Modeling of Heat Transfer in LD Converter (BOF) Lining

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Master’s Thesis

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ABSTRACT

During the production of steel in the LD converter the refractory lining is exposed to high temperature emulsion of steel, slag and gas. It protects the steel body of the vessel to come in contact with the molten steel. The main purpose of this work was to observe the temperature distribution profile in converter refractory lining which is very important to understand the life of the refractory lining of the LD converter. In this study, a three dimensional (3D) heat transfer model for the refractory lining of converter was developed. The lining of the refractory material was considered as magnesite brick for inner lining, dolomite for intermediate lining and steel shell as outer part. In order to do the numerical modeling, the CFD software Ansys Fluent 13.0 was used. After considering the proper dimensions, meshing, properties of the lining material and boundary conditions, the modeling in Ansys was performed in two stages. In the first stage, the modeling was performed by assuming that the converter is already heated and the inside temperature of the furnace is 1923K and the outside temperature of the steel body is 300K. In the second stage, the temperature change of the molten steel, slag and the gas was considered as function of blowing time and slag height based on theories from different references. Firstly, the three dimensional (3D) heat transfer model was used for the refractory lining of the converter to show transient heat flow through the lining at different times. Secondly, 3D modeling results from fluent 13.0 was used to develop temperature distribution profile through the lining at different height for different time steps and at different positions with time and also along the converter height from the bottom to top. It has been noticed that refractories in the lining in contact with steel and slag must be of good quality for the reduction of wear cost and downtime and therefore the reduction of refractory cost per ton of steel production.

Keywords: Mathematical Modeling, LD Converter, Refractory Lining, Ansys Fluent, Temperature Profile Distribution.
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1. INTRODUCTION:
It is very important to understand the properties of refractory materials in the LD converter. It protects the steel body of the converter to come in contact with the molten steel. Due to this reason the properties of the refractories that are used in the converter should be of better quality with the ability of high refactoriness, high viscous behavior and creep resistance at high temperature. Temperature distribution in the refractory lining of the LD converter is important to understand the durability of the refractory materials.

A previous study by Sune Jonsson [9] showed that the weight loss of the refractory material in contact with steel, slag and gas changes linearly with the temperature. It was also found that the penetration of slag in the refractory lining depends on the temperature gradient in the lining. In the converter, a thermocouple or sensors can be placed inside the lining to measure the temperature in the lining. However, it is very difficult to measure the temperature inside the lining.

The aim of the work was to observe the temperature distribution profile in refractory lining of a converter, by considering proper boundary conditions and the dimension of the converter and from this we can get an overview of temperature distribution profile in refractory lining after a certain number of heats. The work was performed in two stages. At the first stage a 3 dimensional modeling was performed by assuming that the converter was already heated and the inside temperature of the furnace was 1923K and the outside temperature of the steel body was 300K. The modeling was performed up to 75 heats and comparison was made by showing how the heat transfers inside the refractories from inside to the outside wall of the converter. In the second stage, the temperature change of the molten steel, slag and the gas was considered as function of blowing time and slag height based on assumptions and experimental data from different references. A three dimensional model was performed up to 90 heats and also comparison was made with the transient heat flow through the lining with the increased number of heat. Moreover, a temperature distribution profile was used through the lining at different height of the converter at different time steps and at different positions with time. In addition, comparison was also made along the converter height.
2. THEORY OF STEELMAKING IN LD CONVERTER:

2.1 Basic Theory:
In Basic oxygen steel making process major production route for steel is the conversion of carbon rich molten iron and scrap to low carbon steel. Carbon amount is reduced by decarburization process, which is done in a reaction vessel called converter. This large vessel has capacity up to 400 ton of melt at high temperatures of 1650 to 1700°C. In Basic oxygen furnace (BOF), hot metal and scrap are blown by oxygen gas at high speed with an addition of slag former which removes phosphorus, sulfur, and vanadium. So, the main function of BOF is to decarburize the hot metal by using oxygen gas. This also oxidizes some of the iron and many of the elements present like Silicon, Manganese, Phosphorous and vanadium.

