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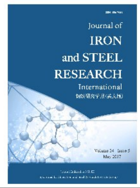

Thermal analysis of walls in a new-type billet caster tundish with a vacuum shell

Jian-bo Xie[1,2], Jian-an Zhou[1,2,*], Lan-hua Zhou[3], Bao Wang[1,2], Hua Zhang[1,2]

[1] State Key Laboratory of Refractories & Metallurgy, Wuhan University of Science & Technology, Wuhan 430081, Hubei, China

[2] Key Laboratory of Ferrous Metallurgy and Resources Utilization, Ministry of Education, Wuhan University of Science & Technology, Wuhan 430081, Hubei, China

[3] School of Resources and Environmental Engineering, Panzhihua University, Panzhihua 617000, Sichuan, China

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ABSTRACT

To reduce thermal loss from molten steel in a tundish during continuous casting production, a new tundish fabricated by welding radiation-proof steel plates onto the steel plates of the exterior walls of a billet caster tundish was proposed. This new tundish was used to investigate the effect of pressures inside the vacuum chamber on the uniformity of the temperature of molten steel and the thermal conditions of the vacuum layer. The results show that the conversion radiation coefficient is not sensitive to pressure and its value at high temperatures is merely 1.5 times greater than that at low temperatures. Pressure is the key factor affecting additional factor of conversion convection. This factor is more than 100 times greater at 10^5 Pa than at 10^2 Pa, and the temperature at inner points at 10^2 Pa is, on average, 4 K higher than that at 10^5 Pa. Meanwhile, the local temperature difference of the inlet at 10^2 Pa is 1 K higher than that at 10^5 Pa. Thus, the proposed vacuum billet caster tundish can achieve low superheat teeming of steel because of the thermal preservation capability of the vacuum, which helps to reduce the tapping temperature and improve the uniformity of the temperature of steel.

Symbol List

C_V—Constant volume specific heat of air, kJ · kg^{-1} · K^{-1};
g—Gravitational acceleration, m · s^{-2};
L—Qualitative size, m;
q—Heat flux, W · m^{-2};
ΔT—Temperature difference, K;
T—Temperature, K;
T_a—High temperature of vacuum chamber, K;
T_{av}—Average temperature, K;
T_b— Low temperature of vacuum chamber, K;
α—Thermal diffusion coefficient, m^2 · s^{-1};
β—Volumetric thermal expansion coefficient, $\beta=1/T_{av}$;
γ—Air thermal insulation exponential;
δ—Thickness of vacuum chamber, mm;
ε_i—Emissivity;
ε_k—Conversion thermal conductivity of convection;
λ— Comprehensive thermal conductivity, W · m^{-1} · K^{-1};
λ_1—Thermal conductivity, W · m^{-1} · K^{-1};
λ_2—Conversion thermal conductivity of radiation, W · m^{-1} · K^{-1};
μ—Air molecular viscosity, J · m^{-1} · K^{-1};
υ — Kinematic viscosity, m · s^{-2};
σ_0— Stefan Boltzmann constant, W · m^{-2} · K^{-1}.

1. Introduction

Thermal loss from liquid steel in a tundish is always inherently incurred during continuous casting process[1], especially through the melt surface and the tundish walls. However, a greater superheat will substantially weaken inclusions removal[2], cause central segregation[3], and even lead to mold breakout. Over the past three decades, several measures have been used to maintain the temperature of liquid steel within a specified narrow range, which can be divided into two groups: thermal insulation and external heating. Slag[4] and cover are two effective measures to reduce thermal loss through the top surface of a melt. Chakraborty and Sahai[5-7] investigated the effect of different slag-layer thicknesses on the phenomenon of temperature stratification. Moreover, the refractory lining of the tundish also plays a critical role in heat transfer; refractory linings should withstand thermal shock, prevent

* Corresponding author. Prof.
E-mail address: *zhou_jianan@sina.com* (*J. A. Zhou*).

