International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 03 Issue: 07 | July-2016 www.irjet.net p-ISSN: 2395-0072

Heat loss in Ladle furnace

Dashrath Singh Kathait

(Department of Mechanical Engineering, S.O.E.T, H.N.B. Garhwal University, Srinagar (Garhwal), Uttarakhand(India)

---***---

Abstract – *To maintain molten steel temperature is one of the important parameters for producing the superior quality of steel. Ladle is one of the important vessels to be used for controlling steel temperature. However, the importance of initial refractory temperature was noticed. This paper will consider the amounts of heat that are lost from liquid iron during secondary steelmaking there will be a continuous reduction of temperature due to heat losses from conduction and radiation. In order to keep a usable temperature into the ladle these heat losses must be compensated by excess heating. This leads to increased cost of melting iron, as well as higher alloy consumption and refractory wear. By means of effective heat conservation, the losses and the cost can be minimized, and thereby reduce the overall cost of produced iron. The heat losses by conduction heat transfer through refractory linings and heat radiation from hot surfaces, will be presented in more details in the following study.*

***Key Words*: Conduction, Heat loss, Ladle Furnace, Radiation, Refractory, Steel.**

1. INTRODUCTION

The refractory lining of industrial furnaces working at high temperature technologies wear out due to the thermal stresses, abrasive erosion and effect of chemical at high temperature materials on the refractory lining. As the lining becomes thinner, the heat loss of the equipment increases. The quality of steel is a major concern in the metallurgical industry and there are various factors affecting the quality of the steel. The molten steel temperature is one of the major factors contributing towards the cleanliness of steel. The large variation in temperature during continuous casting can drastically enhance the quality of steel. The phenomenon of heat losses taking place from molten steel to the atmosphere by three modes of heat transfer named conduction, convection and radiation. It is desirable that variation of ladle stream temperature with time is not significant. In order to obtain small variation of temperature during casting heat loss should be minimized**[10].**

Vasile Putan**[1]** investigated two types of 105-tonne steel ladles. 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. The heat loss fluxes to different ladle heat transfer regions, except for the top free surface, generally exhibit exponential decay with time.

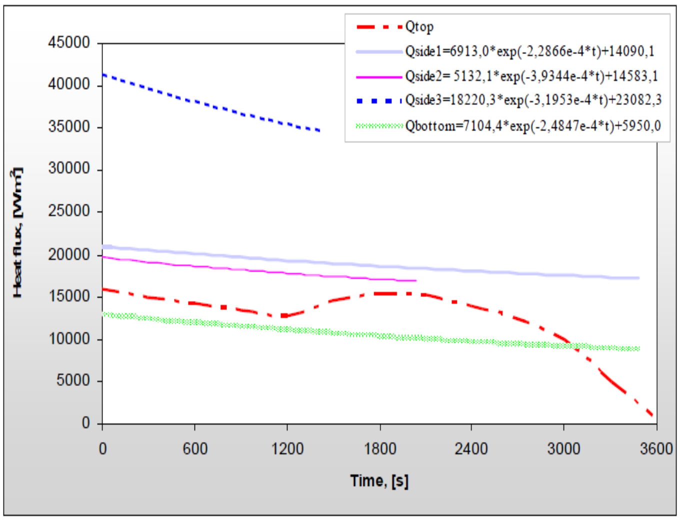

Fig.1.1. Heat loss fluxes with alumina as working refractory in wall

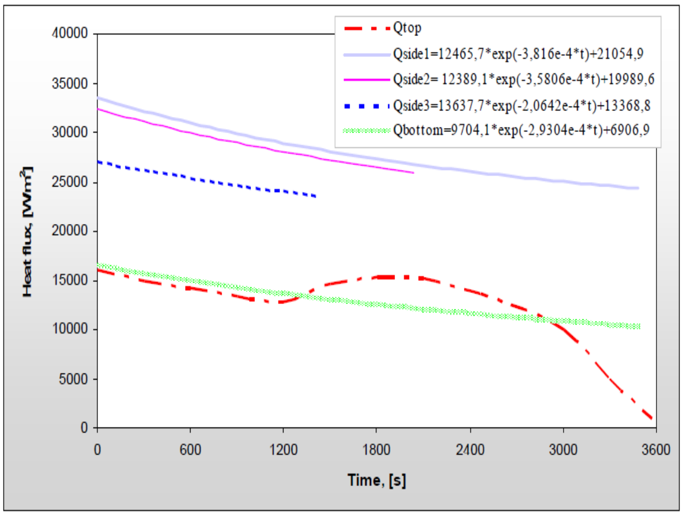

Fig.1.2. Heat loss fluxes with spinel as working refractory in wall

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. 1.1 and FAIG.1.2); 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. 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.

