CHAPTER 2

LITERATURE SURVEY

2.1 HISTORICAL BACKGROUND

The manufacture of iron for tools, implements, and construction material goes back to 4000 BC. From 1850 until 1960, the Coke-Blast Furnace became the leading reduction process. The OHF and pneumatic air blowing – processes were for mass-production of steel. From 1960 onwards, hard coke Blast Furnaces, LD converters and EAF steel making are the today’s basis for 95% of world steel production.

Iron making through coke Blast Furnaces and steel making through LD converter followed by ladle refining, continuous casting and rolling was the established route for integrated steel plants having larger capacities. For the mini mills, Electric Arc Furnace (EAF), using scrap and sponge iron (DRI) followed by secondary refining, continuous casting and rolling was the popular route for manufacturing high value special steels in the mini mills having capacities up to one million ton per annum. As predicted by Willy Korf in the late 1960s, standard long products such as re-bar, wire rod and sections will be produced through alternative state of the art technology and efficient production methods as per Weber (1991). Today, these products make up for more than 30% of world’s steel production and are produced almost exclusively in mini mills.
From the mid 1970s, the steel production in the developed countries started showing a downward trend. This was mainly due to high cost of production and strong pollution control norms. At the same time, the overall consumption of steel worldwide was increasing primarily due to industrialization and infrastructure developments in the developing countries. This resulted in increase of the steel production in the developing nations. The anticipated shift of steel production away from the industrialized countries to the developing countries was certain to have a greater impact on the process technology than it has been in the past. This is mainly due to the fact that at the time of increasing the production capacity of the existing unit or putting up a new production facility, one has to decide and choose the process route, which is suitable for local conditions and also going to be viable for the next few decades. Pfeifer (1988) stated that in Brazil, as well as most developing countries, scrap is scarce, expensive and increasingly contaminated. Power grids are not strong but some sort of coal is usually available. This led to development of new steel making processes in the developing countries to meet their enhanced steel requirements.

2.2 DEVELOPMENT OF EOF

Energy plays a key role in steel making. In 1978, Weber and Wells had an idea of combining oxygen blowing, after burning and scrap pre-heating in one system which emerged as Energy Optimizing Furnace (EOF) as per Pauls (1993). EOF developed at CS Pains, Brazil, was intended to replace three numbers working and one standby OHF and compete with EAF and LD converters for production of commercial steel grades.

The development of EOF started in 1978 with horizontal submerged oxygen blowing into the 30 MT Open Hearth Furnaces. After four years of successful operation, a 22 MT pilot EOF without scrap pre heater
was installed. The purpose of the pilot EOF was to learn more about post combustion of the gases emerging out of the steel bath during processing. The schematic diagram of the 22 MT pilot EOF is shown in Figure 2.1 as stated by Weber et al (1988). In July 1982, decision was taken to build a 30 MT EOF with scrap preheater for commercial production. This EOF was commissioned in the year December 1982.

![Figure 2.1 Pilot EOF – 22 MT per hour](image)

Behind the success of EOF at C.S.Pains was a sound research back up. Weber (1990) has elaborated the tests conducted at the Institute of Ferrous Metallurgy at Aachen Technical University, Germany, to assess the EOF operating performance at different stages of processing. A pilot 100 kg-EOF was installed in the institute’s melt shop. This pilot vessel permitted the calculation of data on a model scale so that a quantitative assessment of the
reactions taking place in the EOF atmosphere could be carried out. The pilot EOF was equipped with measuring devices for the continuous monitoring of:

- Bath temperature
- Gas temperature in the furnace atmosphere
- Off-gas temperature
- Temperature of the furnace lining
- $\text{CO}_2$, CO and $\text{O}_2$ in the furnace off gases
- Volume flows of the gases injected

A hybrid recorder transmitted the data to a computer for processing. The following parameters could be varied in the furnace:

- Distance of the injectors from the liquid bath
- Shape and diameter of the injection tuyeres
- Diameter of the submerged tuyeres
- Volume of oxygen injected above and below the bath.

The development of first EOF at CS Pains emerged out of the steel making practices of the OHF. Due to this, many ideas were taken from the OHF operation such as oxygen lancing through submerged tuyeres, and oxygen enrichment of the preheated post combustion air. The first attempt of development of EOF at CS Pains was very successful and they solved their company problems to replace slow speed, high cost OHF operation. EOF was a commercial success because its cycle time was 30 minutes compared to the best operated OHF of about 4 to 5 hours. After the installation of EOF, steel production doubled at CS Pains using one EOF and as a result the less efficient three OHF were phased out.
Although the first attempt of constructing an Energy Optimizing Furnace was very successful as stated above, however, there are a few areas, which CS Pains could have easily taken into consideration while building the first EOF. CS Pains started with water cool elements on the sidewalls of the EOF but the roof was made of refractory bricks. By the 1980s water cooled roof in EAF was already implemented and was very successful. Hence, EOF should have also started with water cool roof that would have given longer refractory life right from the beginning.

The first EOF built at CS Pains had fixed type bottom. However, the advantages of tilting type OHF as well as EAF for steel processing were very well established in the 1970s. Hence, CS Pains should not have built a fixed type EOF, which has so many limitations for steel processing, such as, metal loss through slag door and carry over slag into the ladle during tapping.

CS Pains used preheated air, enriched with oxygen for post combustion through the atmospheric injectors. However, in the 1970s, in LD converters and EAF use of pure oxygen was very popular in steel making. Hence, CS Pains could have used pure oxygen in the atmospheric injectors in place of pre-heated air. This would have eliminated the complicated air pre-heating system in the EOF.

In order to overcome the above deficiencies, CS Pains carried out the following modifications from 1983 to 1987 in the EOF:

- Water Cooled panels and roof to replace refractory lining.
- Interchangeable bottom with transfer car
- Automatic lime and alloy charging equipment
• Automation for oxygen injection and atmosphere control system.
• Ladle – car
• Three stage scrap-preheater for heavy and light scrap
• Retractable supersonic oxygen lance
• Submerged injection system for coal / lime

These improvements had the following results:

• Campaign – life improved (record- 706 heats)
• Brick consumption reduced below 4 Kg/MT
• Down time for bottom change reduced to 24 hrs
• Oil consumption below 4 Kg/MT
• Heats/day increased (average 23 heats/day; Record 27 heats/day)
• Average blowing time - decrease from 38 to 32 minutes.

