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Experimental and Numerical Analysis of Blast Furnace Cooling Stave with Refractory Lining

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Abstract: *In this present study of Blast furnace cooling stave with the refractory lining, the three-dimensional stave cooler with Refractory linings of a blast furnace has been model and analysed. Further, this model has been utilized for the heat transfer analysis of different thickness of Refractory lining materials (i.e., 0.65m to 0.55m). The heat dissipation and temperature variation by the 3D model are examined by using finite volume method. The Mullite bricks have considered as a Refractory lining, which contents 65% of Al2O3 and 35%of SiO2 and three different stave cooler material has chosen for this analysis, which are Cast iron, copper and aluminium respectively. Subjected Stave cooler identified in Rourkela steel plant (blast furnace #4) in Bosh zone, in this zone, the maximum heat load is obtained. The Experimental data collected from Rourkela Steel Plant is used for developing a 3D model of heat transfer analysis of subjected stave cooler with refractory lining. Further, nitrogen is considered as a cooling agent instead of water due to an abundance of nitrogen available in the steel industry.*

Keywords: Blast Furnace, Heat transfer, Refractory lining, Interface of SCRL, stave Cooler.

I. INTRODUCTION

A Blast Furnace (BF) is a metallurgical device used for smelting the iron ore, generally produce steel after several processes, in a BF, iron ore-coke and limestone are continuously supplied on the top of the furnace, which is upper hopper and lower hopper. While hot blast is blown into the furnace through tuyere, there is the number of tuyeres arranged on the hearth of the furnace so that the combustion takes place inside the furnace from the bottom to top as the material moves. Molten metal collected from tap hole and from the slag hole slag is getting out. Flue gases or exhaust gases out the top of the furnace.

For relining period of the BF would define the campaign life of the furnace and also cooling of the refractory lining (RL) material be the most contributing factor of the furnace life. stave technology is the one of the best product of such efforts, The stave cooler(SC) is consists of one or more than one internal channel which is installed between the outer surface of the RL and the inner side of the steel shell to protect both of it, usually maintained the inner profile. The stave cooler was prepared usually on cast iron. But present days instead of cast iron we have used copper, which transfers more heat than that of others due to its greater conductivity of heat. Cooling Water being used to transfer more heat from the lining of the furnace and also it protects faster wearing out. Fig. 1.1 Arrangement of SC and RL in the Furnace.

Cheng-Peng Yeh et al. [2012] studied the heat transfer (HT) of different RL thickness with the aluminium staves and a sensor bar. Gdula et al. [1985] explained on the transfer of heat of BF hearth which is on the (lower zone) was based on non-identical cooling system and RL material had measured. Chang et al. [2009] found the BF hearth zone of the erosion formation during the tapping process. Y. Kaymak. [2007] Maintained the Thermo-mechanical contact of stave and RL. Maria Swartling. [2008] He analyzed the flow of Heat in the BF Hearth zone. Cheng Hui'er et al. [2007] he explained about the cast steel stave cooling rectangular channel in the furnace. Anil Kumar et al. [2012] considered on computational cooling stave model of BF which is based on the transfer of heat.

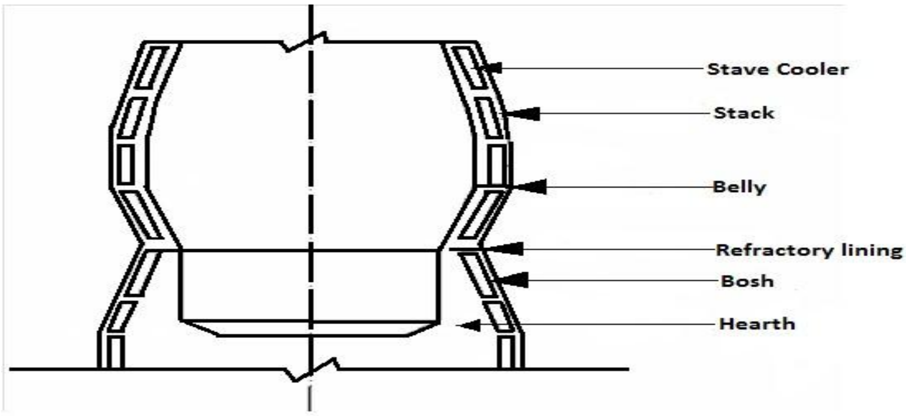

Figure 1.1: Arrangement of SC and RL in the Furnace

Materials used in BF for this experiment

Table 1.1 these materials have been used in the three-dimensional mathematical modelling for the HT analysis of furnace RL with SC.