Anurag Tripathi, Jayanta kumar Saha, Jitendra bhadur Singh and Satish kumar Ajmani **[2]**suggested the formula for calculating the heat flow rate through hot face of ladle. The hot face of ladle is at high temperature; hence radiation heat transfer is very important in calculating net heat losses. In case of empty ladle, the radiation exchange takes place between conical surface of the ladle, bottom surface of the ladle and at the top. However, if the ladle is filled with liquid steel having slag present at the top, the radiation exchange will take place between top surface of steel bath, free board region of conical ladle surface and ambient present at the top. Again, if the ladle is covered at the top with the ladle cover, then the radiation heat exchange will take place with inside surface of ladle cover instead of ambient. Let q1 be the heat flow rate from conical wall, ϵ_1 represents emissivity and $A1$ is the area of this surface. q2 be the heat flow rate from bottom surface in case of empty ladle; while for ladle filled with liquid steel, q2 represents the heat flow rate at the top surface of liquid steel. $\epsilon_2$and $A2$ represents emissivity and area of the surface, respectively. q3 represents the heat flow rate from the inside surface of ladle cover. The emissivity and area for this surface is represented by $\epsilon_3$and $A3$, respectively. The expression for these heat flow rate are mentioned below

$$q_1 = \frac{\sigma T_1^4 - J_1}{(1-\epsilon_1)/\epsilon_1 A_1} \quad \textbf{(1.1)}$$

$$q_2 = \frac{\sigma T_2^4 - J_2}{(1-\epsilon_2)/\epsilon_2 A_2} \quad \textbf{(1.2)}$$

$$q_3 = \frac{\sigma T_3^4 - J_3}{(1-\epsilon_3)/\epsilon_3 A_3} \quad \textbf{(1.3)}$$

Relationship between heat flow rate and radiosity can also be expressed as

$$\frac{\sigma T_i^4 - J_i}{(1-\epsilon_i)/\epsilon_i A_i} = \sum_{J=1}^{N} \frac{J_i - J_j}{(A_i F_{ij})^{-1}} \quad \textbf{(1.4)}$$

Here, N is the no. of surfaces in the enclosure.
i, *j* represents the particular surface.
Fij: View factor from ith to jth surface.
J is defined as radiosity.
It takes into account all the radiant energy leaving the surface. This includes reflected portion of the irradiation as well as direct emission. The net heat flow rate from each surface can be calculated using Eqs. (1.1), (1.2), (1.3) and (1.4). The heat flux at hot face of empty ladle can be given by Eqs. (1.5) to (1.6) and for filled ladle; heat flux can be calculated by Eqs. (1.7) to (1.9).

q (at conical surface) = q_1/A_1 **(1.5)**
q (at bottom surface) = q_2/A_2 **(1.6)**
q (at conical surface not in contact with molten steel) = q_1/A_1 **(1.7)**
q (at slag or molten steel surface) = q_2/A_2 **(1.8)**
q (at inside surface of ladle cover) = q_3/A_3 **(1.9)**

Heat flux continuity boundary condition was applied at the hot face surface in contact with molten steel. Emissivity coefficient used at various surfaces is mentioned below:

Hot face refractory wall = 0.45
Outer ladle shell surface = 0.85
Slag surface = 0.6
Molten steel surface = 0.3

TABLE.1.1. Physical and thermal properties of Ladle walls, Molten steel and Slag

S.NO	Material	Position	Density (Kg/m²)	Thermal conductivity (W/m-k)
1	Molten steel	-	7100	41
2	Slag	-	3807	1.21
3	Steel shell	-	8030	52
4	Ceramic board Al_2O_3-51% SiO_2- 35% CaO-10%	Insulation	750	0.232
5	Castable Al_2O_3-70% Fe_2O_3 -1% CaO-1.75%	Wear lining	2700	1.9
6	80% Al_2O_3 Bricks Al_2O_3-80% Fe_2O_3-2.5%	Safety lining	2750	0.95
7	MgO-C Bricks MgO-92%	Working lining	3000	3.64

Dr. E. G. Hoel, C. M. Ecob and D. S. White **[3]** consider the amounts of energy that is lost from liquid iron during typical foundry operations and looked at some preventive measures as well as the benefits of more effective heat conservation in liquid iron. During processing liquid iron in ladles and holders, there will be a continuous reduction of temperature due to heat losses from conduction and radiation. In order to keep a usable pouring temperature into the mould, these heat losses must be compensated for by excess tapping temperatures at the furnace. This in turn leads to increased cost of heating the iron, as well as higher alloy consumption and refractory wear. By means of effective heat conservation, the losses and the consequences can be minimized and thereby reduce the overall cost of produced iron. The heat losses comprise conduction heat transfer through refractory linings and heat radiation from hot surfaces, as presented in more details in the following section for the ladle shown in **Fig. 1.4**