When carbon is oxidized, it forms carbon monoxide or carbon dioxide and other oxides are also formed as solid or liquid at high temperature. These form slag and float up to the top of the bath and react with phosphorus, sulfur, and vanadium, which are detrimental to the steel. This is why slag former lime is added and it maintains the basicity of the slag (CaO/SiO₂>1). However due to the addition of lime, the converter must be lined with basic refractory bricks. Otherwise it will be corroded at a high rate. This is why the process is called basic oxygen steelmaking.

![LD-Converter Schematic](image)

Figure: 1 Schematic view of top blown LD-Converter that was considered in this work.[10]

2.2 Types of Basic Oxygen Furnace (BOF):
Modern basic oxygen processes are divided into two main groups- top blown processes and bottom blown processes. It depends on how the oxygen is added. The top blown process in
BOS (BOP, BOF and OSM) is called Linz Donawitz, LD process and the vessel is named as LD converter which is shown in figure 1. Here oxygen at high pressure (p<14 bar) and velocity (Ma>1) is added with water cooled lance, which is lowered down into the blowing position. Besides, carbon, phosphorous and other impurities are reduced at high level.

In bottom blown processes crude iron is charged similarly with slag former and scrap. However, oxygen and inert gas are supplied upwards to the bath from the bottom through tuyeres. Here carbon or hydrocarbon fuels such as natural gas or fuel oil are also added.

There are some other processes that have been developed in recent years, such as mixed or combined blowing processes, hybrid processes. In mixed processes, oxygen is added both through a lance from above and tuyeres in the bottom. In hybrid processes oxygen is added through a lance and inert gas is bubbled through tuyeres or porous plugs in the bottom.

### 2.3 Refractories in LD-Converter Process:

Refractories are non-metallic heat resistant materials that can withstand high temperatures without rapid chemical and physical deterioration. They are inorganic, porous, multicomponent and heterogeneous materials which are composed of thermally stable mineral aggregates, additives and binders. The main characteristics of refractories are considered as high temperature creep, high brittleness at low temperatures with high elastic modulus. Moreover, they show high viscous behavior at high temperatures. Because of these properties they are highly used in metallurgical industries. They are used as a lining material in furnaces for heating and melting metals and also used in vessels to transport and hold molten materials and slags. Based on chemical composition refractories are classified into three types. The first type is acid refractories which are mainly silica (SiO$_2$), zirconia (ZrO$_2$). The second type is basic refractories which are mainly magnesia (MgO), magnesite-chrome, magnesite-carbon. The last one is neutral refractories such as alumina (Al$_2$O$_3$), Chrome-Carbon.

In the metallurgical industries magnesite dolomite bricks are used to protect the body of the converter to get in contact with the molten steel. The carbon content of the bricks varies in between 5 to 20 wt-%. The presence of carbon in the refractory bricks decreases the possibility of the slag entering the porous refractory by filling out the porous structure.
3. NUMERICAL MODELING THEORY:

3.1 Heat Transfer Modeling:
The heat transfer or transfer of thermal energy can be performed in 3 ways: conduction, convection and thermal radiation. For the heat transfer by conduction, heat passes through a body by means of a temperature gradient in the body. Heat flows from a body with higher temperature to a body with lower temperature. However the heat transfer by the convection process occurs by the movement of molecules in the liquids or gasses; this type of transfer is not possible in solids due to lack of significant diffusion and bulk current flow. Meanwhile, in the thermal radiation system heat is created by the electromagnetic radiation which is occurred by the thermal motion of the charged particles in matter. In this work only heat conduction is considered because the solid refractories and the steel wall of the converter are used for the heat transfer modeling.

Ansys CFD was used to create geometric models and for meshing. The simulation was carried out by using FLUENT 13.0. ANSYS Fluent is one type of modeling software by which one can model flow, turbulence, heat transfer of metallurgical processes in industrial applications. After designing the metallurgical furnaces with proper dimensions and considering the boundary conditions, and by solving energy equation and setting the properties of lining materials and shell, one can make heat transfer modeling by using ANSYS Fluent software.