In the year 1988, second EOF, having tilting facility, was commissioned at CS Pains having a capacity of 35 MT. EOF No.1 was phased out in the late 1990s. Today, one EOF at CS Pains is producing 0.5 million MT of steel per annum, which is 2.5 times of what three OHF were producing in the 1970s. The EOF at CS Pains is working at very high productivity and low cost, and competing with LD converter based steel plants in Brazil for commercial steels. The EOF at CS Pains is now working for over 25 years and they have produced 10.5 million tonnes of steel up to December 2007.
2.3 40 MT EOF AT RIFS, U.S.A

Bonestell and Weber (1985) have elaborated upon installation of 40 MT capacity EOF at (RIFS) Connecticut Steel Corporation USA. This EOF was scheduled for melting 100% scrap in order to demonstrate the capability of EOF to compete with EAF. Tests for usage of higher percentage scrap in the charge were conducted at CS Pains in their 30 MT EOF. The results of percentage scrap increase beyond 40% were not very encouraging as per Rollinger (1989). With the increase in scrap percentage, there was an increase in oxygen consumption and coke consumption while the blowing time in the EOF remained almost constant as shown in the Figure 2.2 (a), (b) and (c).

The best figures were achieved at 66% hot metal and 34% scrap with scrap preheating. A lot of energy was spent unnecessarily to prove that EOF is as efficient as EAF at higher percentage of scrap in the charge. The electric arc furnace is the best equipment for melting scrap under the strong arc. This is the main reason why the 40 MT EOF at the RIFS did not succeed commercially since they tried to melt higher percentage of scrap.

Figure 2.2(a) Oxygen consumption (Nm$^3$/MT)
There were a few other deficiencies in the EOF installed at RIFS. The stopper mechanism on the EOF tap hole for slag free tapping was not a good idea. In the 1980s, eccentric bottom tapping (EBT) with fast tilt back was already an established practice for slag free tapping. Hence the EBT or
submerged tap hole system along with fast tilt back could have been properly designed for efficient slag free tapping.

Slide gate mechanism below the EOF bottom was also not a good idea either for emptying the EOF or to check the bottom refractory. This was perhaps done since furnace was fixed type and metal could not be drained completely. They should have gone for tilt type EOF at RIFS that facilitates easy drain out of the metal in the furnace bottom for refractory inspection. They should have adopted the practice of changing the working lining of EOF bottom in each campaign and changing the backup lining in every alternate campaign. This would have ensured safe operation of the EOF bottom at all times.

Bonestell and Weber (1985) have also mentioned about the predictability of reaching the end point during EOF processing. They tried to establish that by the time carbon percentage was achieved, the tapping temp was also attained in the EOF. More focus was for energy balance since trials were being conducted using higher percentage of scrap in the charge. This concern is understood since at that time the EOF was put up without ladle furnace. Hence, attaining the right temp in the ladles after tapping, suitable for continuous casting was the most important requirement. If the EOF at RIFS works was installed with a ladle furnace, the success of the EOF would have been better ensured. They further stated that the approximate drop of carbon was 0.15% per minute up to 0.05% carbon. This is a very generalized statement and in the present work, in depth study has been carried out for predictability of carbon in the EOF that is presented in the subsequent chapter.

In the RIFS works, steel was refined in the EOF with slag basicity of (3 to 3.2) in order to reduce sulphur to the extent possible in the EOF. They
were required to do this due to coal injection in the EOF for melting higher percentage of scrap. The coal injection was done through the submerge tuyeres along with oxygen which makes the construction of the submerge tuyeres quite complex and it was also a safety hazard. Moreover, since ladle furnace was not available, effort was made to reduce sulphur in the EOF, to the extent possible, under most difficult condition.

Weber et al (1986) have discussed the placement of scrap preheater on specially designed water cool fingers on top of the EOF roof as shown in Figure 2.3. This was a good concept compared to the down flow scrap preheater since the off gas at high temp would preheat the scrap more efficiently. However, they have not brought out the fact that the furnace was operated with a bypass arrangement to the scrap preheater that automatically opened in case the passage in the scrap gets blocked due to partial melting. Whenever the scrap preheater in the EOF is constructed without the bypass arrangement, the scrap preheater has not functioned very well.

They have further elaborated upon measures taken for slag free tapping and also tapping in the ladle under vacuum in order to improve the quality of steel. However half-hearted effort was made to conduct these trials and therefore not much success could be accomplished at CS Pains. The vacuum treatment would not yield any results in the steel tapped from the EOF since oxygen level is so high. Such degassing treatments are normally given after the ladle furnace operation under reducing slag conditions.

Weber and Rollinger (1987) have reported that EOF with capacity upto 80 MT and 100 MT were engineered for various projects. The 80 MT furnace was installed at TISCO Jamshedpur but 100 MT furnace was not installed anywhere. 80 MT capacity EOF is perhaps the limit for EOF, which is yet to be proved.
Rollinger (1989) has stated an important point with regard to EOF processing – there exists a defined mixing ratio for each set of parameters where a specific furnace touches the limit between autothermic and allothermic, this point being the technical optimum for furnace operation.

The influencing parameters are shown in Table 2.1. These variations hide to some extent the more pronounced dependence of oxygen, coke and blowing time on the hot metal to scrap ratio for a given furnace where all other parameters are kept constant.
Table 2.1 - Influencing parameters on EOF operations

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameter</th>
<th>Variation at CSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chemical Heat in hot metal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4.0 – 4.2 %</td>
</tr>
<tr>
<td></td>
<td>Si</td>
<td>0.5 – 1.2 %</td>
</tr>
<tr>
<td></td>
<td>Mn</td>
<td>0.2 – 0.5 %</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>0.14 – 0.17 %</td>
</tr>
<tr>
<td>2</td>
<td>Hot metal temperature</td>
<td>1250 – 1330°C</td>
</tr>
<tr>
<td>3</td>
<td>Tapping temperature of liquid steel</td>
<td>1650 – 1690°C</td>
</tr>
<tr>
<td>4</td>
<td>Carbon in liquid steel</td>
<td>0.05 – 0.45%</td>
</tr>
<tr>
<td>5</td>
<td>Furnace size</td>
<td>30 MT</td>
</tr>
</tbody>
</table>

This is confirmed by the consumption data shown in Figure 2.4 for the constant hot metal and EOF furnace tapping conditions listed below for a 30 MT EOF at C S pains.