Types of fluids/materials	Specific heat in (KJ/KgK)	Thermal Conductivity (W/mK)	Density of the material (Kg/m3)
Water	4.187	0.6	998.2
Nitrogen	1.040	25.83X 10^{-3}	1.251
Stave materials			
Cast iron	0.460	40	7500
Aluminium	0.871	202.4	2719
Copper	0.381	385	8978
Refractory materials			
Al_2O_3	0.880	18	3690
SiO_2	0.700	1.4	2648
Mullite	0.760	12	2950

Experimental analysis of SC with RL

In this present experimental analysis of particular SC in BF #4 at the Rourkela steel plant (RSP). One SC has been identified on the bosh zone of Furnace for the experimental purpose; this zone is marked to be maximum heat load in the furnace. Actual data of the particular SC has taken from the RSP data centre. We have taken the actual data from the identified SC in the BF.

The temperature measuring device (Thermocouple) is fitted in the inlet and outlet of the identified SC to measure the inlet and outlet temperature of the stave. We have installed a Volume flow meter on the inlet of the SC to measure the flow rate and a pressure gauge was installed in fluid flow coil to point out the fluid pressure.

From the Particular setup, we have measured and collected the data of heat extraction, inlet and outlet temperature, volume flow rate of the water; which is given on the below table 3.1. And the above experiment was being carried out for another fluid in the same setup, initially, we had taken water as a fluid for cooling purpose and then nitrogen being replaced by water for the cooling of RL. The experimental setup of the RSP as shown in Figure 1.2

Figure 1.2: Blast Furnace #4 Experimental setup

II. EXPERIMENTAL DATA OF THE SUBJECTED SC

Experimental data has been taken from RSP (BF #4), Table 2.1.shows the data using water as a cooling agent.

Table 2.1: Experimental Data

Stave cooler	Inlet temp(T_1) in (^oC)	Outlet temp(T_2) in (^oC)	Diff.of temp ($T=T_2-T_1$)	Water collected in litres	Time in (sec)	Volume flow in (m3/hr)	Heat extracted (kcal/hr)
1	27.4	32.8	5.4	30	54	2.00	10800.00
2	24.4	33.9	9.5	30	56	1.93	18335.00
3	24.4	34.2	9.8	30	44	2.45	24010.01
4	24.4	34.1	9.7	30	47	2.30	22310.12
5	24.4	32.6	8.2	30	43	2.52	20595.34
6	24.4	31.5	7.1	30	53	2.04	14467.93
7	24.4	30.6	6.2	30	54	2.00	12400.00
8	24.4	32.7	8.3	30	48	2.25	18675.00
9	24.4	37.6	13.2	30	53	2.04	26928.00
10	24.4	30.1	5.7	30	47	2.30	13110.00
11	22.4	30.4	8	30	51	2.11	16941.17
12	22.4	30.4	8	30	48	2.25	18000.00
13	22.4	28.4	6	30	53	2.04	12240.00
14	22.4	28.1	5.7	30	57	1.89	10800.00
15	22.4	27.8	5.4	30	54	2.00	10800.00
16	22.4	29.1	6.7	30	55	1.96	13156.36
17	22.4	30.2	7.8	30	57	1.89	14742.00
18	22.4	30.1	7.7	30	59	1.83	14094.92
19	22.4	27.2	4.8	30	51	2.11	10164.70
20	22.4	32.7	10.3	30	53	2.04	21012.00

Figure 1: Schematic view of the air bearing model

III. GEOMETRICAL MODEL OF SCRL

In this present study and view the SCRL model of BF has been done, we have been used specially workbench initially for geometry. There are few steps explain below:

The dimension of 3D stave cooler with refractory lining (SCRL) have been taken from RSP data centre, the width of 0.85m, length of 1.640m and height of 0.898m, the diameter of the coil 0.033m and coil bending radius 0.08m drawn by the use of design modular. the total length of the coil been taken as 8.421m as shown in Figure 3.1 respectively .Stave cooler have dimension is of 1.640m length,0.898m height with 0.2m width. Further, it has extruded in the z-direction by 0.65m for adding together of RL material as shown in fig. 3.2 respectively.