3.2 Mathematical Equations for Modeling:
In this work for the solid regions in the converter the energy transport equation is considered as:

\[
\frac{d}{dt} (\rho h) + \nabla (\bar{v} \rho h) = \nabla (k \nabla T) + S_h \ldots \ldots \ldots (1)
\]

In equation (1), \(\rho\) is the density, \(k\) is the thermal conductivity, \(h\) is sensible enthalpy, \(T\) is the temperature and \(S_h\) is volumetric heat source. The second term in left side of equation is the convective energy transfer due to the motion of solid which is zero. The volumetric heat source inside the solid is also zero. The first term on the right side of the equation is the heat flux due to conduction, and also considering the transient heat transfer, the energy equation is reduced to equation number 2,

\[
\frac{\partial (\rho h)}{\partial t} = \nabla (k \nabla T) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ ld
considered as the adiabatic wall. Therefore, different temperature profiles were set as boundary conditions in this work.
4. EXPERIMENTAL METHOD:

4.1 Geometry of LD converter:
The geometry and meshing were created in Ansys CFD 13.0. First, the geometry of 3D modeled converter was generated as shown in figure 2 and was employed in the simulation. A 3D model is necessary to provide sufficient results reflecting the real physical process. The geometry represents one fourth of the converter.

![Figure 2: Symmetrical view of the modeled LD converter](image)

Table 1: Geometry for 3D model converter

<table>
<thead>
<tr>
<th>H1(m)</th>
<th>H2(m)</th>
<th>H3(m)</th>
<th>H4(m)</th>
<th>R1(m)</th>
<th>R2(m)</th>
<th>R3(m)</th>
<th>R4(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>1.5</td>
<td>5</td>
<td>3.7</td>
<td>2.6</td>
<td>3.7</td>
<td>4.9</td>
<td>2.1</td>
</tr>
</tbody>
</table>

The dimensions of the converter are shown in table 2. The converter consists of a 0.1m thick steel shell and refractory linings of different materials and of different thicknesses. In this work the capacity of the converter is considered as 400t. The total height of the converter is considered in this experiment as 11.6 m.

4.2 Selection of Lining Materials:
In this work the conventional lining of the converter were considered as three different layers. In figure 3 the details of the converter lining are shown. From the figure we see that magnesite brick was used as inner lining which is the thickest part. Then dolomite is used as intermediate lining and the outer part is the body of the steel shell.
Magnesite brick (magnesium carbonate, MgCO$_3$) is a high performance refractory, which has high resistance to high temperature and is specifically designed for use in steelmaking industry.

Dolomite, (Mg, Ca)CO$_3$, is almost indistinguishable from magnesite [11]. In steel refining processes, the use of dolomite extends the life of refractory linings. In fact addition of dolomite creates excellent bonding with MgO particles which provides excellent coating protection in the refractory lining.

![Figure 3: Symmetrical view of the modeled LD converter with lining materials](image)

### 4.3 Properties of the Lining Materials:

The required material properties are density, thermal conductivity and specific heat capacity. For all materials, their densities are assumed to be constant. Here thermal conductivities and specific heat capacities are normally expressed as functions of temperature if the value changes significantly with the change of temperature. However, in this work they are also assumed to be constant.

Density and thermal physical Properties of the lining materials are listed in table 2 below.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Magnesite</th>
<th>Dolomite</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density Kg/m$^3$</td>
<td>2910$^{[3]}$</td>
<td>2876$^{[4]}$</td>
<td>7840$^{[1][5]}$</td>
</tr>
<tr>
<td>Thermal conductivity W/m-k</td>
<td>2.314$^{[3]}$</td>
<td>5.3$^{[4]}$</td>
<td>54$^{[2][5]}$</td>
</tr>
<tr>
<td>Specific heat J/kg-k</td>
<td>1515$^{[3]}$</td>
<td>1030$^{[3]}$</td>
<td>465$^{[5]}$</td>
</tr>
</tbody>
</table>
4.4 Mesh Analysis:
A 3D geometric model was created and meshed here. Tetrahedral 4 face meshing technique was adopted in this work. The details of the meshing of the converter are shown in figure 4.