![Figure 2.4 Graphic representation of EOF consumption](image-url)
**Hot metal criteria:**

- Carbon: 4.0%
- Silicon: 0.9%
- Manganese: 0.5%
- Phosphorus: 0.05%
- Sulphur: 0.04%
- Temperature of mixer: 1350° C

**EOF furnace tapping conditions:**

- Carbon: 0.10%
- Temperature: 1640° C

For the conditions stated, a technical optimum would be achieved at or slightly above a mixture of 40 percent scrap and 60 percent hot metal. The economic optimum obviously depends on the prices for the various input materials and on productivity requirements of the plant.

### 2.5 60 MT EOF AT C.S. ALIPERTI, BRAZIL

Weber et al (1989) have examined the initial results of 60 MT EOF at C.S. Aliperti Steel Plant in Brazil that went into operation in August 1988. It can be seen clearly that it is very difficult to switch from a traditional steel plant working in combination of OHF and ingot casting, to a modern, high productive oxygen unit with continuous casting. All changes in logistic and infrastructure systems as well as the adaptation of operating personnel to new conditions require a very significant change than the new melting and casting technology itself. The main factors responsible for the failure to reach the full capacity of the EOF were:

1. Lack of Hot metal and Pig Iron / Steel scrap.
2. No Ladle furnace.
3. 2\textsuperscript{nd} Casting crane required.
4. Waiting for Continuous Casting  
5. Maintenance of de-dusting system – furnace.  
6. Absence of captive oxygen plant and dependence on purchased liquid oxygen and usage through evaporation system

From the above analysis it is very clear that the introduction of new technology in a melting shop has to be considered in lines with upstream and downstream facilities. It should never be considered in isolation in order to achieve over all results and success of the project.

2.6 80 MT EOF AT TATA STEEL

Weber et al (1989) have also deliberated on the 80 MT EOF in the existing open hearth furnace shop No. 3 at Tata steel, Jamshedpur, India. Tata steel has number of LD converters and they have long experience of processing the steel in the same. The EOF was going to work with (65 – 70) MT hot metal. Nevertheless, the high flexibility of the new unit and the low investment cost had triggered the decision by TATA management. They worked out that investment cost of EOF was about 40% of the cost of a new LD plant with conversion cost approximately the same. The EOF started operation in mid 1990 and it was to replace four numbers 220 MT OHF in the existing melt shop. They had also planned to install second EOF of 80 MT capacity to replace the remaining OHF in the Tata melting shop. The EOF at Tata did not succeed commercially due to following reasons:

a) Failures of water cooled panels  
b) Steel tapped from EOF was cast into ingots since continuous casting machine (CCM) was not always available.  
c) Inadequate supply of oxygen
d) Supersonic lance was not installed in the 80 MT EOF having large hearth diameter.
e) Ladle Furnace was not available.

2.7 LIQUID STEEL DECARBURIZATION

Steel making is a refining process, in which impurities of hot metal are oxidized, with the exception of sulphur, where reducing conditions are specifically required. Carbon in hot metal or steel cannot be considered as impurity. Carbon is the most important alloying element in steel. However, carbon in hot metal is around 4.3% while the carbon in steel is below 2%, but in most of the commercial grades of steel, carbon is below 1.3%. Hence, while steel making, carbon-oxygen reaction plays a dominant role. In fact, decarburization of the carbon in hot metal is the rate controlling factor for conversion of hot metal to steel. The removal of other impurities of hot metal such as silicon, manganese, phosphorous etc., takes place side by side while carbon is getting oxidized.

In the open hearth furnace, the oxidation of carbon was a very slow process, since carbon was getting oxidized only through the reaction at slag metal interface. The slag was maintained oxidizing in nature with the use of iron ore while the energy required was supplied through pre-heated air, which at times was enriched with oxygen. Later, in the LD converters with use of high speed oxygen lancing direct reaction of oxygen took place with carbon in hot metal, which speeded up the entire process. Typically, the decarburization cycle in open hearth furnaces was 12 to 14 hours while the cycle time in LD converters was less than one hour. Theoretical background of carbon oxidation is very important for proper understanding of steel making.
2.7.1 Thermodynamics of Refining

Generalized refining reaction in steel refining is represented by:

\[ [X] + [O] = XO \text{ (any phase)} \]

Where \([X]\) stands for any element dissolved in the melt.

The equilibrium constant for the above reaction is:

\[
K = \frac{a_{XO}}{a_X \cdot a_O} \quad \text{where } a = \text{activity}
\]

The evaluation of \(k\) need either free energy change of the reaction or activity co-efficient values of \(X\), \(O\) and \(XO\). The activity co-efficient of various solute elements in the melt have been experimentally determined in binary \(Fe - X\) and ternary \(Fe - X - i\) iron melts. The effect of third element ‘i’ on the activity co-efficient of ‘X’ is generally represented in form of plots between \(\log f_i^{[X]}\) and concentration of ‘i’. These semi log plots are generally linear at low concentration levels of ‘x’ and ‘i’ and they can be represented as

\[
\log f_i^{[X]} = e_i^{[X]} \% i
\]

Where \(e_i^{[X]}\) is known as interaction co-efficient expressing the effect of ‘i’ on ‘x’. Knowing the interaction co-efficient the Henrian activity of a solute in a complex melt can be mathematically computed as

\[
\log h_x = e_x^{X} \%X + e_{x1}^{X} \% X_1 + e_{x2}^{X} \% X_2 + \ldots\ldots \log \% X
\]

Where \(X_1, X_2, X_3\) etc are solute elements.
These valves obtained are accurate only for very dilute solutions but in
the absence of more information, it can be used for concentrations up to few
% of solute element without much error. For higher concentrations, graphical
computations are more accurate.

Similarly activity co-efficient of oxides have been experimentally
established for many binary and ternary slags. The activities are generally
represented in the form of iso-activity lines in the ternary diagrams.

The activity of the oxidizing agent [O] can be estimated in the form of
partial pressure of oxygen in the gaseous phase and as activity of iron oxide in
the slag phase. During refining as the oxidizing agent is brought in contact
with the melt, oxygen may dissolve in iron up to its solubility limit. Any
further addition of oxygen results in insoluble oxide products in the melt. In
general, the equilibrium concentration of oxygen in the melt is inversely
proportionate to that of the solute elements in the melt.