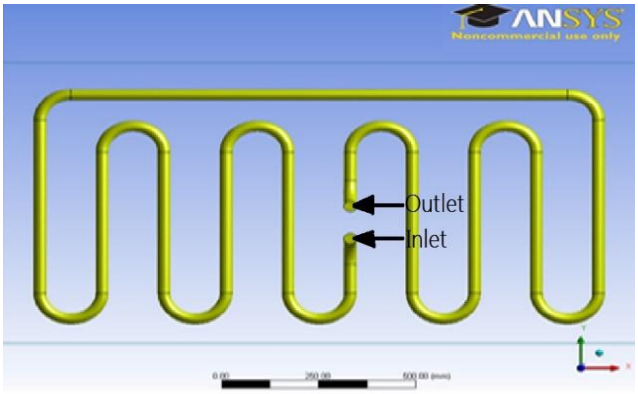

Figure 3.1: Front view of SC coil

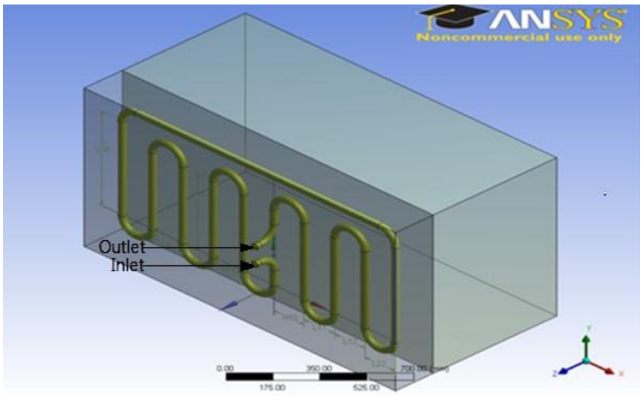

Figure 3.2: Front view of SCRL

Governing equation of fluid flow:

1. Continuity equation: (to apply the conservation of mass)

$$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \quad (1)$$

2. N-S equation: (to apply conservation of momentum)

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=\rho x-\frac{\partial p}{\partial x}+\frac{1}{3}\mu\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+\mu\nabla^2 u \quad (2)$$

3. Energy equation :(to apply conservation of energy)

$$\rho c_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=\left(u\frac{\partial p}{\partial x}+v\frac{\partial p}{\partial y}+w\frac{\partial p}{\partial z}\right)+k\nabla^2 T+\mu\phi \quad (3)$$

Where,

$$\phi=2\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial w}{\partial z}\right)^2\right]+\left[\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2+\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)^2+\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)^2\right]$$

$$-\frac{2}{3}\left[\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right]^2$$

4. Heat extraction, Q (Kcal/hr), $Q=m\times C_p\times dT$ (4)

Whereas, $\dot{m}$ = mass flow rate of water, kg/s

C_p = specific heat of water, kcal/kg^{0}C

T_2 = outlet temperature of water, ^{0}C

T_1 = inlet/atm temperature of the cooling water, ^{0}C

These above equations are used to solve the fluid flow problem using the finite volume method in a fluent, generally, energy equation is used in this problem for finding the outer temperature of stave cooler.

IV. RESULTS AND DISCUSSION

The 3D model of SCRL numerical analysis was done by using a different cooling agent (water and nitrogen) and the inlet and outlet temperature difference of SC is being compared. Figure 4.1(i) shown the contour of SCRL and it shows the temperature variation across the plane of 0.65m thickness. The inner surface of the heat wall (inside the furnace) shows the maximum temperature of 1440K due to the combustion takes place in inner surface. From the inner surface of the furnace to the outer wall shell temperature gradually reduce and the RL and the SC interface temp found 398K.

Initially inlet temperature of the fluid taken as 299K, inner surface temperature taken as 1440K and after the simulation outlet temp found to be 306.8K, temperature difference becomes 7.8K.

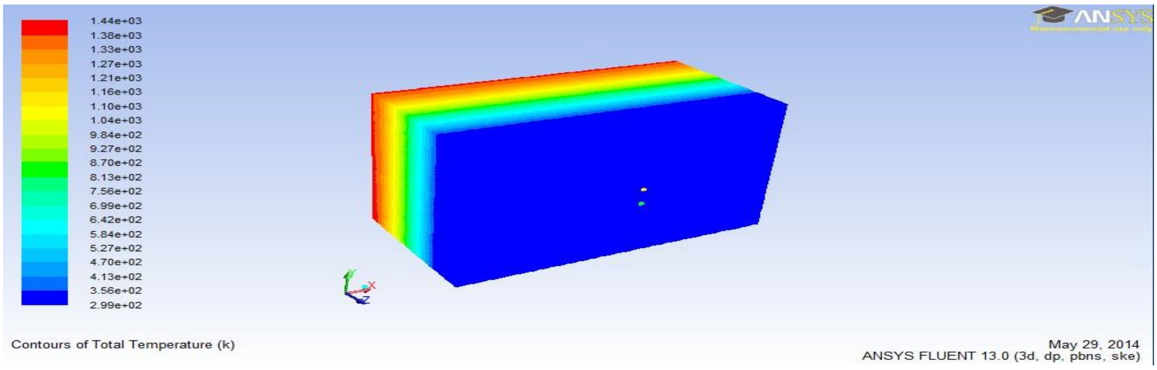

Figure 4.1: Isometric view SCRL 3D model of 0.65m refractory thickness.

