ANNALS OF FACULTY ENGINEERING HUNEDOARA
– INTERNATIONAL JOURNAL OF ENGINEERING
Tome IX (Year 2011). Extra Fascicule. (ISSN 1584 – 2673)

[1.] Vasile PUȚAN

HEAT LOSS FLUXES FROM STEEL MELT TO DIFFERENT BOUNDARY REGIONS OF A LADLE

[1.] UNIVERSITY "POLITEHNICA" TIMIŞOARA, FACULTY OF ENGINEERING OF HUNEDOARA, ROMANIA

ABSTRACT: One of the important outputs of the heat conduction model is the heat loss flux from steel melt to different heat transfer regions of a ladle. These papers present examples of the predicted heat loss fluxes to different heat transfer regions of mid-aged 105-tonne steel ladles lined with alumina and spinel as working refractory in walls. The heat loss fluxes to different ladle heat transfer regions, except for the top free surface, generally exhibit exponential decay with time.
KEYWORDS: steel ladle, numerical simulation, CFD, fluid flow, heat loss

❖ INTRODUCTION

In modern steelmaking throughout the world, continuous casting (CC) is the dominating process for producing semi-finished steel products (billets, blooms and slabs). However, the CC process requires a strict control on the temperature of liquid steel in the tundish. Further, the tundish temperature is influenced considerably by the temperature of teeming steel streams coming from the ladles. Therefore, it would be of practical importance to predict the teeming stream temperature as a parameter for further prediction and control of the steel temperature in tundishes.

Three numerical models were developed. Firstly, a one-dimensional (ID) numerical model for simulating heat conduction in ladle wall, bottom and top slag layer for the whole ladle operation cycle was established. This model was used for predicting steel ladle heat loss fluxes. Secondly, using the predicted heat loss fluxes as thermal boundary conditions, a two-dimensional (2D) CFD numerical model was developed for simulating natural convection flow in steel ladles during holding. Thirdly, a three-dimensional (3D) CFD model was also developed for simulating fluid dynamics in steel ladles with drainage flows during teeming. The 3D CFD model was used for predicting the teeming stream temperatures.

In the present parameter numerical experiments, two types of 105-tonne steel ladles were investigated: the one lined with alumina as working refractory in wall, the other lined with spinel as the working refractory in wall. Other lining materials were the same for both types of ladles. Totally 18 simulation cases are performed for the two types of steel ladles lined with alumina and spinel, respectively. Table 1 gives the parameter of numerical experiments.

Table 1. Parameter of numerical experiments

Simulation case No. *		Hot-face temperature [^{0}C]	Slag thickness ** [mm]	Holding time [min]	Teeming rate*** [t/min]
A1	S1	1000	83	30	2,816
A2	S2	1000	55	20	2,488
A3	S3	1000	28	10	2,229
A4	S4	800	55	30	2,229
A5	S5	800	28	20	2,816
A6	S6	800	83	10	2,488
A7	S7	600	28	30	2,488
A8	S8	600	83	20	2,229
A9	S9	600	55	10	2,816

* "A" refers to alumina ladles and "S" refers to spinel ladles
** The slag thickness of 28, 55 and 83 mm corresponds, respectively, to 500, 1000 and 1500 kg slag
*** The teeming rates are calculated based on 105 tonne liquid steel drained for 38, 43 and 48 minutes, respectively.

❖ SIMULATION METHODS

The mathematical models used in this work for carrying out numerical experiments were established in two computer software environments. The one is a special-purpose computer program, TEMPSIM [1], for only simulating heat transfer in steel ladles. The other is a general-purpose CFD modelling computer code, ADINA-F (Automatic Dynamic Incremental Nonlinear Analysis). The former numerically solves the heat conduction equation for ladle wall, bottom and top slag layer, while the latter numerically solves the Navier-Stokes type momentum, energy and turbulence equation group for the steel melt bounded by ladle wall, bottom and top slag layer.