2.7.2 Carbon Reaction

The carbon reaction plays a dominant role in steel making. The
activity of carbon in liquid iron shows negative deviation from ideality. The
presence of carbide forming elements such as Cr, W, Mo, V etc. decreases the
activity co-efficient of carbon while non-carbide forming elements such as
Cu, Ni, Co, increase the activity co-efficient of carbon

\[ [C] + [O] = \{\text{CO} \]
Equilibrium constant of the above carbon oxidation reaction is

\[ K = \frac{p_{CO}}{h[C] \cdot h[O]} \]

\[ f_c[\%C] \cdot f_o[\%O] = \frac{p_{CO}}{K} \]

**Figure 2.5 Carbon Vs Oxygen at iso-baric graph**

The relationship of C & O at various partial pressures of CO is shown in the Figure 2.5. The product of mere [C] and [O] along the iso-baric curve is not constant. Hence, the activity co-efficient must be taken into account in the calculation of equilibrium constant. Temperatures dependence of equilibrium constant is represented by the following equation:

\[ \log K = \frac{1056}{T} + 2.131 \]
At 1600 °C, the value of k (equilibrium constant) is 500. It is thus possible to produce steel less than 0.1% using oxygen as the oxidizing gas. The product of carbon oxidation is a gas that passes off into the atmosphere. Hence, the reaction of carbon oxidation always goes in the forward direction. Steels much below 0.1% can be produced under vacuum or under inert gas atmosphere, where partial pressure of CO drops.

2.7.3 Oxygen Transport Mechanism In Open Hearth Furnace

In the pneumatic processes, such as open hearth furnaces, oxygen exists at the gas metal interface. The rate of reaction is affected by the diffusion of carbon to the interface. The stirring of the bath caused in this process helps to speed up the carbon transport and thus decarburization at higher rate. In the hearth process, oxygen from the furnace atmosphere has to diffuse across the slag layer and the metal layer to reach the pore metal interface. The physical solution of oxygen in slag is negligible. Oxygen dissolves in slag in ionic form. The transport of oxygen from the atmosphere to metal phase to form CO bubble is shown in Figure 2.6 hereunder:

\[
\frac{1}{2}[O_2] + 2e^- \rightarrow (O^{2-})
\]

**Figure 2.6 Carbon oxidation mechanism in hearth process**
The iron in the slag oxidizes as:

\[ 2 \ (\text{Fe}^{2+}) \rightarrow 2 \ (\text{Fe}^{3+}) + 2 \ e^- \]

The overall reaction is:

\[ 2 \ (\text{Fe}^{2+}) + \frac{1}{2} \ (\text{O}_2) = 2 \ (\text{Fe}^{3+}) + (\text{O}^2-) \]

Due to thermal diffusion \([2(\text{Fe}^{3+}) + [\text{O}^2-]]\) migrate from gas / slag interface to slag / metal interface. The oxygen \((\text{O}^2-)\) is delivered to the metal which diffuses to pour metal to form \((\text{CO})\) bubble with carbon. The \(2 \ (\text{Fe}^{2+})\) migrates again to slag / gas interface. Thus the transport of oxygen from furnace atmosphere to metal phase gets completed and it repeats itself.

The oxygen diffusion process can be speeded up by adding ferrous oxide \((\text{Fe}_2\text{O}_3)\) in slag which settles at slag metal in the face since it is heavier than slag but lighter than metal. It supplies oxygen as

\[ < \text{Fe}_2\text{O}_3> \rightarrow 2 \ (\text{FeO}) + [\text{O}] \]

This is an endothermic reaction known as “OREING OF SLAG”. The overall reaction is

\[ \frac{2}{3} <\text{Fe}_2\text{O}_3> + 2 \ [\text{C}] \rightarrow \frac{4}{3} \ (\text{Fe}) + 2 \ \{\text{CO}\} \]
\[ \Delta H = +65 \text{ Kcal} \]

If low pressure oxygen is sprayed on the slag surface, the above endothermic reaction is replaced by

\[ [\text{C}] + [\text{O}] = \{\text{CO}\} \]
\[ \Delta H = -89 \text{ Kcal.} \]

This is an exothermic reaction and speeds up decarburization.
\[
\frac{dc}{dt} = (0.12 - 0.18) \% \text{C/hr} \quad \text{For normal OH process}
\]
\[
= (0.6) \% \text{C/hr} \quad \text{With oreing process.}
\]
\[
= (3) \% \text{C/hr} = \text{With oxygen injection during refining period}.
\]

2.8 MIXING AND MASS TRANSFER STUDIES IN LD AND EOF

Chatterjee et al (2005) have presented cold model studies of mixing and mass transfer in steel making vessels, namely, LD converter and EOF. For over 40 years, most of the steel in the world is produced through LD converter route and it has maintained a Pre-eminent position ever since because of continuous process improvement. One of the major innovations in LD steel making has been the introduction of a small amount of inert gas from bottom of the converter to accompany oxygen injection from the top through vertical lance. This development is commonly referred as “combined blowing”, which has found widespread acceptance, so much so, that at present, exclusively top blown LD converters are virtually non-existent in the world. The EOF is also a top and side combined blown furnace. There are neither many EOFs operating in the world nor has there been so much of study in the area of mixing and heat transfer carried out in the EOF. We have to learn from the conclusions drawn in the studies made on LD converters and try to apply those inferences on EOF to our advantage.

Several investigators have carried out mixing and mass transfer studies in hot as well as cold models to understand various aspects of top blowing, bottom blowing and combined blowing. Ueda et al (1981) determined the mixing time in 2.5, 170 and 250 MT converters, and found that when 4% of the top gas was injected through the bottom, optimum
mixing was obtained in the metal phase. Nakanishi et al (1982) measured the mixing time in a 5MT pilot converter equipped with a top blowing lance as well as tuyeres for bottom agitation. The mixing time was found to decrease with an increase in the amount of bottom blown gas. Kohtani et al (1982) conducted cold model experiments to assess the effect of different bottom tuyere configurations and the flow rate of bottom gas on the mixing time. They found that the number of tuyeres did not have any appreciable effect, but the tuyere configuration certainly influenced mixing in the bath. Taguchi et al (1983) also carried out water model studies with different numbers of bottom tuyeres and found that the mixing time decreased with an increase in the extent of bottom blowing. In mixing experiments in a 1:19 scaled down water model of a 240 MT combined blown converter, Oymo (1983) used a double row arrangement and he observed that with some particular bottom tuyere configurations, the mixing time could be reduced by 50% when the top gas was augmented by a small amount of gas through the bottom tuyeres. Furthermore, the double row arrangement was found to be better than the circular set up. Koria and Lange (1986) studied the mixing time in a 1:19 scaled down model of a 230 MT converter following simultaneous injection of top and bottom/side gas. In their studies of the effect of tuyere configuration on the mixing time in the presence/absence of melting scrap, they concluded that for all flow rates of basal gas and under all top blowing conditions, the bottom tuyeres helped in mixing the bath faster than the side tuyeres.