The details of the meshing information are summarized in table 3:

<table>
<thead>
<tr>
<th>Parameter/Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Number of Cells</td>
<td>290340</td>
</tr>
<tr>
<td>Total Number of Nodes</td>
<td>54615</td>
</tr>
<tr>
<td>Total Number of Faces</td>
<td>592634</td>
</tr>
</tbody>
</table>

Figure 4: Meshing of 3D modeled converter
4.5 Modeling Procedures:
Modeling was performed in two stages. In the first step, the temperature inside and outside of the converter was estimated as fixed temperature. On the other hand in the second step, real temperature inside and outside of the converter was considered which was not fixed in real case.

4.5.1 Boundary Condition:
As mentioned earlier, the work was done in two stages, two different boundary conditions were considered in those stages.

4.5.1.1 First Step:
In this step the converter was considered as heated. The initial temperature of the outer wall was considered as 300K and the inner temperature of the converter lining was considered as 1923K. In this step the temperature of the gas, slag and steel were considered as the boundary condition.

4.5.1.2 Second Step:
In this step the converter was not considered as heated. The inner surface of the lining from the bottom to top is in contact with the steel, slag and gas. For this reason the temperature of the steel (T_{st}), slag (T_{sl}) and gas (T_{gas}) were set as boundary condition.

The temperature of molten steel was set as a logarithmic function of the blowing time [7]. The equation is shown below:

\[ T_{st} = 80ln(t + 1) + T_f \] \[ \text{(3)} \]

In the equation 3, \( t \) is the blowing time which is expressed in minute. And \( T_f \) is the temperature of molten steel before blowing, which is almost 1696K.

The temperature change of foaming slag was considered as a linear function with blowing time [7], which is shown in equation 4.

\[ T_{sl} = \frac{300}{16} \times \frac{t}{60} + 1623 \] \[ \text{(4)} \]

The temperature of the gas above slag was determined as a function of the blowing time and the slag height by trial and error method. Therefore, the gas which is close to the slag has almost the same temperature and the temperature decreases as the gas height increases. Here, \( y \) is the height changing from the slag height upto the upper portion.

\[ T_{gas} = \frac{300}{16} \times \frac{t}{60} + 1623 - \left( \frac{150}{y - 2.9} \times (y - \text{slagheight} - 2.9)^2 \right) \] \[ \text{(5)} \]

The slag height also changes with the blowing time, which can be expressed as follows.

\[ \text{Slag Height} = f(\text{BlowingTime}) \]
From the literature review, the initial height of the slag was assumed about 0.1m [7]. The two linear functions were defined for these two intervals as:

\[
\text{SlagHeight} = \frac{4.7}{6} \times \left( \frac{\text{current time} - (16 \times 60 \times j)}{60} \right) + 0.1 \; ; \; 0 \leq t \leq 6 \; \ldots \ldots \; (6)
\]

\[
\text{SlagHeight} = -\frac{4.7}{10} \times \left( \frac{\text{current time} - (16 \times 60 \times j)}{60} \right) + 7.62 \; ; \; 6 < t \leq 16 \; \ldots \ldots \; (7)
\]

The equation (6) is valid from 0 to 6 min but equation (7) is valid from 6 min to 16 min.

The above two equations can be explained properly by figure 5.

Hence, according to the figure it is seen that after about 6 minutes the foam height reaches to its maximum height, which is about 4.8m, and thereafter, it decreases to 0.1m again.

The equations were defined as functions (UDF) and were written in C programming. The whole program was hooked to ANSYS FLUENT model to get the model results.
5. RESULTS & DISCUSSIONS:
In this work, after considering proper dimension and meshing conditions and the properties of the lining materials, the modeling work was performed in two steps. The main purpose was to see the transient heat flow through the converter lining after a certain number of heats and how the heat flow affects the refractory lining in the converter.

5.1 Step 1:
In the first step, it was assumed that, converter was already heated. So, the temperature inside the converter was fixed as 1923K and the outside temperature of steel was fixed as 300K. In this step modeling was performed up to 75 heats (1200 min). One heat was considered as 16 minutes. Thus, the following models were developed after the 1st heat and after the 10th heat.