TEMPSIM assumes the heat conduction is either in radial direction through ladle wall or in axial direction through ladle bottom and top slag layer. Accordingly, it was used to establish the ID heat conduction model described previously (Fig. 1). This heat conduction numerical model was applied in this work for predicting heat loss fluxes. Figure 2a schematically illustrates the computation domain with grid lines defined by the heat conduction model. Note that the computation domain used by the model excludes the region marked with "ABCD" standing for the steel bath. Moreover, in this computation domain, five heat transfer regions named as "Bottom", "Top", "Side1", "Side2" and "Side3" are further defined, (Fig. 2a). The region "Bottom" is the interface between steel melt and bottom lining; the region "Top" is the interface between steel melt and top slag layer; the regions "Side1", "Side2" and "Side3" are, respectively, the interfaces between steel melt and sidewall lining at different levels.

With all these numerical models available, a three-step modelling strategy was employed in the present work in which,

a. the ID heat conduction model was first implemented to the wall, bottom and top slag layer in steel ladles to provide the thermal boundary conditions (e.g., heat loss fluxes) to the 2D and 3D CFD models; then,
b. the 2D CFD model was applied to simulate natural convection in the ladles and to provide the initial conditions (velocity and temperature profiles) to the 3D CFD model; and, finally,
c. the 3D CFD model was executed to simulate fluid flow and heat transfer in the ladles with drainage flows during teeming and to predict the teeming stream temperatures. This three-step modelling methodology was applied to each simulation case listed in Table 1.

Table 2. Thermal-physical properties of lining materials used in numerical simulations [2]

Lining material	Density [kg/m^3]	Heat conductivity [W/m ^{0}C]					Heat capacity [J/kg ^{0}C]				
		200 ^{0}C	600 ^{0}C	1000 ^{0}C	1400 ^{0}C	1600 ^{0}C	200 ^{0}C	600 ^{0}C	1000 ^{0}C	1400 ^{0}C	1600 ^{0}C
Ceramic fibre	80	0,02	0,03	0,04	0,04	0,04	850	1000	1100	1200	1200
Chamotte	2100	1,56	1,65	1,76	1,87	1,87	860	977	1084	1200	1200
Slag line brick	3110	4,00	2,60	2,09	2,00	2,00	1010	1194	1280	1368	1419
80%Al_2O_3	2900	2,15	2,00	1,84	1,74	1,65	850	1030	1125	1180	1200
Spinel (10 % C)	3000	7,40	7,40	7,40	7,40	7,40	850	1030	1125	1180	1200
Bottom mass	2750	1,00	1,30	1,50	1,70	1,80	850	1030	1125	1180	1200
Slag scull	3648	3,91	3,46	3,41	3,08	2,99	840	993	1073	1120	1137

❖ SIMULATION CONDITIONS

In steel plant, the steel ladles are operated in the following cycle: tapping (from electric furnace EBT) → ladle furnace LF → continuous casting CC → ladle maintenance → transfer to EBT or to preheating station → tapping. The liquid steel held in ladles goes through LF treatment where the steel is homogenized by argon bubbling and its temperature is adjusted to 1570 - 1590°C. After that, the liquid steel is transported to the CC station and cast into slabs. The time lapse between the end of LF treatment and the start of teeming is around 10-30 minutes, which is defined as the holding time in this work.

Since the ladles to be simulated are mid-aged, which means that they have normally been in operation for more than 30 heats, quasi-steady thermal states have more likely been reached in the ladle linings.

Numerical experiment cases are executed under the following conditions (Table 1):

- ❖ after the end of teeming, all the ladles without preheating are directly transported to the EBT and prepared for tapping;
- ❖ just before the start of tapping, the average hot-face temperatures, weighted by the areas of heat transfer regions (Fig. 2a), are set at 600°C, 800°C and 1000°C, respectively, by manipulating the cooling time of the ladles after teeming and before receiving the next heat;
- ❖ all heats of liquid steel (105 tonne) together with different amounts of slag (500 kg, 1000 kg and 1500 kg) are tapped from EBT into the ladles during 5 minutes and have the same tap-end temperature of 1675°C;
- ❖ 25 minutes after tapping, the ladles are covered with a refractory lid for 30 minutes corresponding to the period of LF treatment;
- ❖ at the end of LF treatment, all heats of liquid steel are homogeneous and have the same temperature, 1580°C;
- ❖ the holding periods, i.e., the duration of steel melt held in the ladles after LF treatment/homogenization and before the start of teeming, are 10 min, 20 min and 30 min, respectively; and, finally,
- ❖ the teeming time is designed to be 38 min, 43 min and 48 min corresponding to teeming rates of 2.816 tonne/min, 2.488 tonne/min and 2.229 tonne/min, respectively.