The affect of the presence of a slag layer on the mixing time in gas stirred ladles was investigated by Haida et al (1980) and Ying et al (1983). Their conclusion was that the mixing time increased in the presence of slag. Siemsson and Lange (1989) determined the mixing time in the presence of slag in a model of a combined blown converter, and found no simple relationship between the mixing time and the specific energy input into the
system. Asai et al (1983) obtained a capacity coefficient (similar to a mass transfer coefficient) for the transfer of benzoic acid between tetraline (slag phase) and water (metal phase) by making electrical conductivity measurements. A relationship was found between the capacity coefficient and the gas flow rate. Matway and Co-workers (1989 and 1991) studied the effect of gas flow rate, tuyere configuration and tuyere size on mass transfer between two immiscible liquids at room temperature in a 1:13 scale model of a BOF. A correlation between the volumetric mass transfer coefficient and the gas flow rate was obtained, the value of the exponent in the gas flow rate term was found to change with an increase in gas flow rate.

It needs to be mentioned that many investigators have assumed in their studies that a decrease in mixing time automatically indicates increased mass transfer rates. Matway and co-workers clarified that a decrease in the mixing time corresponded to increased mass transfer only when the bath configuration was the same. Thus, liquid-liquid mass transfer rates in combined blowing can be directly correlated with mixing time only for a given tuyere configuration and top blowing conditions. Schlarb and Frohberg (1985) used a water model of a combined blown converter to measure the rate of transfer of caprylic acid between water and oil in an attempt to estimate the interfacial area. Kim and Fruehan (1987) investigated the transfer of thymol between two immiscible liquids in a scaled down model of a gas stirred ladle, and observed that the mass transfer parameter K (mass transfer coefficient x interfacial area) increased gradually with increasing gas flow rate at lower flow rates followed by an abrupt increase of K at higher flow rates. Mixing as well as mass transfer in combined blowing as well as in ladle stirring have been studied by Koria et al (1988 and 1990).

Amit Chatterjee et al (2005) carried out the cold model trials by fabricating the actual vessel for 130 MT LD converter and 80 MT EOF,
where the linear dimensions were scale down by 1/6th to arrive at the model dimensions. The modified Froude number was used to select the blowing condition in the model studies. Water, Paraffin Oil and Compressed air were used to simulate steel, slag and oxygen / argon respectively. The mixing time experiment in the EOF was undertaken in the same way as in the case of LD. However, a few experimental runs were conducted with an oil layer on top of water to simulate the slag. In general, the number of experiments in the EOF was limited since operation of 80 MT EOF was suspended in TATA Steel. The flow rate of gas through submerged tuyeres as well as through the two sets of inclined injectors Figure 2.7 was varied; the experimental condition employed are given in Table 2.2.

![Figure 2.7 Position of injectors in vessel 3 (EOF)](image-url)

- Injector’s angle from vertical (27º) fixed
- Injector’s angle from horizontal (0º) fixed
- Position P: Inj1, Inj3, Inj6, Inj7
- Position Q: Inj2, Inj4, Inj5, Inj8

Figure 2.7 Position of injectors in vessel 3 (EOF)
Table 2.2 Experimental conditions for mixing studies in vessel 3 (EOF)

<table>
<thead>
<tr>
<th>Flow rate of gas in eight submerged tuyeres, (min⁻¹)</th>
<th>Flow rate of gas in four injectors at position P (min⁻¹)</th>
<th>Flow rate of gas in four injectors at position Q (min⁻¹)</th>
<th>Blow Profile nomenclature used</th>
<th>Oil Thickness on top of water (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>86</td>
<td>142</td>
<td>98</td>
<td>86/142/98</td>
<td>0</td>
</tr>
<tr>
<td>57</td>
<td>109</td>
<td>109</td>
<td>57/109/109</td>
<td>0</td>
</tr>
<tr>
<td>86</td>
<td>0</td>
<td>0</td>
<td>86/0/0</td>
<td>0</td>
</tr>
<tr>
<td>57</td>
<td>0</td>
<td>0</td>
<td>57/0/0</td>
<td>0</td>
</tr>
<tr>
<td>86</td>
<td>142</td>
<td>98</td>
<td>86/142/98</td>
<td>15</td>
</tr>
<tr>
<td>57</td>
<td>57</td>
<td>109</td>
<td>57/57/109</td>
<td>15</td>
</tr>
</tbody>
</table>

All the results obtained from the mixing experiments carried out in vessel 3 are shown in Figure 2.8 as stated by Amit Chatterjee et al (2005). It can be seen that the mixing time with blowing condition 86/142/98 was ~ 45% lower than for blowing condition 57/109/109, both without any slag layer.

Figure 2.8 Summary of mixing time results obtained under given blow conditions in vessel 3 (EOF)
Mixing times with blowing conditions 86/0/0 and 57/0/0 were comparable to those for blowing conditions 86/142/98 and 57/109/109 respectively (all with no slag layer). This shows that the inclined top injectors had no significant influence on bath homogenization – an important conclusion for EOFs. Under all blowing conditions, the mixing times increased whenever slag, represented by the oil layer of 15 mm thickness, was present. However, the magnitude of the retarding effect of the slag layer varied depending on the blowing conditions, e.g. the mixing time increased by ~72% in the presence of slag with a blow profile 86/142/98, but only 8% with a blow profile 57/109/109. The reason for the more marked increase in mixing time in the presence of the slag layer in the former case was because oil, which is relatively more viscous than water, dampened the surface velocities in the bath quite appreciably when the mixing conditions were inherently better, but when the mixing time without any slag layer was already fairly high, the retarding effect was naturally much less. This implies that surface velocity in the metal bath has a major role to play in determining the effect of the slag layer.