After 1 heat, 16 min  
After 10 heats, 160 min

For a better understanding the heat flow in the converter lining was magnified and is shown in figure 7 (a) for the heat number 1 and (b) for the heat number 10. From the figures it is seen that as the heat number increases the heat flow inside the refractory wall also increases from inner wall to the outer wall. However, the distance of entering the refractory lining is not so much.
Figure 7 Magnified view of vertical part of the converter lining after (a) 1 heat (b) 10 heats

Figure 8 shows the results after 30 heats and after 50 heats. Here it is also seen that heat flow through the lining is increasing from the inner to the outer wall of the refractory lining with the increasing number of heats. The magnified views of the vertical part of the converter lining for these heats are shown in figure 9 (a) for 30 heats and figure 9 (b) for 50 heats.

Figure 8 Modeled diagram after heat number (a) 30 heats and (b) 50 heats
After 30 heats, 480 min                                     After 50 heats, 800 min

(a)                                                             (b)

Figure: 9 Magnified view of the vertical part of the converter lining after (a) 30 heats (b) 50 heats

After 70 heats, 1120 min                                         After 75 heats, 1200 min

(a)                                                             (b)

Figure 10: Modeled diagram of the converter after a) 70 heats and b) 75 heats.

The temperature contours after 70 and 75 heats are shown in figure 10 (a) and (b) and the magnified part of the converter is shown in figure 11 (a) for 70 heats and (b) for 75 heats. From the above mentioned figures it is also seen that with the increasing number of heats the temperature inside the refractory wall increases from the inner to the outer wall of the refractory.
In the first step the temperature inside and outside of the converter was considered as fixed. Besides, the steel, slag and gas temperature was considered as the same temperature. In the second step three different equations are considered for the steel, slag and gas part.

5.2 Step 2:

By setting the proper temperature of steel, slag and the gas as boundary conditions, modeling work was performed using ANSYS Fluent software. Figure 12 (a) (6 minutes) and (b) (16 minutes) are for the first heat. From the figure below it is seen that during the first heat the steel and slag temperature is increasing continuously to its highest temperature and at the end of the first heat the steel and slag temperature is the same. In addition, gas temperature is decreasing from slag temperature to its lowest temperature.

The modeling was also performed for the second heat at 22 minutes and 32 minutes apart from the 6 minutes and the 12 minutes. According to the theoretical review, it is found that after 6 min of oxygen blowing [7], slag height reach its maximum. Therefore, the temperature is high in that portions and it is easily seen from the left model of figure 12 (a) and 13 (a). After 6 minutes of oxygen blowing, the slag height decreases with the increasing time of blowing. It is also seen that the temperature distribution at the end of second heat is the same with the first heat. And the gas temperature decreases to its lowest temperature in the upper portion of the converter.
The figure 14 below shows the temperature contours (a) after 10 heats and (b) after 30 heats. The temperature distribution at the end of 10 heats and at the end of 50 heats is same, which is also similar to the end of first heat and to the end of second heat. Nevertheless, the only difference is the heat flow distribution through the lining from the inner to the outer wall. With the increasing number of heat, the heat flow through the lining is also increasing.
After 10 heats (160 min)  
After 30 heats (480 min)

Figure 14: Modeled converter after (a) 10 heats and (b) 30 heats.

Modeling for second step was performed up to 90 heats (1440 min). Figure 15(a) is for 50 heats and figure 15 (b) is for 90 heats. The figures show that the temperature distribution is the same for above all six models with different times. Therefore, it can be concluded that at the end of all heats, the temperature distribution is the same. However, the heat flow through the lining is increasing from the inner to the outer wall of the refractory lining with the increasing number of heats.

After 50 Heats (800 min)  
After 90 Heats (1440 min)

Figure 15: Modeled converter after (a) 50 heats (b) 90 heats.
### 5.2.1 Temperature Profile Along The Converter Height:

The models developed for second step are used to show the temperature distribution profiles along the vertical part of the converter from its bottom to top with increasing time.

Figure 16 shows the temperature changes in the vertical part of the converter. X-axis indicates the position of the converter from bottom to top and Y-axis shows the temperature. In the figure there are 3 curves for 2 min, 4 min and 6 min. It is seen that from 2 to 6 min the inner wall temperature is increasing for the steel, the slag and the gas. But the gas temperature is decreasing from the slag temperature to its lowest temperature in the upper wall. And it is also seen that at 6 min the slag height is maximum.

