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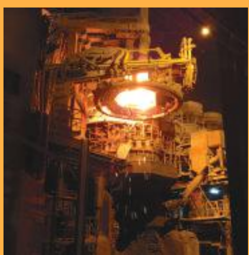
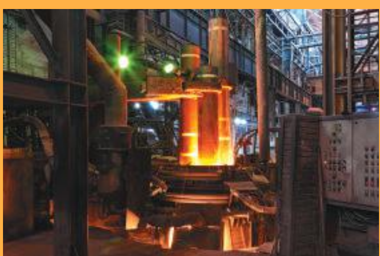
COMPENDIUM

ENERGY EFFICIENT TECHNOLOGY PACKAGES FOR ELECTRIC ARC FURNACE





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Certificate of originality

An original work by TERI done under the project 'Energy Audit and Development of Energy-Efficient Technology Compendium for the Electric Arc Furnace (EAF) Sector'

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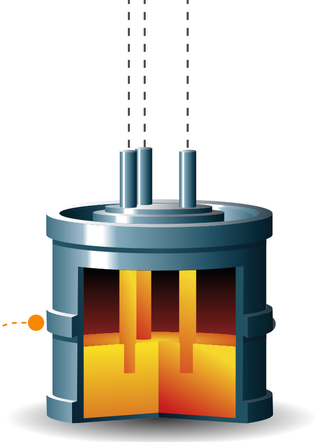

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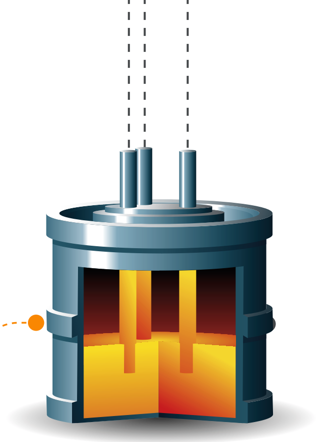

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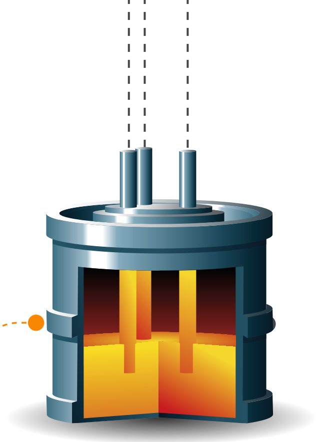

Foreword

India has become the third largest steel producer in the world with a production of 90 million tonnes (MT) with an installed capacity of 122 MT in 2015/16. The Indian steel industry contributes approximately 2% to the country's GDP and employs about 25 lakh people (5 lakh directly and about 20 lakh indirectly). Backed by a positive growth at 5.3% in 2015 as against negative growth witnessed in China (-5.4%) and Japan (-7.0%) in the same year, the Government of India (GoI) has set an ambitious steel production target of 300 MT by 2030. One-third (100 MT) of this target is expected to come from the vibrant micro, small, and medium enterprises (MSMEs) in the country. This amounts to almost doubling the steel output from the MSME sector from the 2015/16 level.

The steel units in the MSME sector primarily use scrap, pig iron, direct reduced iron (DRI), etc. as raw material to produce steel through the electric arc furnace (EAF) or the electric induction furnace (EIF) route. These units are extremely important because they cater to the low-volume local demand for steel in hinterlands, besides providing employment opportunities to the local population.

These energy-intensive MSME units, with most of them using outdated technologies, offer huge potential for energy savings and reduction in greenhouse gas (GHG) emissions. Through deployment of energy-efficient technologies (EETs) in the MSME steel units, India aims to reduce GHG emissions to the tune of 2.6–2.7 tonnes per tonne of crude steel production (DRI-EAF/EIF route) by the terminal year of 2030.

The United Nations Development Programme (UNDP) has played a pivotal role, jointly with the Ministry of Steel (MoS), Government of India, towards penetration of low-cost EETs in the steel re-rolling mill (SRRM) and electric induction furnace (EIF) sectors. Over 321 units were directly supported by the Steel Project to become energy efficient and cost competitive.

The EAF sub-sector—comprising about 40 units scattered across the country and producing around 25 MT of steel in 2015/16—is also highly energy intensive. To explore the possibilities of bringing in energy efficiency in the EAF sector, the UNDP-MoS Steel Project had taken an initiative to identify and compile economically feasible EET options, packages, and practices for the EAF sector. This document is an outcome of such an approach.