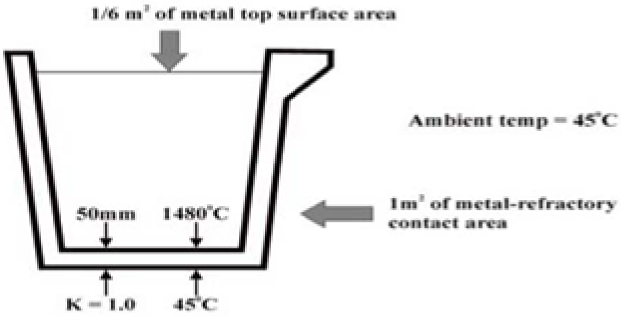

Fig.1.3. Heat Conduction through a single component wall

Conduction heat transfer is governed by Fourier's law of conduction:

$$q=-k\frac{dT}{dx} = -k\frac{T_3-T_1}{L} = k\frac{T_1-T_3}{L}$$

where q is the heat transfer per unit area (W/m^2), k the thermal conductivity (W/m^0K), T_1 the temperature of the hot surface (K), T_3 the temperature of the cold surface (K), and L the refractory thickness (m). The quantity is negative because heat transfer is contrary to the direction of the heat gradient. Thermal conductivity varies between different refractory materials, and with temperature, for multiple component linings case, the heat transfer can be stated as follows:

$$q = \frac{T_1-T_3}{\frac{L_1}{k_1}+\frac{L_2}{k_2}}$$

where k_1 is the conductivity and L_1 the thickness of material 1, etc.

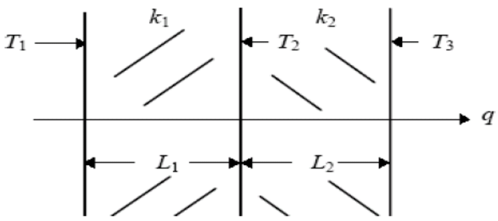

Fig.1.4. Heat conduction through a multiple component wall

Heat radiation is the main cause of heat loss from a hot surface (metal or inner ladle) and is given by the following:

$$Q = \varepsilon\sigma (T_1^{\,4} - T_2^{\,4})$$

Where ε is the emissivity of the radiating body, σ the Stefan-Boltzmann constant ($5.67X10^{-8}$ W/m^2K^4), T_1 the temperature of the radiating body, and T_2 the temperature of the receiving body. The emissivity for a black body is 1, and for grey bodies between 0 and 1. Some common values are given in **Table.1.2** below.

TABLE.1.2. Some Common Emissivity values

Surface		T(^{0}C)	ε
Sheet steel		25-50	0.81-0.83
Molten iron		1400-1600	0.25-0.40
Al_2O_3 –SiO_2	Low Al_2O_3	1000-1500	0.65-0.80
	High Al_2O_3		0.45-0.60

2. THE LADLE

Ladle is a container extensively used in the continuous casting cycle to transport molten steel from the furnace to the casting machine**[4]**. Ladles are designed to be heat insulated, apart from being heat resistant and strong.. Proper heat insulation is required so that the molten steel contained in the ladle remains at a proper temperature in different capacities. A general construction of a typical ladle is as follows:

Fig.2.1. Ladle Furnace

TABLE.2.1. Constructional details of a typical ladle**[5].**

Ladle dimensions		
1	Height	2-4m
2	Internal radius	1.2-1.8m
3	capacity	65-275tonnes
Operational data		
1	$T_{initial}$	1850K
2	Wall flux,q_w,	50 -150 kW/m²
3	Base flux,q_b	30- 100 k W/m²
4	Cycle time	6 hour
5	life	50 cycle
Steel properties		
1	Viscosity of steel,μ	$5.5x10^{-3}$kg/m.s
2	Density,ρ	7000kg/m³
3	Heat capacity,c_p	627J/kg.K
4	Thermal conductivity,k	28.8W/.K
5	Coefficient of thermal expansion,β	$14x10^{-5}K^{-1}$

The inner face of the ladle is built from specialized refractory bricks. These bricks are resistant to high temperature, thus making it possible for the ladle to hold molten steel. Two types of bricks are used to construct the inner surface viz. a type of brick which interacts with the liquid steel while the other type is exposed to the slag layer above the molten steel. A mass layer is also added to the brick layer which is followed by a safety layer and an insulation layer covered by a steel shell. All these layers altogether making the ladle wall to withstand high temperature. A lid is used to cover the top of the ladle**[6].**

3. MATHEMATICAL MODEL

The governing equations were formulated based on following assumptions:

1.The thermal properties of Molten steel, slag and refractory walls were independent of change in temperature.