Numerical Analysis

There are four lines (Line A, Line B, Line C , Line D) drawn on the inner face of the stave which is adjoined on the interface of the SC and RL. Stave has a safe temperature (ST) limit of 400K (taken from RSP data centre).Generally stave materials consider for this observation are cast iron ,aluminium and copper along with the refractory thickness of 0.65m,0.60m and 0.55m and in the graph 1,2,3 indicate cast iron line ,4,5,6 indicate Al line and 7,8,9 indicate Cu line respectively,

Figure 4.2 -4.5, graph drawn corresponding to the inner face of the stave,

It has been observed that aluminium and copper stave material temperature has always maintained below ST line, Among these three stave materials copper has high heat dissipation rate .we had seen that cast iron lines are very nearly the ST line, Cast iron temperature is maximum compared to other materials further reduction of thickness would damage the stave and also decrease the refining period. Variation of the inner face temperature along the stave length is plotted below.

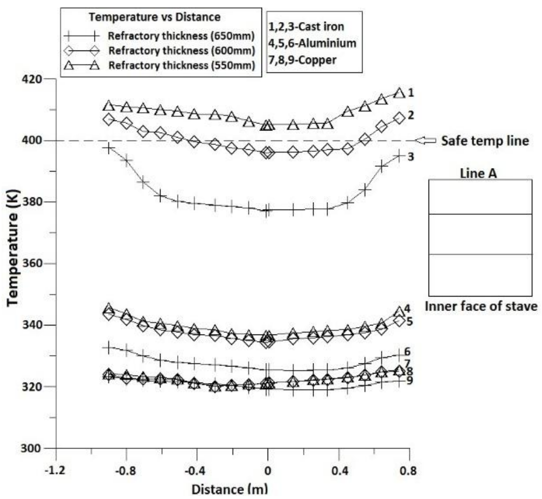

Figure 4.2

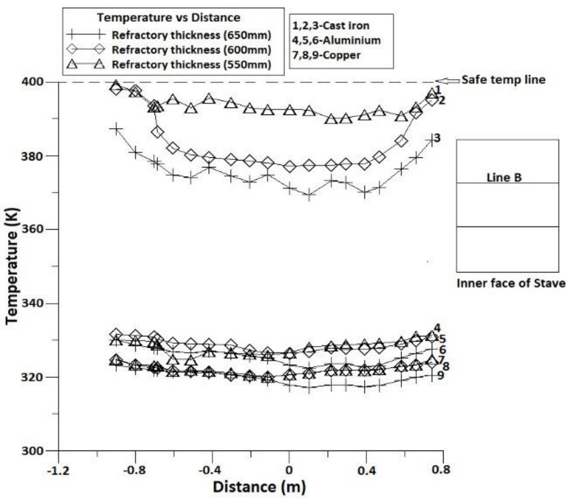

Figure 4.3

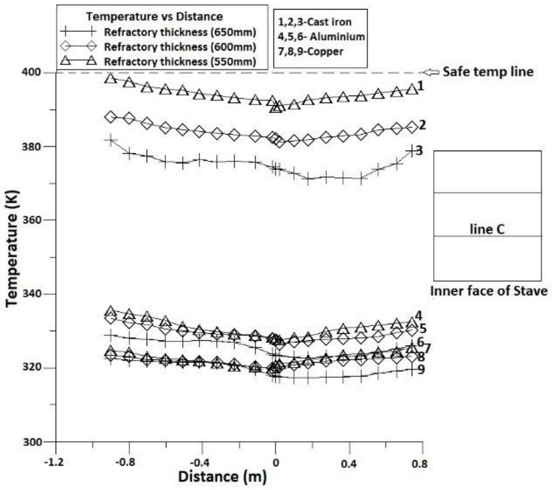

Figure 4.4

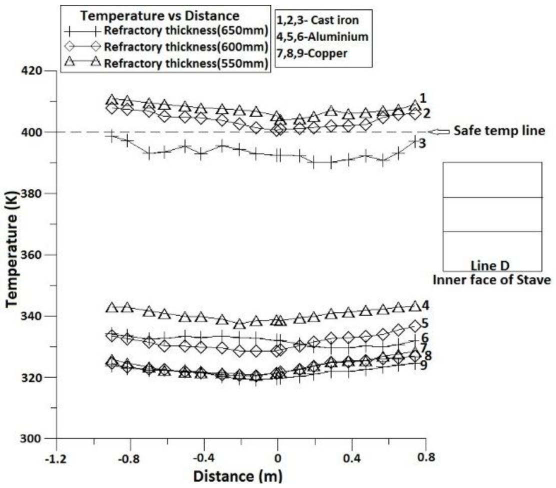

Figure 4.5

Fig.4.6-4.9 shows that the temperature variation along increasing coil length having the refractory thickness by using altered cooling agent nitrogen and water. In this graph, it has been observed that if we considered the mass flow rate of liquid nitrogen 4 times than that of cooling water, a similar result would be obtained. The exit temperature is slightly higher than that of the entry temperature due to heat absorption in the whole process respectively.

