CHAPTER 3

ENERGY OPTIMIZING FURNACE EQUIPMENTS

Schematic drawing of a modern Energy Optimizing Furnace as per Paul (1993) is shown in Figure 3.1.

Figure 3.1 Schematic view of modern EOF
The Energy Optimizing Furnace (EOF) consists of the following main equipments:

3.1 **EOF HEARTH**

Dish shape EOF hearth constructed using boiler quality plate and lined with refractory bricks that holds liquid steel while processing. Since this is basic oxygen steel making, the refractory in the working lining is primarily made of carbon magnesia bricks. The back up lining is made up of magnesite bricks. The carbon magnesia bricks near the tuyere area are higher density blocks since there is more erosion of the refractory in this area. From time to time the refractory bricks get eroded which is repaired using magnesite base gunning materials. Special refractory gunning machine is used for hot repair of the EOF bottom.

Submerged tap hole along with quick back tilting ensures slag free tapping of liquid steel suitable for subsequent secondary refining. The tap hole is a very important part of the EOF hearth since the entire steel is to be tapped into the steel ladle through the tap hole. Whenever the diameter of the tap hole becomes large, the same has to be brought back to 200 mm using a steel pipe and filling the balance area with gunning material. Before charging the hot metal into the EOF, the tap hole has to be blocked properly, otherwise, it may lead to pre-mature opening of the tap hole which is most undesirable. Hence tap hole management in the EOF is one of the most important operation.

3.2 **EOF SHELL AND ROOF**

It is constructed with water cooled panels which reduces furnace refractory consumption. The circular shaped EOF shell and compact design keeps heat losses to a minimum. The EOF shell has hot metal launder for
pouring liquid hot metal from the hot metal ladle in to the EOF hearth using a EOT hot metal charging crane. The hot metal launder is also refractory lined and it needs repairs from time to time which can be carried out while the EOF is in operation without losing any operational time.

EOF shell has slag door on the opposite side for continuous removal of slag during processing. The slag door can be operated up and down using the pneumatic cylinder. The slag door is also utilized for drawing process samples from the liquid steel and also to take temperature of the liquid steel during processing. It is through the slag door of the EOF the hot gunning of the refractory is carried out. The cleaning of the tap hole and blocking the same prior to charging is also carried out through the slag door. This is why sometime the slag door is also known as working door.

The EOF water cooled roof consists of roof upper piece and sliding skirt. There is no refractory in the EOF roof. Through the top opening in the EOF roof the hot gases from the EOF are transferred to the scrap pre-heating area. When the furnace shell tilts backward and forward, it does so along with the EOF roof. Between the sliding skirt and scrap pre-heater lower piece, cast iron chillers are placed to minimize the ingress of atmospheric air into the scrap pre-heater.

The furnace shell and roof are very important to contain the off gases from the steel bath and carry out post-combustion of the gases before they are transferred to the scrap pre-heating area. Through proper instrumentation negative pressure of 200 mm water column is maintained inside the EOF.
Key design parameters of water cooled panels in the EOF are shown in Table 3.1.

**Table 3.1 Cooling water requirement - water cooled elements**

<table>
<thead>
<tr>
<th>Type</th>
<th>Exposed area</th>
<th>Heat load</th>
<th>Delta Temp</th>
<th>Total flow</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>M²/elem</td>
<td>M.cal/M²/hr</td>
<td>deg C</td>
<td>M³/hr</td>
</tr>
<tr>
<td>Lower panels</td>
<td>1.32</td>
<td>180.6</td>
<td>15</td>
<td>63.6</td>
</tr>
<tr>
<td>Upper panels</td>
<td>1.79</td>
<td>180.6</td>
<td>15</td>
<td>215.5</td>
</tr>
<tr>
<td>Door frame</td>
<td>0.82</td>
<td>103.2</td>
<td>15</td>
<td>5.6</td>
</tr>
<tr>
<td>Working door</td>
<td>1.69</td>
<td>86.0</td>
<td>15</td>
<td>9.7</td>
</tr>
<tr>
<td>Burner injectors</td>
<td>0.29</td>
<td>344.0</td>
<td>15</td>
<td>39.9</td>
</tr>
<tr>
<td>Roof Panel HV</td>
<td>1.27</td>
<td>180.6</td>
<td>15</td>
<td>122.3</td>
</tr>
<tr>
<td>Roof Upper piece</td>
<td>1.88</td>
<td>172.0</td>
<td>15</td>
<td>86.2</td>
</tr>
<tr>
<td>Shell upper piece</td>
<td>0.58</td>
<td>180.6</td>
<td>15</td>
<td>32.7</td>
</tr>
<tr>
<td>Shell lower piece</td>
<td>2.1</td>
<td>180.6</td>
<td>15</td>
<td>101.1</td>
</tr>
<tr>
<td>Shell panel</td>
<td>1.12</td>
<td>180.6</td>
<td>15</td>
<td>27.0</td>
</tr>
<tr>
<td>Supersonic lance</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>25.0</td>
</tr>
</tbody>
</table>

