper parts of the vessel and also reaches the upper cone; with a solids fraction of 20%
As the temperature of the solid-liquid phase is increased, the viscosity of the system decreases. This is shown in Fig. 2, which illustrates the effect of solids fraction on the slag projection during air blow. Fractions of simulated solids and measured viscosities: (a) 10% (0.0481 Pa s), (b) 20% (0.0737 Pa s) and (c) 30% (0.4421 Pa s).

The Fig. 2(b) shows that the projection is concentrated in an intermediate region of the vessel, without significant projection in the upper cone, and with 30% solids, the slag hardly reaches the upper parts of the vessel focusing on its middle region (Fig. 2(c)).

3.2 Thermodynamic simulation: solids fraction prediction and evolution of effective viscosity during Slag Splashing

As the interaction between the slag and N$_2$ jet occurs, slag temperature is gradually reduced, which substantially impacts the phase distribution and, consequently, the effective viscosity. In order to illustrate this effect, was take sample of industrial slag with the following composition (% by mass). This sample was considered a representative average of normal industrial process: SiO$_2$: 15.6, Al$_2$O$_3$: 3.03, FeO: 22.15, CaO: 46.67, MgO: 7.95, MnO: 3.08, P$_2$O$_5$: 1.52. From Fig. 3, one can observe that only Magnesium–Wüstite solid solution coexists with liquid phase in temperature range of 1400–1690 °C; at lower temperatures, precipitation of calcium silicate also occurs. The increase in total solids fraction with decreasing temperature can be seen in Fig. 4(a). Fig. 4(b) shows the viscosity of the liquid phase of the slag along with effective viscosity, which includes solids fraction in the Einstein–Roscoe model. One can see that, for temperatures greater than 1525 °C, liquid phase viscosity and effective viscosity are approximately equal, indicating that the effect of solids is not pronounced in fractions below 10%. However, at temperatures below 1500 °C, solids fraction causes an evident increase in the effective viscosity.

Industrial slag viscosities were predicted using thermodynamic simulation and compared with experimental cold viscosity values. As shown in Fig. 5, for a maximum of 25% solid fraction, the viscosity values predicted by the thermodynamic model are consistent with laboratory temperature measurements for the soybean oil + polypropylene particle system. For the 30% solids fraction, there is a significant deviation between predicted and measured values, suggesting that the Einstein–Roscoe parameters need to be adjusted to handle higher concentrations of emulsion solids. Given the similarity of the thermodynamic and experimental results of the cold model, it can be suggested that computational thermodynamics combined with the development of accurate models for effective viscosity would be very important to establish correlations between the results of cold physical simulation and those of industrial practice.
4. Conclusion

The conclusions of the present study are as follows:

(1) It was possible to perform the physical simulation of Slag Splashing process, with easiness of visualization of the converter coating as a function of solids fraction present in the slag.

(2) Thermodynamic simulation allows evaluating the phases and the viscosity evolution during Slag Splashing.

(3) The agreement between the values predicted by the thermodynamic model and the cold tests for solid fraction slag are limited for range below 30%.

(4) Computational thermodynamics has the potential to contribute to correlations between simulated results in the physical laboratory and those practiced in industry.

Fig. 4 – Influence of temperature on (a) solids fraction and (b) liquid phase and effective viscosity.

Fig. 5 – Effective viscosity as a function of solids fraction. Experimental values of cold measurements, soybean oil + polypropylene particles, and thermodynamic simulation of slag cooling.

Conflicts of interest

The authors declare no conflicts of interest.

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