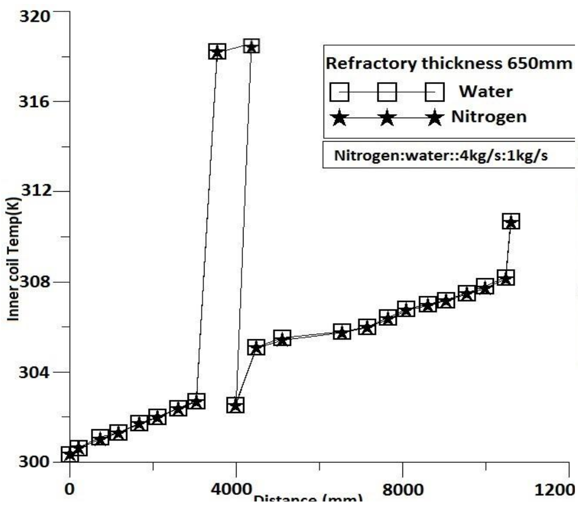

Figure 4.6: Inner Coil temperatures along the Length of the stave coil

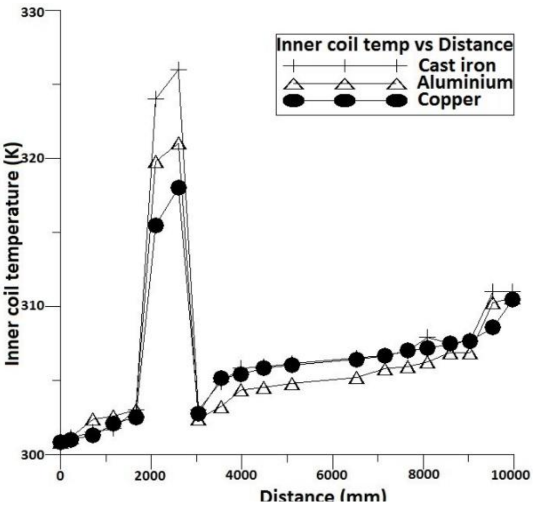

Figure 4.7: Coil temperatures along length of the stave

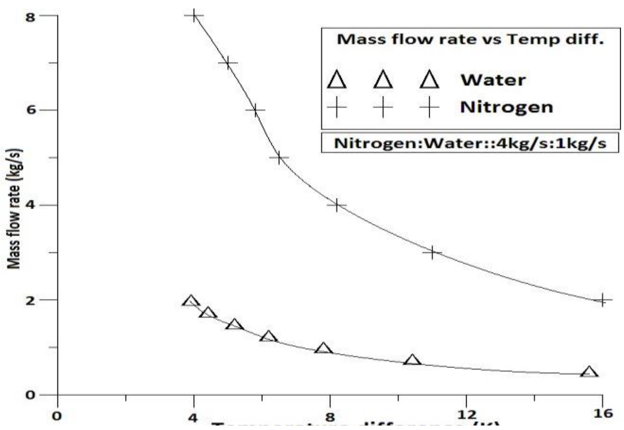

Figure 4.8: Mass flow rate versus temperature difference

However, it is observed that difference of temperature occurs identically for the water and nitrogen.

V. CONCLUSIONS

This Analytical and Numerical research work has been done on the 3D model of cooling stave with RL .the Analytical and Numerical result almost similar. From this outcome, we can be concluded that:

Instead of cast iron if we would use copper and aluminium as stave material, heat extraction rate from the refractory to the cooler stave to be enhanced and the factor of safety of the cooling stave material will be increase because of higher thermal conductivity. As a result, the stave cooler could be sustained for a long time and also relining period of the RL to be enhanced. Furthermore, the production rate would be high and the cost of relining and manpower to decrease significantly. If we consider the Mass flow rate of liquid nitrogen four-time than that of cooling water, desirable results would be obtained, as compared to water.

Conflict of Interests

The author does not have any conflict of interest regarding the publication of paper.

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