We congratulate the team for putting such valuable information together in one place. We are confident that the stakeholders in the EAF sector will take advantage of this publication and lead the EAF sector towards sustainable and cleaner production.

Dr S N Srinivas
Programme Analyst
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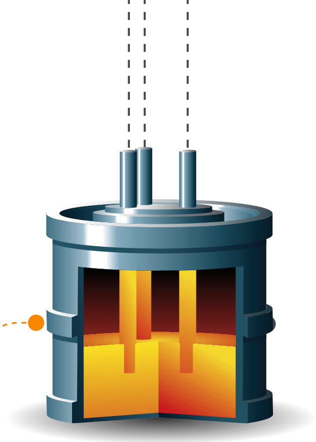
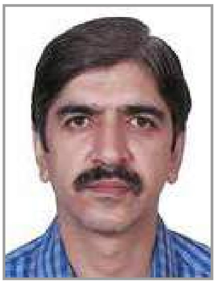


Preface



The industry sector plays a critical role in the Indian economy due to its close impact on the development of the country. The sector is highly diversified and comprises both large and small industries. It accounts for about half the country's total commercial energy consumption. Amongst the industry sector, the iron and steel industry is one of the key drivers of the Indian economy. The sector consists of integrated steel plants and secondary steel industries. While the integrated steel plants have been taking steps to improve their energy- efficiency levels through various in-house initiatives, the secondary steel sector has been lagging behind in terms of adopting energy efficient technologies and practices.

An important sub-sector under the secondary steel sector is the Electric Arc Furnaces (EAF), which accounts for a considerable share of steel production. A close look at the Indian EAF sub-sector shows that it employs electric arc furnaces of varying capacities, vintages, and energy performance. With this background, the United Nations Development Programme (UNDP) had entrusted The Energy and Resources Institute (TERI) with a project to undertake energy audits in representative electric arc furnace units and to prepare a technology compendium on 'Energy efficient Technology Packages for Electric Arc Furnaces' that can act as a reference document.

TERI followed a number of key steps towards the preparation of the technology compendium. Comprehensive energy audits of representative electric arc furnace units having different production capacities, furnace design, and operating practices were conducted. The audits helped in arriving at the baseline energy performance as well as in identifying potential for energy-efficiency improvements in furnace and its auxiliary systems. An exploratory exercise was carried to identify energy-efficient technologies and practices available at national and international levels. A pool of energy-efficient technology options was identified for potential adoption by the Indian EAF sector. These technology options were further validated through intensive stakeholder consultation and focussed group discussions with sectoral experts.

The technology compendium explains relevant energy-efficient technologies in furnace design, operation, and practices that provide details about the salient features of the energy-efficient technologies, saving potential, investment requirements, and GHG reduction potential. The compendium further describes potential future technologies that are either commercially available or under demonstration, which can make large impact in terms of energy efficiency in the sector.

The EAF industries in India and other stakeholders such as technology experts would find this compendium a useful document for initiating energy efficiency in individual EAF units.

Girish Sethi
Senior Director
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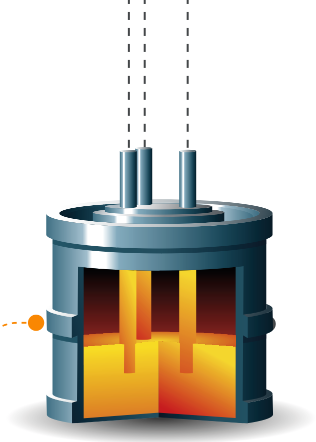

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The Energy and Resources Institute (TERI) expresses its sincere gratitude to the United Nations Development Programme (UNDP) for providing opportunity to work on the project titled 'Energy audit and development of Energy-Efficient Technology Compendium for the Electric Arc Furnace (EAF) Sector'. We express our sincere thanks to Dr S N Srinivas (Programme Officer), Mr Ramakrishna Bhatta (Manager – Finance & Administration), and Mr K Shanmuganathan (Project Associate – Technical) from the UNDP and Mr Arindam Mukherjee (Senior Program Officer) from InsPIRE Network for Environment who provided support in the selection and coordination with the EAF units for conducting energy audits and in the preparation of the technology compendium.