Figure 2.9 shows the variation in transfer ratio (for benzoic acid transferring from water to paraffin oil) with time for the two different blowing conditions included in Table 2.3 as mentioned by Amit Chatterjee et al (2005). Figure 2.9 also compares the concentration ratio under EOF conditions with that obtained in the BOF (vessel 1). Mass transfer with blow profile 86/142/98 in the EOF case was greater than with blow profile 57/109/109, as indicated in Table 2.3, but even the 86/142/98 blow profile gave rise to much lower transfer ratios than just pure top blowing using a THL in vessel 1.
Figure 2.9  Variation in concentration with time for given blowing conditions in vessel 3 (EOF) and vessel 1 (LD)

Table 2.3 Mass transfer experiments in vessel 3 (EOF)

<table>
<thead>
<tr>
<th>Blow profile nomenclature</th>
<th>Number of side injectors</th>
<th>Rate constant min(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>86/142/98</td>
<td>8</td>
<td>0.0128</td>
</tr>
<tr>
<td>57/109/109</td>
<td>8</td>
<td>0.0083</td>
</tr>
</tbody>
</table>

The entire set of results for mass transfer under all conditions studied in the present work (top blowing, bottom purging, combined blowing in vessel 1 (BOF) and a separate set of studies in vessel 3 (EOF) is summarized in Figure 2.10 as given by Amit Chatterjee et al (2005). It can be
seen that even the highest rate constant for the EOF (blowing condition 86/142/98) was much lower than that obtained either with top lancing or with combined blowing in BOF vessel 1. The EOF rate constant was only comparable to the exclusive bottom purging case in the BOF (a condition never used during accrual steel making).

![Graph showing mixing time for different blowing conditions](image)

(C.B.: Combined Blowing, THL: Three hole lance, SHL: Six hole lance)

**Figure 2.10  Summary of rate constant values obtained in vessel 3 (EOF) and vessel 1 (LD) under different blowing conditions**

Of course, it is important to point out here that the ratio of water / paraffin oil in vessel 3 and vessel 1 was different – about 8:1 and 7:1, respectively – but this slightly adverse ratio cannot account for the substantial decrease in rate of mass transfer in the EOF case. It, therefore, became abundantly, clear in Tata Steel that for the furnace geometry, bath conditions and blowing profiles using submerged tuyeres and side injectors adopted in
the 80 MT EOF, the rate of mass transfer between the metal and slag phases would be relatively poor. In some successfully operated EOFs, two supersonic vertical lances above the bath have been employed to supplement oxygen injection through the submerged tuyeres/inclined injectors. From the evidence gathered in the present work, it can be stated that the use of one/two vertical lances may be the only way to ensure efficient EOF operation. If vertical supersonic lances have to be a part of EOFs (at least large EOFs), questions would naturally then arise with regard to the overall EOF geometry (why it should be very different from any BOF).

It is very thought provoking that how TATA steel, with so much of experience in LD steel making, overlooked the importance of supersonic lance in EOF, which injects oxygen at a very high velocity near the slag metal interface and helps in mass and heat transfer in the bulk steel, slag metal interface and in the bulk slag. The supersonic lance would have made a big difference for mass transfer in the 80 MT EOF at Tata Steel and thus improving the overall operations.

Bonestell (1989) has tried to make critical evaluation between EOF and BOF (LD Converter). The LD converter is a proven, high productivity, low cost steel making process that is well suited for high capacity, large heat size melt shops. However EOF is expected to be competitive in both capital and operating cost for capacities up to 1.8 million ton per year. Bonestell has also evaluated critically between EOF and EAF. When EOF is compared to the most efficient EAF, the EOF shows significant capital and operating cost advantages.
2.9 EOF ENERGY CONSUMPTION

Bonestell (1989) has compared energy consumption of different steel making processes under development using high scrap rates is shown in Table 2.4.

Different steel making processes:
1. EOF - Energy optimizing Furnace
2. KMS - Klockner Maxhutte Stahlerzeugungsverfahren, Germany
3. EFK - Erhohter Feststoffeisatz im Konverter, GDR
4. TULA - Converter process developed in the Soviet Union
5. KVA - Klockner VOEST Alpine Verfahren, Austria

Table 2.4 Comparison of energy consumption of different steel making processes using high scrap rates

<table>
<thead>
<tr>
<th>Process</th>
<th>EOF (KWh/MT)</th>
<th>KMS (Kg/MT)</th>
<th>EFK (Kg/MT)</th>
<th>TULA (100% scrap)</th>
<th>KVA (Kg/MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical Energy</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>42</td>
</tr>
<tr>
<td>Fine Coke (Kg/MT)</td>
<td>10</td>
<td>72</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lump Coke (Kg/MT)</td>
<td>0</td>
<td>0</td>
<td>58 – 60</td>
<td>93,5</td>
<td>0</td>
</tr>
<tr>
<td>Oxygen (Nm$^3$/MT)</td>
<td>72</td>
<td>120</td>
<td>85 – 90</td>
<td>160</td>
<td>90</td>
</tr>
<tr>
<td>Natural Gas (Nm$^3$/MT)</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>31</td>
<td>14</td>
</tr>
<tr>
<td>Fuel Oil (Kg/MT)</td>
<td>0</td>
<td>0</td>
<td>NA</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Basis: 50% Scrap + 50% Hot metal: 1670°C Tapping Temperature

Weber (1991) has stated that the energy consumption and scrap melting potential in oxygen blowing process techniques depend largely on what degree of CO after-burning is achieved and what percentage of the
energy generated in the process is transferred to the bath. It must be noted here that CO₂ will dissociate above temperatures of 2,000° C. This fact on its own imposes limitation on after-burning in the refractory-lined upper part of the LD converter. In the EOF, the water cooled sidewall and roof panels keep the temperature in the after burning zone at a lower level and thus, the efficiency of after burning is very high. Heat transfer to the bath essentially takes place through the foaming slag and by means of droplets of ferrous oxide and slag that are hurled into the gaseous zone. The EOF has added advantage in this energy feature.

Horst Rainer Pauls (1993) has given a good insight of chemical reactions that take place in the EOF to generate energy as under.

\[
\begin{align*}
[\text{Si}] + 2[\text{O}] &= (\text{SiO}_2) \\
[\text{Mn}] + [\text{O}] &= (\text{MnO}) \\
[2\text{P}] + 5[\text{O}] &= (\text{P}_2\text{O}_5) \\
[\text{C}] + \{\text{O}\} &= \{\text{CO}\} \\
[\text{C}] + (\text{FeO}) &= [\text{Fe}] + \{\text{CO}\} \\
\{\text{CO}\} + (\text{Fe}_2\text{O}_3) &= 2 (\text{FeO}) + \{\text{CO}_2\} \\
[\text{Fe}] + \{\text{O}\} &= (\text{FeO}) \\
2 (\text{FeO}) + \{\text{O}\} &= (\text{Fe}_2\text{O}_3)
\end{align*}
\]

The EOF uses the following three sources of energy:

1. Chemical Energy released by the reaction of the injected and dissolved oxygen with the elements in the bath.

2. Chemical energy generated by the combustion of CO in the metal, slag, and the furnace atmosphere and radiation energy:

\[
\begin{align*}
\{\text{CO}\} + (\text{O}) &= \{\text{CO}_2\} \\
\{\text{CO}\} + (\text{FeO}) &= [\text{Fe}] + \{\text{CO}_2\} \\
\{\text{CO}\} + \{\text{O}\} &= \{\text{CO}_2\}
\end{align*}
\]
3. Enthalpy from the preheated solids

Temperature: approx. 700 – 900 °C

The carbon required for the reactions is introduced either as a constituent of hot metal or as solid carbon (coal fines of coke breeze) which is injected into the bath.