In addition, the conditions (5) to (7) are also used in CFD simulations of the same ladles during holding and teeming periods.

❖ SIMULATION RESULT

One of the important outputs of the heat conduction model is the heat loss flux from steel melt to different heat transfer regions of a ladle. Figures 2 and 3 illustrate, respectively, examples of the predicted heat loss fluxes to different heat transfer regions (Fig. 1) of mid-aged 105-tonne steel ladles lined with alumina and spinel as working refractory in walls. The simulation conditions follow cases No. A5 and S5 in Table 1 for both types of steel ladles. It can be seen from both figures that the heat loss fluxes to different ladle heat transfer regions, except for the top free surface, generally exhibit exponential decay with time. A comparison between the two figures shows that the alumina ladle loses more heat per unit area and time to the top region of the wall (Side3), which is slag-line brick having greater heat conductivity than alumina, (Fig. 2a and Table 2); while the spinel ladle loses most heat per unit area and time to the lower regions (Side1 and Side2) of the wall. This difference is not surprising, because spinel (mixed with 10% graphite) is much more conductive than alumina and slag-line brick (Table 2).

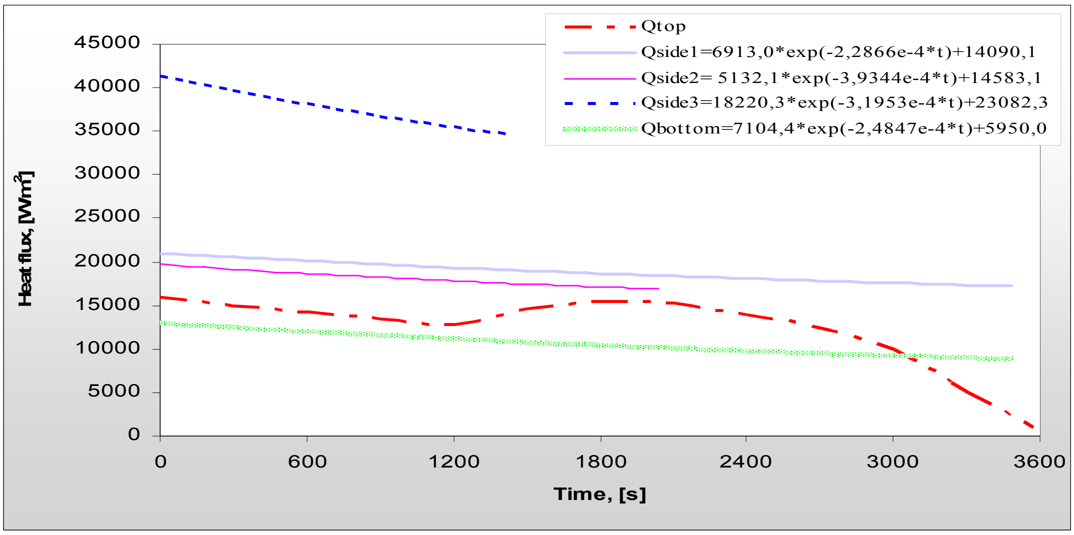

Fig.2. Predicted heat loss fluxes to different region of a mid-aged 105-tone steel ladle with alumina as working refractory in wall