![Converter height vs Temperature Profile](image)

**Figure 16: Converter height versus temperature profile from 2 minutes to 6 minutes.**

According to a theoretical review [7], the slag height decreases after 6 min, which is also seen in the following diagram. The steel and slag temperature is increasing continuously to its highest temperature and at the end of first heat after 16 min the steel and slag temperature is the same as shown in figure 17. Furthermore, the gas temperature decreases from the slag to the upper wall of the converter.

Figure 18 below shows the temperature distribution profile for the second heat from 18 to 22 minutes. After the first heat (first 16 min) the steel and slag temperature is the same. Because at the start of the first heat converter was cool. But after the first heat during oxygen blowing the converter has been heated. Thus, during the second heat after a few minutes of oxygen
Figure 17: Converter Height versus Temperature profile change from 8 to 16 minutes.

Figure 18: Converter Height versus Temperature profile change from 18 to 22 minutes.
blowing the heat is maximum. It is also seen that the gas temperature increases with time but it is decreasing from slag temperature to its lowest value along the upper portion.

![Converter Height vs Temperature Profile](image)

**Figure 19: Converter Height versus Temperature profile from 28 to 32 minutes.**

Figure 19 shows the temperature distribution profile from 24 to 32 minutes along the vertical part of the converter. After 22 min during the second heat the slag height decreases. It is also seen that the gas temperature also decreases from the slag temperature with increasing time.

### 5.2.2 Temperature Profile Distribution at Fixed Positions:

The model that was developed during the second step was also used to show temperature profiles through the lining at different positions. In this work 4 different positions were selected for a better understanding of this temperature profile through the lining. Furthermore, the diagram shows the temperature distribution at the end of oxygen blowing at different time steps.

Figure 20 shows the temperature changes through the lining of the converter at the position of \( X = 1.3 \text{m} \) for 8 different steps up to 70 heats. This part of the converter is exposed to the steel. Therefore, the maximum point in the diagram is at the highest temperature. The temperature is decreasing from the hot surface to the bottom through the lining. Plus, in a particular position the temperature increases with the increasing number of heats. This is in good agreement with diagrams resulted by numerical study [8].
Figure 20: Temperature distribution through the lining from the hot surface at X=1.3m.

Figure 21: Temperature distribution through the lining from the hot surface at Y=2.15m.
Figure 21 shows the temperature changes in the bended part of the converter at the height of 2.15m for 8 different heats up to 70 heats. This part of the converter is exposed to the steel and the slag. The maximum point of all the curves in the diagram is also at the highest temperature. In all steps the temperature is continuously decreasing from that the hot surface through the lining from the inner to the outer wall of the converter. And in a particular position the temperature increases with the increasing number of heats.

Figure 22 shows the temperature profiles through the lining at y=5.5m height. Similarly, the temperature is continuously decreasing from the hot surface through the lining from the inner to the outer wall of the converter. Moreover, in a particular position the temperature increases with the increasing numbers of heats.

Figure 23 shows the temperature changes in the bended part of the converter near its mouth section at the height of 9.7 m for 8 different heats up to 70 heats. This area of the converter is accumulated with gas which has comparatively lower temperature. In the diagram there is a maximum point after 50 and 70 heats because the converter has been heated for long time. Consequently, when the surface of the wall is exposed to the lower temperature, the heat has not yet transferred through the lining and there is a maximum temperature.
5.2.3 Temperature Distribution at Different Points at Fixed Position:

The models developed for the second step was also used to show the temperature versus time curve at different points from the hot surface at different heights of the converter. Five different heights were selected with this regard and 3 to 4 points were selected from the outer to the inner surface, which are shown in the following figures.
Figure 24 shows the temperature distribution profile at different points from the hot surface at x=1.3 m from the center. The three curves in the figure represent different heights of the converter. One is for y=1.2m, other two curves are for y=1m and y=0.8m. For all curves the temperature is increasing with the increasing number of heats. And for a distance of 0.2 m from the hot surface (y=1.2m), there is a significant change of temperature with time in comparison to other positions. The reason can be described as such that the hot surface of this bottom part of the converter is exposed to the steel.