Gupta et al (2005) have presented for the first time the specific energy input for a steel plant using EOF which is shown in Table 2.5.

**Table 2.5** Specific energy inputs in steel making through MBF - EOF - LRF - CCM route

<table>
<thead>
<tr>
<th>I. Mini Blast Furnace (Iron Making)</th>
<th>S. No.</th>
<th>Thermal Inputs Item</th>
<th>Consumption</th>
<th>Specific Energy in Kcal/Kg</th>
<th>Total Energy in Kcal/MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Coke</td>
<td>640 Kgs/THM</td>
<td>6880</td>
<td>44,03,200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Power</td>
<td>110 Kwh/THM</td>
<td>860</td>
<td>94,600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 LDO</td>
<td>0.42 Kg/THM</td>
<td>10500</td>
<td>4410</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Oxygen</td>
<td>7NM3/THM (3.15KWh/MT)</td>
<td>860</td>
<td>2709</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 LPG</td>
<td>0.2 Kg/THM</td>
<td>11800</td>
<td>2360</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>4507279 Kcal/THM</strong></td>
<td><strong>4.507 G cal /THM</strong></td>
<td></td>
</tr>
</tbody>
</table>

**II. Steel Melt Shop**

| 1 Power                            | 183 KWh/MT | 860 | 1,57,380 Kcal/MT |
| 2 Furnace Oil                      | 7.6 Kg/MT  | 10000 | 76,000 Kcal/MT  |
| 3 LDO                              | 3.024 Kg/MT | 10500 | 31,752 |
| 4 Oxygen                           | 70 Nm³/MT (31.5 KWh/MT) | 860 | 27,090 |
| **Total:**                         |         |                     | **2,92,222 Kcal/MT** | **0.292 Gcal/T of Steel** |

**III. RMS**

| 1 Power                            | 60 KWh/MT | 860 | 51600 Kcal/MT |
| 2 Furnace Oil                      | 47.5 Kg/MT | 10000 | 475000 Kcal/MT |
| 3 Oxygen                           | 3 Nm³/MT (1.35 KWh/MT) | 860 | 1161 Kcal/MT |
| **Total:**                         |         |                     | **527761 Kcal/MT** | **0.528 Gcal/MT** |

**Summary - Energy Inputs in Hospet Steel:**

1. Iron Ore to Hot Metal - 4.507 G cal/TPH
2. Hot Metal to cast Steel - 0.292 G cal/T steel
3. Cast Steel to Rolled Products - 0.528 G cal/T steel
4. Iron Ore to cast steel - 4.799 G cal/MT
5. Iron Ore to Rolled Products - 5.327 G cal/MT
2.10 EOF POLLUTION CONTROL

Any steel making process will succeed only if it is environment friendly. Pauls (1993) has tried to quantify the pollutants in the EOF for the first time in Table 2.6 as under.

<table>
<thead>
<tr>
<th>Pollutants in EOF off gases</th>
<th>EOF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust at chimney</td>
<td>Mg/Nm$^3$</td>
</tr>
<tr>
<td>CO</td>
<td>Mg/Nm$^3$</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>Mg/Nm$^3$</td>
</tr>
<tr>
<td>NO$_X$</td>
<td>Mg/Nm$^3$</td>
</tr>
<tr>
<td>Noise at furnace</td>
<td>dB</td>
</tr>
<tr>
<td>Labour protection</td>
<td>Against fumes</td>
</tr>
</tbody>
</table>

2.11 60 MT EOF AT AFS, TRIESTE, ITALY

Pfeifer et al (1998) has presented the commissioning of 60 MT EOF at AFS, Trieste, Italy. The EOF had a tap-to-tap time of 55 minutes and produced 26 heats per day of carbon steels. In the year 1996, the melt shop capacity was increased to 80 MT with the installation of Eccentric Bottom Tapping (EBT). This modification was not really warranted as the average heats per day reduced to twenty two. The main problem in this plant was that the maximum refractory life per campaign achieved was 280 heats. Since they modified the EOF with EBT tapping system, changing of the bottom had become more complicated and took more time. In any case, the plant finally stopped in the year 2002 due to general recession in steel market in Europe and uneconomic production. If they would have kept the furnace capacity at 60 MT along with two shuttle bottom cars having complete shell and using 80% hot metal and 20% scarp, since they had good back up of blast furnaces, the performance of the EOF as well as the melt shop would have been better.
Pfeifer et al (1998) have presented material balance for a 300,000 MT per annum EOF based steel plant (Figure 2.11).

Figure 2.11  Material balance of integrated steel plant
They also for the first time quantified that during post-combustion
when CO is burnt to CO$_2$, out of the total heat energy generated, about 30% is
returned to the steel bath.

2.13 LD CONVERTER – EXCESSIVE OXIDATION CONTROL

Naito et al (2002) have studied the effect of BOF (LD) top blowing
and bottom stirring conditions on suppressing excessive oxidation. From this
study also, we can draw many conclusions for EOF to avoid over oxidizing of
the steel bath. They have concluded that to suppress excessive oxidation, it is
important to decrease the top blown oxygen feed rate and to enhance bottom
stirring energy. Bergman (1992) conducted experiments for directly
producing low carbon steel in a 6 MT BOF equipped with a low flow-rate
lance and a bottom stirring system and reported that the apparent partial
pressure of CO gas, calculated from the equilibrium of carbon and oxygen in
molten steel, was $<0.4$ atm in most of the experiments. This means that
suppressing oxidation to a considerably lower level is possible under
appropriate operating conditions. Okohira (1984) reported, on the basis of a
water model, that the contribution of top blowing energy to stirring was only
10% of the total kinetic energy of the top blown jet. The effects of top
blowing and bottom stirring have been quantitatively estimated and a
decarburization model was developed by modifying the model proposed by
Kishimoto (1989).