2.Steel bath was homogenized.

3.The flow of molten steel was considered to be inviscid and ir-rotational during teeming.

4.The effect of natural convection was neglected in the present calculation.

5.The radiation effect was incorporated as boundary condition in the present model.

3.1. STEADY STATE HEAT CONDUCTION LOSS

Rate of steady state heat loss is given by

$$q = \frac{T_s - T_a}{\frac{1}{2\pi H r_1 h_i} + \frac{\ln(\frac{r_2}{r_1})}{2\pi H k_1} + \frac{\ln(\frac{r_3}{r_2})}{2\pi H k_2} + \frac{\ln(\frac{r_4}{r_3})}{2\pi H k_3} + \frac{1}{2\pi H r_4 h_o}} \quad \textbf{(3.1)}$$

where q=heat loss (W)

T_s=molten steel temperature (^{0}C)

T_a=ambient temperature (^{0}C)

H=height of ladle (m)

h_o= convective heat transfer coefficient outside ladle (W/m^{2}K)

k_1, k_2, k_3 and r_1, r_2, r_3, r_4 are thermal conductivity (W/mK) and radii(m) of working lining, safety lining and permanent lining respectively.**[7]**

3.2. STEADY STATE HEAT RADIATION LOSS

Consider a furnace which is at an average temperature T and is enclosed by the refractory. Of this incident radiation, some part absorbed and some reflected. Due to incident flux the refractory surface is heated to a temperature T_R and refractory surface will emit energy. At steady state, heat balance is**[8,9]**:

Heat loss/unit area through the furnace wall to the surroundings = Rate of absorption of heat from the furnace − Rate of emission of radiation back into the furnace

$$\frac{Q}{A} = 5.67X\, \epsilon_R[\left(\frac{T_F}{100}\right)^4 - \left(\frac{T_R}{100}\right)^4]\ W/m^2 \quad \textbf{(3.2)}$$

3.2.1. EFFECT OF REFRACTORY SURFACE

Consider a system in which three surfaces A_1,A_2 and A_3 forms an enclosure as shown in the figure. Each surface is characterized by its own uniform temperature T_1,T_2 and T_3 respectively. Also $A_1$and A_2 surfaces are shaped such that each cannot use itself. The following assumptions are made:

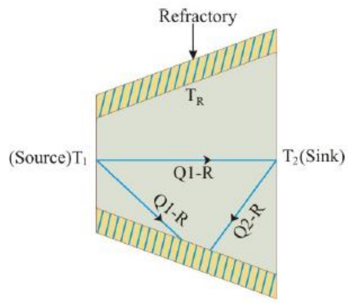

Fig.3.1. A System formed by three surfaces, source sink and refractory.

1. Enclosure is adiabatic: refractory surface A_R does not allow any heat which means all incident flux is re-radiated or reflected,
2. Surfaces A_1 and A_2 are black.

Heat flows directly from A_1 to A_2 and to A_R. As a result of incident radiation, A_2 is heated and also begins to radiate. Of the total energy leaving from A_1 to A_2 fraction is absorbed by A_2 and is controlled by F_1. F_1 is view factor and corresponds to fraction total energy leaving a1 which is absorbed by surface 2.The remaining fraction(1-F_1) is intercepted by surface A_R. After a while surface A_2 is heated up. Of the total energy leaving the surface A_2, F_2 is absorbed by surface $A_1$and (1-F_2) is intercepted by A_R. F_1 and F_2 are related by

$$F_1 \times A_1 = F_2 \times A_2$$
$$F_2 = F_1 \times (A_1/A_2)$$

Direct heat exchange between A_1 and A_2

$$Q_{1-2} = 5.67XA1X\ F1[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4]$$

Heat exchange between A_1 to A_R and A_2 to A_R

$$Q_{1-R} = 5.67XA1X\ (1 - F1)[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_R}{100}\right)^4]$$

$$Q_{2-R} = 5.67XA2X\ (1 - \frac{F_1 X A_1}{A_2}) A_2[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_R}{100}\right)^4]$$

Since there is no heat flow to the refractory

$$Q_{1-R} + Q_{2-R} = 0$$

After solving we get

$$T_R = [\frac{(A_1 - F_1A_1)T_1{}^4 + (A_2 - F_1A_1)T_2{}^4}{A_1 + A_2 - 2F_1A_1}]^{0.25}$$

$$Q_{1-R} = -Q_{2-R} = 5.67[\frac{(A_1 - F_1A_1) + (A_2 - F_1A_1)}{A_1 + A_2 - 2F_1A_1}][\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_R}{100}\right)^4]$$

Above equation is the additional indirect heat exchange between A_1 and A_2 as obtained by reflection and re-radiation from surface A_R.