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thermal loss, prevent oxidation of the liquid steel, and resist corrosion[8]. The other approach is external heating by induction or plasma. Such technologies have been successfully applied in the facilities of a few companies, including Nippon Steel[9] and Kawasaki Steel Corporation. In the plasma system, a plasma torch generates a plasma arc by ionizing inert gas (e. g., Ar or N_2). Matsumoto et al. [10] and Kubota et al. [11] reported that the heating efficiency of a plasma system is in the range from 60% to 80% and that the variation of temperature is not more than 5 ℃ even during unsteady-state operation, which enables the basic oxygen furnace (BOF) tapping temperature to be reduced by 20 ℃. In comparison to plasma, a 1000-kW induction heater was demonstrated to achieve 90% greater thermal efficiency[12,13]. However, external heating technologies for tundishes have not been extensively used because of the heavy investment required, the potential danger, and the exfoliation of refractories[14].

Because of thermal insulation of vacuum, the authors designed a new type of tundish[15] surrounded by a vacuum cavity chamber to reduce the thermal loss from the tundish walls by reducing the vacuum absolute pressures and to explore the effect of the absolute pressure on the thermal conditions inside the vacuum chamber. And the temperatures inside the vacuum chamber were measured and the temperatures of molten steel in the tundish were also measured in a five-strand billet caster tundish.

2. Experimental

2.1. Vacuum billet caster tundish

The wall of a conventional billet caster tundish comprises the working layer, the permanent layer, and the thermal insulation layer; their physical parameters are shown in Table 1. By contrast, the wall of a vacuum billet caster tundish comprises four layers, as shown in Fig. 1. When fabricating the vacuum billet caster tundish, all of the inner surfaces of the steel plates (Q-345) were polished and subsequently coated with radiation-proof materials prior to welding the plates. These polished steel plates were subsequently welded onto the exterior walls of a conventional billet caster tundish to form cavity shells. The spherical valves and pressure gages were installed onto the external walls of the welded tundish as the tundish was being constructed. After the air in the cavity was evacuated by a mechanical vacuum pump, the cavity shell became the vacuum layer; the welded tundish is referred to hereafter as the vacuum billet caster tundish. The physical modeling was performed on the basis of a five-strand billet caster tundish. The vacuum layer of the tundish does not extend to the bottom wall of the tundish.

Table 1
Parameters of tundish walls

Component	Material	Thermal conductivity/($W \cdot m^{-1} \cdot K^{-1}$)	Thickness/mm
Working layer	Magnesia brick	$(2.10 \pm 0.19) \times 10^{-3} T$	50
Permanence layer	Light clay brick	$(0.26-0.29) \times 10^{-3} T$	120
Thermal insulation layer	Asbestos board	$(0.167-0.190) \times 10^{-3} T$	30
Vacuum layer		λ	100

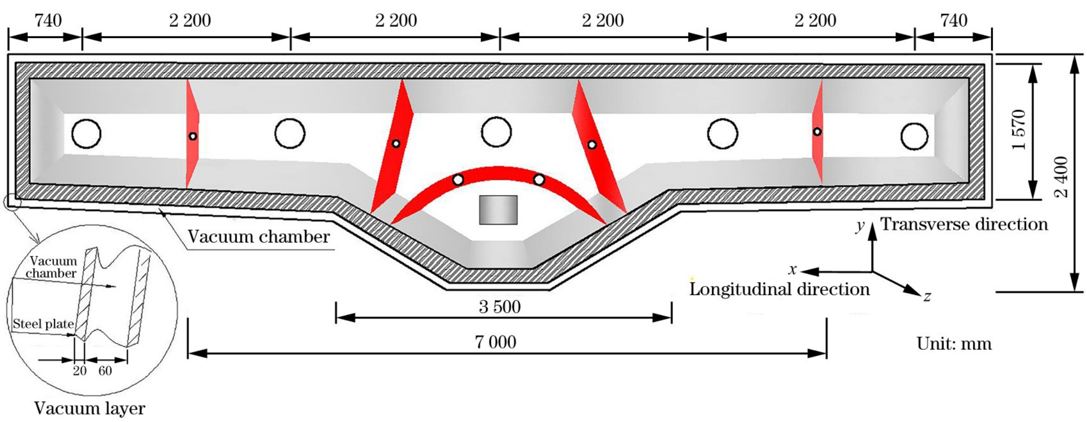

Fig. 1. Structure devices of vacuum billet caster tundish.

2.2. Experimental method

The experimental procedure is described at the beginning of the trials. First, the spherical valves were opened and the air in the vacuum chamber was pumped out by a mechanical vacuum pump (2XZ-2); the pressure was held stable for 1—3 h. The pumping procedures for the vacuum chamber were designed such that the pressure is reduced from high to low, which can save time and improve working efficiency. In the