The oxygen that is not consumed in decarburization is distributed
between the bulk steel and the bulk slag. Under a low top blown oxygen feed
rate and high bottom stirring energy, the oxygen that is not consumed during
decarburization decreases. The model studies conducted reproduces the
suppression of excessive oxidation under decreased top blown feed rate and
gives predictions in good agreement with both 6 MT BOF experiment and
350 MT commercial BOF operation with regard to oxygen Vs carbon variation as explained by Naito et al (2002) is shown in Figure 2.12.

![Figure 2.12 Comparison between calculated and experimental changes [C] and [O] (35 MT BOF)](image)

Since top blown oxygen plays an important role in promoting mass transfer at the slag metal interface in the reaction zone, decreasing the top blown oxygen feed rate will result in prolonged blowing time. However, increasing the bottom blowing energy is expected to be effective in preventing this.

The in-depth study of the work done in the area of LD converter was very useful to create the conditions in the EOF to arrive at short blowing period as well as low tap-to-tap time in order to maximize the productivity in the EOF.
2.14 COMMISSIONING OF TWO ENERGY OPTIMIZING FURNACES IN INDIA

Going through the literature survey of all the publications on this subject, it is very clear why EOF succeeded initially at CS Pains and continues to be efficient steel maker even today. From 1985 to 1995, it was a period when four of EOF were put up, but they were not successful since they spent lot of energy in trying to melt higher volume of scrap in the EOF in order to compete with EAF. Moreover, during this period, 60 MT and 80 MT EOF were not successful in new plants because they did not have any experience to run an established EOF of 30 MT or 40 MT capacity along with other upstream and downstream imbalances.

Finally after 1995, two EOF of 30 to 40 MT capacity were planned to be installed in mini mills in India. Scherer et al (1999) introduced the commissioning of 35 MT EOF at Southern Iron & Steel Company Ltd (SISCOL) in the year 1998 for the production of carbon steel. They also presented the commissioning of 40 MT EOF at Hospet Steels Limited, India, for production of 100% special steels. Gupta et al (2005) have presented the excellent result, which they achieved during manufacture of special steels at Hospet. EOF has great strength to produce steel with low phosphorous due to which they could control banding in low alloy steels within 30 microns. Amit Ganguly et al (2005) have presented the development of high nitrogen micro alloy steel for crank shaft application, development of low titanium ball bearing steels with 6 ppm oxygen level, at Hospet Steels Ltd.

It was quite evident by now that the EOF had good potential to achieve low capital investment as well as low conversion cost under certain conditions.
The problems envisaged at the time of installation of the EOF in India were listed below.

1. Hot metal to scrap ratio to be followed for economic steel production.
2. Charge to liquid metal yield.
5. Use of scrap preheater.
7. Control of blowing time and tap-to-tap time.
8. Control of refractory consumption / life
9. De-phosphorization
10. Manufacturing of special steels through EOF

Hence, further research work and EOF shop floor trials were necessary to ensure that the EOF performs as per the design norms for high productivity and low cost under Indian conditions. This was very crucial since only one EOF was planned for each of the two plants in India. Successful working of the EOF was very essential for the success of the project. To make EOF successful on commercial scale, under Indian conditions, is the main area for research in the present work.

2.15 OBJECTIVE AND SCOPE OF RESEARCH

Developing countries, such as India, are increasing the steel production due to increasing internal market and good possibility of export as the steel production in developed countries was going down. While putting up a new capacity for steel manufacturing or enhancing the capacity of the existing steel plant, the question remains how to convert hot metal to crude steel at low capital investment, high productivity and low cost of conversion.
The LD converter, Electric Arc Furnace and EOF are the three alternatives for manufacture of crude steel. While deciding between the above processes, important factors are cost of installation and cost of conversion.

Cost of installation and cost of conversion in various steel making routes are given below:

<table>
<thead>
<tr>
<th></th>
<th>Cost of installation</th>
<th>Cost of conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. LD convertors</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>2. Electric arc furnace</td>
<td>low</td>
<td>High</td>
</tr>
<tr>
<td>3. Energy optimizing furnace</td>
<td>low</td>
<td>Low</td>
</tr>
</tbody>
</table>

The cost of installation in the case of EOF is lower than EAF considering the investments in the electrical systems. The conversion cost in the EAF using 60% hot metal and balance scrap / DRI (sponge iron) is Rs. (1500 – 2000) per MT higher than EOF. In India steel making through EAF route using 100% scrap/DRI is not economical except for very high value-low-volume steel production. While comparing with LD converters, the investment cost of EOF is approximately half of LD converter. The cost of conversion of EOF and LD converters are comparable, except for the fact that EOF needs to further improve in respect of:

1. Charge to Liquid Metal yield
2. Blowing time (productivity)
3. Refractory life / consumption.
However, EOF has a capacity limitation and up to the present work, largest size successful EOF working was 40 MT capacity while LD converter capacity is usually 80 MT and above. Hence, the EOF is suitable for plants up to one million tons per annum capacity while LD converters are suitable for capacities above one million tonne per annum in order to achieve the desired rate of return on the investment. However, EOF has certain advantages over LD converters for manufacturing special steels and more flexibility on the amount of solid charge used. Hence, the EOF was envisaged to be suitable for mini mills producing special steels in long products. Therefore, in India the competition was mainly between EOF and EAF. The LD converters were suitable for large steel plants mainly for flat products. In steel making, the cost of production is location specific depending on availability and cost of raw material and energy cost. The location of the plant also has significant affect on the logistics and cost of transportation of raw material and finished goods.

In India, conditions appeared to be suitable for steel making through EOF since iron ore is available in abundance at reasonable prices and supply of metallics was most economical through the blast furnace route. Since EOF can utilize up to 80% hot metal in liquid form, it can utilize the sensible heat of the hot metal as well as the advantage of chemical energy through oxygen blowing. On the other hand, scrap availability is poor and the cost is very high. The power availability is also unpredictable and the grid power is very expensive. India also has the advantage of availability of good technical staff and work force at reasonable cost. Under the above situation, EOF has good potential to succeed in India.
In light of the above, following problems were defined for the Research Work with regard to energy optimizing furnace:

1. To make suitable modifications in the EOF for commercial production of steel under Indian conditions.

2. To lower cost of production through EOF route.

3. Successfully commissioned the world’s largest 65 MT EOF and takes it to operational mode for commercial production.