![Temperature vs Time Curve at different Points at Y=2.15m height](image)

**Figure 25: Temperature changes with time at different points from the hot surface at Y=2.15m.**

Figure 25 shows the temperature versus time curve at three different points at a fixed height y=2.15m of the converter. This part of the converter is exposed to the steel and the slag. Therefore, for all curves the maximum temperature reached is higher. And at the position of x=3.2m which is near the hot surface of the converter, it is seen that the change of temperature with time is maximum comparing with the other two curves which are inside the refractory lining at x= 3.4 and 3.6 m.

Figure 26 below shows the temperature distribution profile at four different points (x=3.75m, x=4m, x=4.1m and x=4.2m) from the hot surface at a fixed height y=2.95m of the converter. From the figure below it is seen that for all points the temperature is increasing with the increasing number of heats. At y = 2.95 m of the converter the refractory lining is exposed to the steel and the slag. Thus, from the diagram it is seen that, near hot surface at x=3.75m, there is also significant change of temperature with time. But as the distance is increasing from hot surface to the inner wall the points (at x=4m, x=4.1m and x=4.2m) are not changing so much. This is in good agreement with the diagrams based on experimental data [8].
Figure 26: Temperature changes with time at different points from the hot surface at the height of $Y=2.95m$.

Figure 27: Temperature changes with time at different points from the hot surface at the height of $Y=5.5m$.

Figure 27 shows the temperature distribution profile at four different points ($x=3.85m$, $x=4m$, $x=4.1m$ and $x=4.2m$) at $y=5.5m$ height. For all the positions the temperature is increasing with the increasing number of heats. However, the maximum temperature reached (for the position $x=3.85m$) after 70 heat (67200sec) is not so high compared to the previous diagram. In addition, as the distance increases from the hot surface (for the points, $x=4m$, $x=4.1m$ and $x=4.2m$), the temperature increases very slowly.
Figure 28: Temperature changes with time at different points from the hot surface at the height of Y=9.7m.

Figure 28 above shows the temperature distribution profile through the lining for three different points (at x=3.1m, x=3.3m and x=3.5m) at y=9.7m height. Here the temperature of the lining is changing very slowly up to 70 heats (67200sec) for all positions. This is because that area of the converter is accumulated with the gas which has lower temperature than the slag. Furthermore, as other cases with positions near hot surface (x=3.1m), the change of temperature is more comparable to the other positions (x=3.3m and x=3.5m).
6. CONCLUSION:

In this work a 3D model of the temperature distribution in the lining of LD converter has been presented. This model gives a transient heat flow through the lining for different times. As mentioned earlier it was performed in two stages. In the first stage, a fixed temperature was considered for the inner and the outer wall; in the second stage a user defined function was used by using C programming and then it was hooked to Ansys Fluent Software for computing. To summarize, the main findings from the model are:

- The model shows temperature changes in the vertical part of the converter for the 1\textsuperscript{st} heat (from 2 min to 16 min) and also for the 2\textsuperscript{nd} heat (18 min to 32 min). The temperature in the vertical part of converter lining increases with the increase number of heats.

- It shows the temperature distribution for four different parts of the converter and the height of the converter at the end of oxygen blowing.

- The model is used to show the temperature distribution in different points of the converter from the hot surface to the steel body at different heights up to 70 heats.

- Considering the model, it can also be concluded that in order to develop a good heat transfer model, we have to use refractories with excellent properties as the inner lining.

- It is very difficult to measure the temperature change in the converter lining during the operation. So by using ANSYS CFD software we can get an idea about the possible conditions during the steel making processes in the converter lining. Furthermore, applying the model, industries can reduce the wear cost and the amount of downtime and therefore decreased the refractory cost per ton of steel produced.
7. FUTURE WORK:
To better understand the temperature profile distribution in the converter lining the following suggestions can be made:

- In this work all the analyses were based on assumptions and theories from different references. However more accurate and reliable results can be obtained by considering industrial data.

- For a better understanding of the real process, we can suggest considering the taphole and the mouth section of the converter in the modeling.

- Meshing technique should be adapted to develop finer mesh for getting smoother curve.

- First order simple scheme CFD was used in this study. It can be advised to do the modeling by using second order simple scheme CFD to get more accuracy.
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