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- ISMT Limited, Steel Division Jejuri, Pune
- Mahindra Sanyo Special Steel Pvt Ltd, Khopoli
- Mukand Limited, Thane

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TERI extends a special thanks to the sector experts — Mr Jivraj Sutaria, Mr S P Chhabra, and Mr Suman Mukherjee for sharing knowledge on energy-efficient technologies and practices in electric arc furnace sector.

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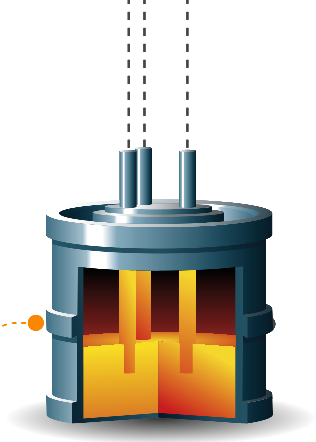
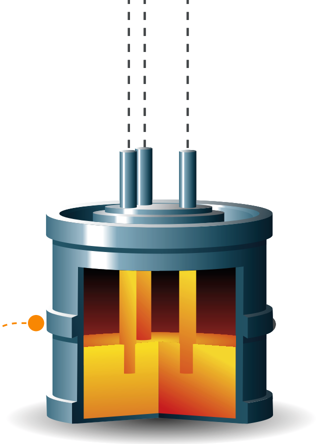
Last but not the least, we are thankful to project advisors from TERI —Mr Girish Sethi (Senior Director – Energy Program) and Mr Prosanto Pal (Area Convenor – Industrial Energy Efficiency & Sustainable Technologies) for their inputs and support.



Abbreviations

AC	Alternating Current
BEP	Best Efficiency Point
BOP	Best Operating Practices
C	Carbon
CO	Carbon monoxide
CO_2	Carbon dioxide
CT	Cooling Tower
DC	Direct Current
DM	Demineralized water
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EBT	Eccentric Bottom Tapping
ECM	Energy Conservation Measure
EE	Energy Efficiency
EET	Energy-Efficient Technology
EMS	Electro-magnetic stirrer
FRP	Fibre Reinforced Plastic
FY	Financial Year
GDP	Gross Domestic Product
GHG	Greenhouse Gas
H_2	Hydrogen
HBI	Hot Briquetted Iron
hp	Horse Power
HP	High Power
ID	Induced Draft
IF	Induction Furnace
KPI	Key Performance Indicator
kW	Kilo Watt
kWh	Kilo Watt Hour
Mn	Manganese
MS	Mild Steel
mt	Million tonne
NG	Natural Gas
O_2	Oxygen
P	Phosphorous
SCM	Standard Cubic Metre
SEC	Specific Energy Consumption
SFC	Specific Fuel Consumption
SMS	Steel Melting Shop
Si	Silicon
SPP	Simple payback period
SS	Stainless Steel
t	tonne
TERI	The Energy and Resources Institute
toe	tonnes of oil equivalent
tpd	tonne per day
tpy	tonne per year
TTT	Tap-to-tap time
UHP	Ultra High Power
UNDP	United Nations Development Programme
VOD	Vacuum Oxygen Decarburization
WHR	Waste Heat Recovery



Project Background

The secondary steel electric arc furnace (EAF) sector plays an important role in the overall steel production chain in India. An EAF uses steel scrap or mix of steel scrap and sponge iron as raw material, producing billets, which are used in steel rolling mill sector.

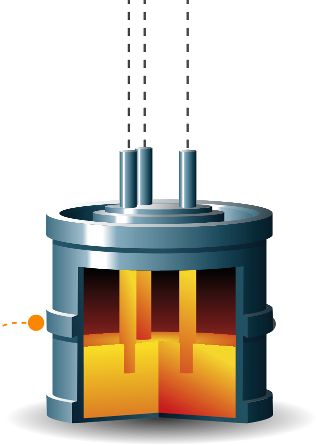
The major energy forms used in an EAF include electricity and chemical energy. The specific energy consumption (SEC), that is, the energy required to produce one tonne of liquid metal, of an EAF is dependent on the type of raw materials used and capacity utilization. Although there are a number of EAFs operating in India, their capacity utilization has been quite low in recent years. Hence, wide variations in SEC levels are observed in EAF operations. There is a significant scope for energy savings and corresponding greenhouse gas (GHG) reduction in the sector through the adoption of 'energy-efficient' (EE) technologies and practices.