### 3.3 SCRAP PRE-HEATING

Scrap Preheating is constructed with water cooled fingers and water cooled panels where scrap for the subsequent heat is pre-heated to 900º C by the off-gases from EOF. The scrap pre-heater (SPH) in the earlier EOFs used to be two stage or three stage since the EOF were designed for higher percentage of solid charge. The recent EOFs are having single stage scrap pre-heating system. The fingers are divided into two halves and they can be in open or close position using hydraulic actuated cylinders. The SPH fingers are in close position when scrap is charged on to the fingers. The scrap is kept on
the top of the fingers during the entire processing of heat where it gets pre-heated by the sensible heat off gases. Once the previous heat has been tapped out and the tap hole is blocked, the fingers are opened and the scrap is allowed to fall inside the EOF bottom. This is the unique feature of the EOF whereby the scrap pre-heater is placed directly on the top of the EOF roof such that the off gases are collected at the highest temperature possible for pre-heating the scrap. In some of the EOFs a by-pass line is provided for the scrap pre-heater where the gases can be sent through the by-pass channel to avoid melting of the scrap on top of the scrap pre-heater. However, in some of the recent EOFs the by-pass arrangement was not provided and it was planned that the off gases temperature control shall be carried out through dilution air by the forced draft blowers which would automatically be put on once the off gases temperature goes high. The dilution air stated above is released in the SPH area. The lime and ferro alloys are also discharged by the automatic feeding system below the SPH fingers and are thus discharged into the EOF. CO-CO$_2$ analyser is also installed in the SPH area and whenever the CO gas percentage increases beyond a particular percentage the dilution air is automatically put on using forced draft blowers in order to oxidize the same and avoid explosions in the SPH area.

3.4 SCRAP CHARGING EQUIPMENT

Prepared scrap, in specially designed bottom discharge scrap bucket, is charged through the EOF top using an EOT crane. After scrap charging, the sliding door is closed. Normally there are five scrap charging buckets which are in circulation in order to avoid any delay of the EOF operation for want of scrap charging. Whenever the scrap is ready, the scrap charging bucket is placed on the stand using EOT crane over the top sliding door of the EOF. Thereafter the EOT crane is released and whenever the scrap is to be charged into the SPH area, the scrap bucket is lifted using the hydraulic cylinder such that its bottom discharge flaps open and discharge the
scrap on the SPH fingers. The scrap should be well prepared and no piece should be above 400 mm in order to avoid any damage of the SPH fingers, water cooled fingers and roof upper piece when the scrap is discharged into the EOF.

3.5 OXYGEN BLOWING

The Oxygen blowing system is the most important part of the EOF for steel processing. The oxygen blowing is through submerged tuyeres, atmospheric injectors, and supersonic lances. The oxygen has to be conveyed into the steel bath as well as for post combustion in a precise manner at a particular pressure and flow rate controlled by the sophisticated instrumentation installed in the valve stand. The oxygen profile specified for the heat processing has to be followed from the beginning to the end. Brief description of each of the blowing system is presented hereunder:-

3.5.1 Submerged Tuyeres

Four numbers submerged tuyeres in the hearth are placed at 45°, 135°, 225° and 315° position assuming the tap hole at 0° deg position. The tuyeres are placed 300 mm above the furnace bottom. The tuyere outer pipe made of stainless steel in which the copper tuyere is placed concentrically. The outer diameter of the copper tube has helical grooving and it is cooled with the help of DM water and nitrogen gas, which promotes formation of nugget on the tuyere tip inside the furnace. The nugget formation helps to minimize the tuyere tip consumption to the extent of 2 to 3 mm per heat. The entire tuyere assembly has good safety system for trouble free working. The tuyeres are sliding type through the refractory block and when required the tuyere can be pushed inside the furnace to avoid refractory erosion around the tuyeres. Oxygen blowing through the tuyeres help in decarburization and churning of the bath. The cooling of the tuyere pipe using DM water is the
most important and critical feature. So long as the tuyere is cooled and even if oxygen pressure drops, liquid steel from the EOF will not come out. However, if the cooling water fails and oxygen is on, there will be very fast erosion of the submerged tuyere resulting in EOF hearth break out which can be very dangerous. For this reason, there is a standby DM water tank which could be immediately brought into operation in case of fall in DM water pressure or flow rate. The oxygen injection into the steel bath through submerged tuyeres is one of the unique features of the EOF.

3.5.2 Atmospheric Injectors

Four numbers atmospheric injectors are fixed on the furnace shell for post-combustion of the gases emerging above the steel bath. The atmospheric injectors are located exactly above the four tuyere positions. The body of the atmospheric injectors are also water cooled and all the four injectors point downwards towards the center of the steel bath. The basic activity in the post combustion is oxidation of CO-CO$_2$ and the energy thus generated is partly transmitted back to the steel bath and bulk of it flows along with the flue gases in order to pre-heat the scrap for the subsequent heat placed on the water cooled fingers in the SPH. The post combustion of the off gases within the furnace vessel is also one of the unique features of the EOF.