Total heart flow $=Q_{1-2} + Q_{1-R}$

By above equation

$$Q = 5.67XA1X\ Fc[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4]$$

Where Fc is a composite geometrical factor for the closed system of two black surface A_1, A_2 and A_R

$$F_C = \frac{\frac{A_2}{A_1} - F_1{}^2}{1 + \frac{A_2}{A_1} - 2F_1}$$

It is to be noted that the above derivation we have identified furnace to consist of source, sink and refractory as independent entities and each one is at uniform temperature. However in practical situations, it is not often easy to separate the source, sink and refractory and the temperature may be far from uniform. Thus a careful engineering judgment is necessary for accurate calculations**[8,9].**

3.2.2. EFFECT OF EMISSIVITY OF SURFACE

For most general calculation it is necessary to take into account the effect of emissivity of the source and sink surface. If A_1 and A_2 are not black but grey surfaces with emissivity ϵ_1 and ϵ_2.

$$Q = 5.67XA1X\ F[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4]$$

Where

$$F = \frac{1}{\frac{1}{F_C} + \left(\frac{1}{\epsilon_1} - 1\right) + \frac{A_1}{A_2}\left(\frac{1}{\epsilon_2} - 1\right)}$$

Then F=Fc Where ϵ_1 and ϵ_2=1

4. CONCLUSIONS

According to above equations heat loss to the surrounding depends on the inside surface temperature of the refractory, surrounding temperature and the thermal resistance offered by the refractory wall. The difference between the inner surface temperature of the refractory and the furnace temperature can be reduced further by increasing the thickness of the wall and using refractory of lower thermal conductivity. This study suggested that the inner surface temperature of the refractory wall is close to the average temperature of the furnace. For the lower thermal conductivity refractory the heat loss is minimum. But thickness of refractory also plays a major role in the rate of heat transfer from the furnace wall to the surrounding. On the other hand radiation heat loss increases too much from the upper portion of the furnace, as the temperature of molten steel increased to maintain fluidity of steel. Radiation heat loss increases at higher temperature. The overall heat loss is the addition of heat loss through conduction and heat loss through radiation. Above described mathematical equation shows that emissivity of the refractory has an important role in the heat loss through radiation mode. So we have to choose the refractory lining according to the emissivity.

REFERENCES

[1] Vasile Putan, University Politehnica Timisoara, Faculty of Engineering of Hunedoara of Romania.

[2]Numerical Simulation of Heat Transfer Phenomenon in Steel Making Ladle Anurag Tripathi, Jayanta Kumar Saha, Jitendra Bhadur Singh and Satish Kumar Ajmani ,Research & Development Division, Tata Steel, Jamshedpur-831001 India.

[3] Dr. E. G. Hoel, C. M. Ecob and D. S. White; Elkem Foundry Products,Reviewed 2005-07-10

[4]Saving Energy in ladle metallurgy Dalibor Jancar ArcelorMittal Ostrava a.s., Vratimovská 689, 707 02 Ostrava,

[5]S. Chakraborty and Y. Sahai, "Effect of slag cover on heat loss and liquid steel flow in ladles before and during teeming to a continuous casting tundish",Metallurgical Trans. 23B (1992), 135-151.

[6] P. R. Austin, S. L. O'Rourke, Q. L. He, and A. J. Rex, ―Thermal modelling of steel ladles,‖ in 1992 Steelmaking Conference Proceedings, 1992, pp. 317–323.

[7]Hata K., Takeuchi Y., Shiotsu M. and Sakurai A., 1999, Natural convection heat transfer from a horizontal cylinder in liquid sodium Part 1: Experimental results, Nuclear Engineering and Design, 193, 105-118

[8]D.R. Poirier and G.H. Geiger: transport phna in material; processing.

[9]R. Schumann: Metallurgical engineering, volume 1engineering principles

[10] Dashrath Singh Kathait ,Ladle Furnace Refractory Lining: A review. (Department of Mechanical Engineering, S.O.E.T, H.N.B.Garhwal University, Srinagar (Garhwal),Uttarakhand(India)