UNDP is facilitating the diffusion of energy-efficient low-carbon technologies in the EAF sector in India with a focus on bringing down the end-use energy level, reducing GHG emissions, improving productivity and cost competitiveness. With this background, the UNDP had entrusted TERI to undertake a comprehensive energy audit study of a select few EAF furnaces in India and develop a technology compendium and a ready-reckoner booklet that can act as a guide to the other EAF units in the country.

The following are the objectives of the project

- Conducting energy audits in six EAF units
- Developing a technology package compendium 'Energy Efficient Technology Packages for Electric Arc Furnace'
- Developing a booklet 'Ready reckoner on Energy Efficient Technology Packages for Electric Arc Furnace'
- Conducting two national-level stakeholders meetings inviting officials from the Ministry of Steel, EAF unit owners, consultants, experts, vendors and representatives of industry associations.

1 ELECTRIC ARC FURNACE SECTOR IN INDIA



Electric Arc Furnace Sector in India

1.1 Overview of the sector

The total crude steel production at the global level was 1,630 mt during 2016. A sustained rise in domestic crude steel production had elevated India to the 3rd-largest crude steel producer in the world.[1] The total production capacity of the Indian iron & steel[1] industry was 122 mt, producing about 91 mt during 2015–16. The iron and steel sector contributes for about 2% to the country's GDP (Gross Domestic Product). India's per capita steel consumption is 61 kg which is much lower than the global average (208 kg) and that of China (489 kg), thus indicating a significant growth potential of the Indian steel industry.

The production of iron and steel is highly energy-intensive. The main products of the sector are pig iron, sponge iron, and finished steel. The main finished steel products are plates, strips, rods and bars, profiles (sections), wires, and tubes. Most of these products are further processed by the engineering industry as per different end-use applications, while some finished products, such as bars and profiles are directly used by the construction sector.

The Indian steel industry can be broadly categorised based on the route followed in the production process. The primary iron and steel producers manufacture steel from iron ore using Blast Furnace-Basic Oxygen Furnace (BF-BOF) route and coking coal. These producers have large integrated steel-making facilities. The secondary steel producers use scrap, pig iron, sponge iron/direct-reduced iron (DRI), and ferro-alloys to make steel through the electric arc furnace (EAF) or induction furnace (IF) route. The share of BF-BOF route remains at about 42% of the total production, and the EAF route had increased from 26% to 28% during the period 2011–12 to 2015–16.

Share of production route in steel production

Process route	2011–12	2015–16
Basic Oxygen Furnace (BOF)	42%	42%
Electric Arc Furnace (EAF)	26%	28%
Induction Furnace (IF)	32%	30%
Total	100%	100%

Source: Ministry of Steel, Government of India (2017)

The secondary sector forms an important link to the overall steel production chain in India. As of March 2016, there were 308 sponge iron producers[2] that use iron ore/ pellets and non-coking coal/gas providing feedstock for steel production, 47 electric arc furnaces, and 1,128 induction furnaces that use sponge iron and/or melting scrap to produce semi-finished steel. A typical EAF unit uses scrap or mix of scrap and sponge iron as the raw material and produces ingots or billets, which are suitable for use in the steel re-rolling sector.

To meet the greenhouse gases (GHG) emission-reduction targets under the Paris Declaration, the Ministry of Steel has submitted the Intended Nationally Determined Contributions (INDC) in the iron and steel sector. The CO_2-reduction target for BF-BOF route is 2.2–2.4 tonne per tonne of crude steel, whereas it is 2.6–2.7 tonne per tonne of crude steel in DRI-EAF route by the terminal year of 2030. For achieving GHG emission-reduction targets, the sector needs to make consistent efforts to improve its energy performance through the adoption of

EE technologies and best practices. The Indian EAF sector should further consider the adoption of state-of-art technologies, which would substantially bring down the energy intensity.

1.2 Production process

The alternating current (AC) electric arc furnace melts the charged material using an electric arc. The energy required for producing the melt is provided by the electric arc between each of the three electrodes and the metallic charge.[3] Through the EAF route it is possible to produce steel using 100% scrap mix, which would reduce the energy consumption for making steel as compared to primary steel-making through the blast furnace route.

