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Heat Transfer in Steelmaking Ladle

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Abstract: The heat transfer in a steelmaking ladle was studied. The evaluation of heat transfer of the steel was performed by measuring steel temperature in points including all refining steel process. In the ladle, the temperatures in the refractories and the shell were also measured. To evaluate the thermal profile between the hot and cold faces of the ladle in the slag line position, an experiment which shows the importance of thermal contact resistance was carried out. Higher heat losses in the tapping and the vacuum were verified. The temperature measurements of the ladle indicate distinct thermal profiles in each stage of steel refining. Moreover, as each stage of the process depends on the previous one, the complexity of the ladle thermal control is incremental. So a complete model of heat losses in the ladle is complex.

Key words: heat transfer; steelmaking; ladle; refractory; mild steel

The decrease in heat losses during steel refining could reduce steel production costs and increase both steel productivity and quality. Reduction in heat losses could minimize thermal oscillations in the liquid steel during the process, facilitating steel temperature control in its downstream production and more predictable physical-chemical phenomena throughout steel refining. It is good to reduce thermal oscillations, because the peaks in the steel temperature are associated with a high increase in refractories and electrodes consumption. The reduction of heat losses supplies a more thermally stable process and means a reduction in batches losses, lesser times in stops and reheating necessary to maintain the steel in the adequate temperature for casting. As said by Nath N K et al[1], proper control of process parameters during ladle furnace processing of liquid steel is essential.

Then, in steel refining, a good control in liquid steel temperature is important, which depends on heat losses. The importance of liquid steel temperature control was the object of many studies, such as Volkova O and Janke D[2], Jonsson P J and Jonsson L T I[3], Xia J L and Ahokainen T[4], Austin P R et al[5]. These researchers developed models to predict steel temperature in the steel secondary treatment. Generally, these models correspond to parts of refining process, or when they approach to the whole process, they are simplified owing to the complexity of this problem. In these studies, the model presents good compatibility with the data found in the practice; however, its generalization could incur in errors, because of the peculiarities of each steel refining process and/or each steel refining plant.

The programming and control of the steel refining process have a direct impact on the heat losses of the system ladle-steel as shown in the published report review of Fredman T P[6]. Baker R and Irving W R[7] gave emphasis on the need to provide a correctly balanced charge to the steelmaking process, minimization of slag carryover between vessels, and maintenance of a strict temperature between steel plant and continuous casting machines.

The knowledge of heat losses in steelmaking helps to reach an adequate temperature to the casting and could reduce problems like freezing and breakout in the ingot.

The present study is to investigate the main sources of heat losses in the refining of steel (mechanical construction type), using liquid steel temperature and temperatures in the ladle (refractories

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and shell).

1 Materials and Methods

A ladle used in the refining of mild steel was instrumented with N-type thermocouples in the slag line position on the wear refractory back face of wear zone, which is MgO-C brick. To evaluate the heat gradients and temperatures in diverse points of the ladle, as the external shell and wear refractories faces, a monochromatic pyrometer was used.

Concomitantly, the steel temperatures between the tapping and casting were measured with an immersion thermocouple.

From the values of temperature measurements and the intervals of time in the process, the heat transfer was calculated in terms of heat losses through the average energy of the liquid steel between the tapping and casting using Eqn. (1) to Eqn. (4).

$$Q=m\times c\times \Delta T \quad (1)$$

$$Q=E_t \quad (2)$$

$$P_a=\frac{E_t}{\Delta t_s} \quad (3)$$

$$C=P_a\times \Delta t_h \quad (4)$$

where, Q is amount of heat energy, GJ; m is mass, kg; c is specific heat capacity of liquid shell, ($J \cdot kg^{-1} \cdot K^{-1}$); ΔT is change in temperature, K; E_t is thermal energy, J; P_a is average power, MW; Δt_s is change in time, s; C is energy consumption, MWh; and Δt_h is change in time, h.

Eqn. (1) is the classic equation of the calorimetry and expresses the amount of heat supplied or received for a material under variation of the temperature. In Eqn. (2), simplification is admitted so that all the heat energy lost or received by the liquid steel (E_t) is converted and transferred under the heat form Q. To know the consumption energy [C, in the Eqn. (4)], it is necessary to know the average power [relation of energy per unit time in seconds—Eqn. (3)] and multiply it with the variation of the time in hours.

To evaluate the thermal profile between the hot and cold zones of the ladle in the slag line position, an experiment was performed, as shown in Fig. 1. All the materials between wear zone and shell were disposed like in the ladle, but with its half thickness size with the format of 85 mm versus 85 mm. Each material is set with two K-type thermocouples and the temperature of the hot source was maintained at 600 ℃ since higher temperature could result in great

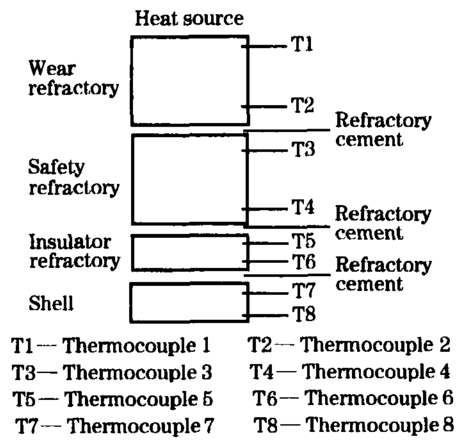

Fig. 1 Experimental scheme of simulating thermal profile between hot and cold zones of ladle in slag line position

degradation in the wear refractory, because of its decarbonation. The materials used in the experiment were involved with insulator material.

2 Results and Discussion

Table 1 presents the typical steel temperature during the steel refining process. It initiates in the tapping of fused steel, in which the steel is drained to the ladle and transported to the ladle furnace, where the steel is heated to an adequate temperature during the casting. Then, the ladle with the steel passes for the vacuum system to take out the gases dissolved in the steel and finally, it is directed for the casting. It can be noted in Table 1 that the highest heat losses occur in the tapping and in the vacuum, as can be observed in the negative (decrease) change of temperature.

For tapping, the steel is about 1 680 ℃ when it lost heat for the work environment and, mainly, for the ladle, which has lower temperature, as shown in Fig. 2. The heating system of the ladle provides heterogeneous temperatures, in which the temperature in some part of the refractories (Fig. 2) could be 1 000 ℃ less than the liquid steel.

In this study, using Eqn. (2), for a total of 55 t of liquid steel between the tapping and ladle furnace stages, the amount of heat losses for the liquid steel (Q) arrives at 3. 47 GJ, considering a specific heat of the liquid steel of 630 $J \cdot kg^{-1} \cdot K^{-1}$. The heat loss during this stage, here calculated as the energy consumption for the liquid steel in the form of heat [C of Eqn. (4)], was approximately 0. 96 MWh.

Therefore, in the tapping, the ladles with lower temperatures are the ones that provoke the highest