3.5.3 Supersonic Lances

Two supersonic lances force a jet of oxygen close to the slag level inside the EOF, which helps in high speed de-carburization as well as rigorous churning of the bath. The supersonic lance is having a copper tip and steel body which is water cooled. The supersonic lance is re-tractable on the inclined frame work supporting the supersonic lance. Each supersonic lance is placed on either side of the slag door. The oxygen supplied by the SS lance is primarily used for decarburization of the steel bath and also partly for
post-combustion. EOF being combined blowing system, the oxygen injection on the top is primarily through SS lance and the side blowing of oxygen from the bottom is done through submerged tuyeres. The SS lance has been provided with instrumentation and control systems for safe working.

3.5.4 **Hand Lances**

Oxygen lancing is done through hand lancing in the slag / metal interface for quick fluidization of slag. Normally two numbers hand lances are used manually through the slag door. Metered quantity of oxygen is released through the lancing pipes into the steel bath. The hand lances are also used to clear the tap hole at the end of tapping from the EOF.

3.6 **VALVE STAND**

The oxygen flow through submerged tuyeres, atmospheric injectors and SS lance is controlled through a valve stand consisting of very sophisticated instrumentation controlled by a computer. In the valve stand, for safety of operation of the submerged tuyeres, there is a facility to change over from oxygen to Nitrogen, or to Argon gas in case of any emergency where heat is required to be held inside the EOF for a longer period. The valve stand is the heart of EOF operation that controls the precise oxygen blow profile in order to achieve the desired oxygen blow period in the EOF.

3.7 **SPARE SHELL**

The entire EOF bottom, shell and roof are mounted on a trolley moving on rails. There is a spare EOF bottom, which is lined with refractory and ready to go into operation. At the end of the refractory campaign of the hearth, the EOF shell is raised using hydraulic cylinders and the bottom in-use is pulled out and the spare EOF bottom, refractory lined, is brought in
place within twelve hours and the EOF is put back into operation. Hence the EOF contains of 2 nos. trolleys, 2 nos bottoms and 1 no. EOF shell and Roof.

3.8 LIME AND ALLOY FEEDING SYSTEM

The lime and alloy feeding system consists of storage hoppers, weighing systems and conveyor belts. Lime and alloy feeding system is provided to feed the exact quantities of any additive in a regulated manner into the EOF bath. This system is used basically to feed lime in the EOF. This system sometimes is used to feed ferro manganese for manganese boil before tapping of steel. This system is also used at times to feed sponge iron to control the bath temperature. There is a second automatic feeding system for charging the lime and alloys into the ladle during tapping the steel from EOF. This is basically for primary de-oxidation of steel and making reducing slag for subsequent secondary refining processes. Since EOF is high productivity, short cycle time process, lime and alloy feeding system into the EOF as well as in the ladle during tapping is very important part of EOF system to ensure the requisite additions matching the furnace productivity.

3.9 GAS CLEANING PLANT

The Gas Cleaning Plant (GCP) is wet type and it consists of down-comer, quenching chamber, venturi, cyclone separator, ID fans and chimney. The down comer is to convey the off gases after the SPH system into the quench chamber. The down comer is refractory lined and it has water spray nozzles to cool the gases as well as separate the dust from the gases to the extent possible. In the combustion chamber there is a direction change of the off gases along with a big shower of water which not only lowers the temperature of the gases but also separates some quantity of dust. The venturi is the heart of the GCP system which not only helps in separating the dust from the off gases due to sudden pressure release but also controls the furnace
negative pressure very precisely through electrical actuated pair of flaps. The cyclone separator is the final device for separating the dust from the off gases. The dirty water collected from the quench chamber and the cyclone separator is conveyed to the thickener after chemical dozing. In the thickener the dust is allowed to settle down and the clear water is circulated back into the GCP through the pumping system. The clean air (less than 50 mg/M$^3$) is pulled by a series of two ID fans (one standby) and let out in the atmosphere through a tall chimney. The clean gas thus generated is primarily pure steam which appears like white cloud when it emerges out of the chimney. The wet sludge, filtered in the above process is collected in the thickener where the solid particles having 68 to 70% Fe is charged back in the sinter plant.

Dry type GCP is also possible in the EOF which was installed at Trieste, Italy.

3.10 OIL BURNER

Air-Oil burner, using low sulphur liquid fuel, is used for pre-heating the newly lined EOF hearth and shell. This ensures proper thermal balance while processing the first heat. Thereafter, between the heats, burner is not required to be used. In case of any long stoppage, it is desirable to pre-heat furnace before charging subsequent heats.

3.11 ELECTRICAL AND CONTROL SYSTEM

The present day EOFs are equipped with very elaborate instrumentation where total control is through an on-line PLC/computer system. Safety net provided is exceptionally good in order to ensure safe operation and repeatability of the process. The computer has the facility for automatic data logging and also for raising the alarm system when any subsystem is malfunctioning.
Schematic view of a modern EOF system on the computer screen is shown in Figure 3.2.

Figure 3.2 Energy optimizing furnace overview