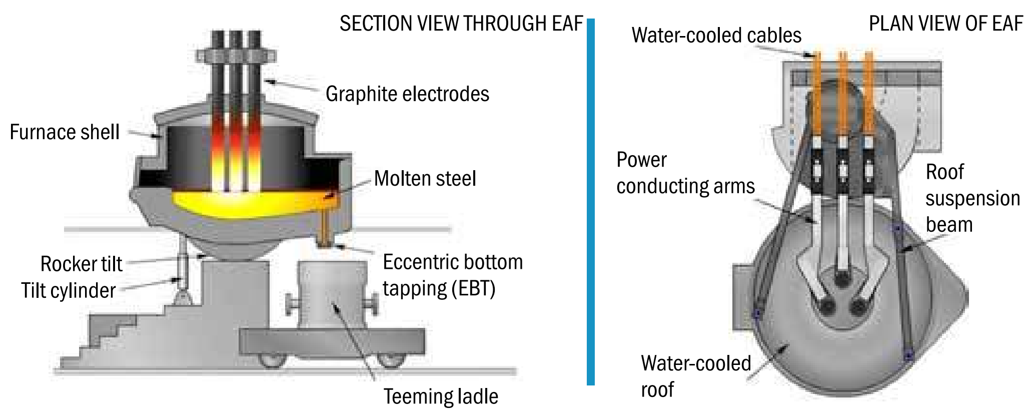
The construction of EAF encompasses an outer cylindrical steel shell internally lined with several layers of designated refractory materials, with the whole system mounted on a motorized tilting mechanism. The three electrodes enter the furnace from the roof through three cylindrical openings at an angle of 120°. The roof is made of refractory brick, usually of high alumina. The vertical movement of electrodes is generally controlled automatically with a thyristor-based system. The crucible, roof, and electrodes are water cooled to maintain the temperature and improve the service life. EAFs are generally provided with a door at the back to carry out alloying, oxygen lancing, and de-slagging. A pouring spout is present at the front in case of a launder pouring system and an opening is present at the bottom in case of an 'Eccentric Bottom Tapping' (EBT) which leads to slag-free tapping and shorter tap-to-tap times.

The steps involved in EAF operations include: (i) charging (ii) complete meltdown (iii) oxidation and refining (iv) de-oxidation, and (v) tapping into ladle. The process steps[4] explained briefly, as follows:

Charging: The first step in a batch furnace (tap-to-tap cycle) is the 'charging' of raw material into the furnace. Typically, a schedule is established by the EAF unit prior to each production shift and the charge is prepared in the charge buckets accordingly. The preparation of charge bucket is a key step to: (1) ensure proper chemistry and (2) confirm good melting conditions. The scrap material is stacked in layers in the charging bucket according to size and density to facilitate quick melting while providing protection to the furnace from electric arc radiation. Typically, a 'steel melting shop' (SMS) is provided with two to three charging buckets, each of which is kept charged as soon as it becomes empty. Modern units in developed countries are equipped to charge the furnace at once so as to reduce idle time in operation, thereby ensuring productivity.

Complete meltdown: The melting is at the heart of the furnace operation. Energy for melting includes

Electric arc furnace (section and plan views)

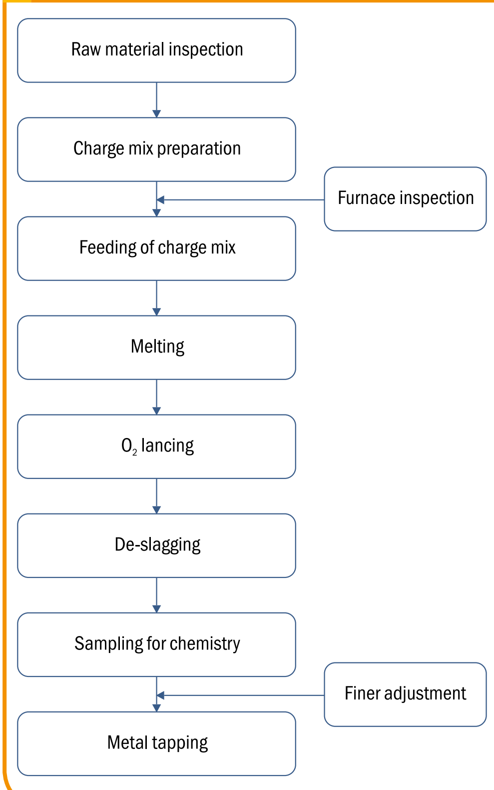


Source: www.steeluniversity.org

both electrical and chemical. Electrical energy is fed through three graphite electrodes which is the major energy input. At the start, an intermediate voltage tap is selected until the electrodes bore into the scrap. Usually, light scrap is kept on top of the charge to quicken initial melting and create molten metal pool. Approximately, 15% of scrap melts during the initial period.