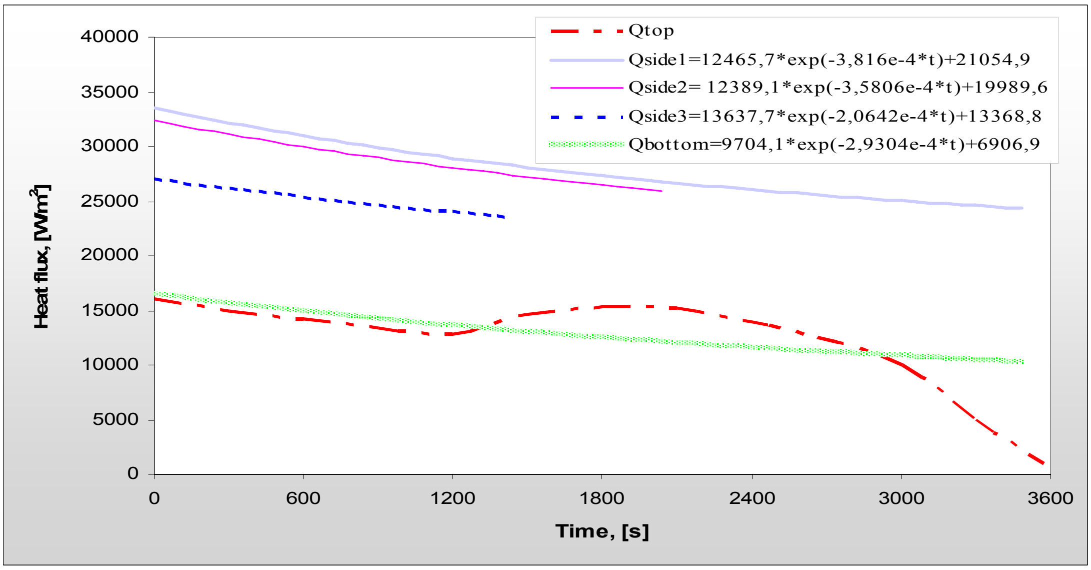

Fig.3. Predicted heat loss fluxes to different region of a mid-aged 105-tone steel ladle with spinel as working refractory in wall

❖ CONCLUSIONS

The influences of some important parameters on fluid flow and heat transfer in steel ladles during holding and teeming, which are normally inconvenient or impossible to examine directly using experimental methods, have been studied by means of mathematical modelling through performing numerical experiments. In this work, a three-step modelling strategy for the numerical experiments has been adopted. Two types of mid-aged 105-tonne production steel ladles, lined with alumina and spinel in walls, have been investigated, respectively. The following conclusions can be drawn from the present parameter numerical simulation studies.

It can be deduced that local heat losses from top and bottom regions of the steel bath to nearby boundaries will play a decisive role in affecting the top and bottom temperatures (hence the extent of thermal stratification). Generally, for the same bulk-cooling rate, larger heat fluxes to ladle bottom and lower section of sidewall (resulting in further lowered bottom temperatures) will lead to a greater extent of thermal stratification than uniformly distributed heat fluxes; while larger heat fluxes to top slag layer and upper section of sidewall (resulting in lowered top temperatures) may lead to smaller extent of thermal stratification than uniformly distributed heat fluxes.

❖ REFERENCES

[1] Fredman T. P., Scand. J. Metall., Vol. 29, 2000, pp. 232-258.

[2] Kitamura M., Kawasaki S., Kawai S., Kawai K. and Miyake K., Trans. Iron Steel Inst. Jpn., Vol.23,1983,pp. B165.

[3] Minion R. L. and Leckie C. F., Steelmaking Conference Proceedings, Vol. 69, 1986, Iron and Steel Society, Washington, U.S.A., pp. 335-343.

[4.] Olika Bekele, "Simulation of Ladle Lining and Steel Temperature in Secondary Steelmaking", Licentiate Thesis, 1992, Lulea University of Technology, Sweden.

ANNALS OF FACULTY ENGINEERING HUNEDOARA
– INTERNATIONAL JOURNAL OF ENGINEERING

Faculty of Engineering Hunedoara,
5, Revolutiei, 331128, Hunedoara,
ROMANIA
http://annals.fih.upt.ro