The electrodes penetrate the scrap adequately a few minutes after the start. This ensures the usage of a long arc to reduce the damages to the roof structure. The long arc ensures maximum transfer of power to the scrap and a liquid metal pool is formed in the furnace hearth. In the beginning, the arc is generally erratic and unstable. As the furnace heats up, the arc becomes stable and the average power input rises. Upon the melting of a sufficient quantity of scrap, the charging process is repeated.

Process flow diagram in EAF



Oxidation and refining: EAF usually exhibits a pattern of hot spots and cold spots around the hearth perimeter, with cold spots generally located between electrodes. The state-of-the-art EAFs are provided with oxy-fuel burners on the sidewalls which ensure a more uniform heating of steel. Additional energy is provided through oxygen and carbon injection into the furnace. While this was being achieved through lances in the slag door in traditional furnaces, modern EAFs use multiple wall-mounted injection arrangements.

Once liquid steel is formed, oxygen can be directly lanced into the bath to accelerate the oxidation of solutes, starting with carbon in the bath followed by the oxidation of iron, silicon (Si), manganese (Mn), and phosphorous (P). These reactions are exothermic and provide additional energy in the melting process.

The carbon monoxide (CO) escapes as gas and produces 'carbon boil' in the melt. The carbon boil is an essential part of the refining process and helps in: (i) heat transfer by agitating the bath (ii) cleansing the bath of the retained oxides as slag (iii) accelerating reactions at the gas metal interface, and (iv) aiding the removal of H_2 and N_2.

Heat of reactions inside EAF

Exothermic reaction	Heat of reaction at 1650 °C (kWh per kg)
$Fe + ½ O_2 (g) \longrightarrow FeO$	1.275
$Si + O_2 (g) \longrightarrow SiO_2$	9.348
$4Al + 3 O_2 (g) \longrightarrow 2 Al_2O3$	8.650
$C + ½ O_2 (g) \longrightarrow CO (g)$	2.739
$CO (g) + ½ O_2 (g) \longrightarrow CO_2 (g)$	2.763
$C + O2 (g) \longrightarrow CO_2 (g)$	9.184
$Mn + ½ O_2 (g) \longrightarrow MnO$	2.044
$H_2 (g) + ½ O_2 (g) \longrightarrow H_2O (g)$	34.614
$CH_4 (g) + 2 O_2 \longrightarrow CO_2 (g) + 2 H_2O$	13.994

Phosphorus is removed during oxidising period whereas sulphur is removed during reducing period. The lime or dololime added in the process helps in de-slagging. The calcium oxide in lime reacts with silicon dioxide and forms calcium silicate slag:

$2\,P + 5\,FeO \longrightarrow (P_2O_5)_{SLAG} + 5\,Fe$

$(P_2O_5)_{SLAG} + 3\,(CaO)_{SLAG} \longrightarrow Ca3(PO4)2_{SLAG}$

$(CaO)_{SLAG} + [FeS]_{BATH} \longrightarrow (CaS)_{SLAG} + [FeO]$

$(CaC2)_{SLAG} + 3\,[FeS]_{BATH} + 2\,(CaO)_{SLAG} \longrightarrow 3\,[Fe] + 3\,(CaS) + 2\,(CO)_{GAS}$

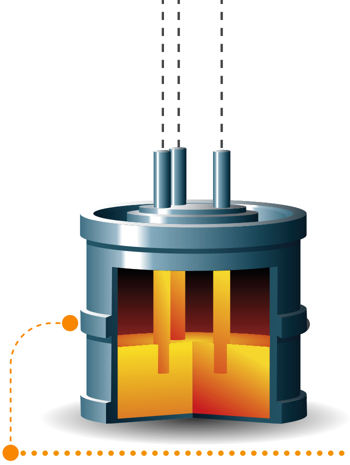
$2\,CaO + 2\,SiO_2 \longrightarrow 2\,(CaO.SiO_2)_{SLAG}$

The composition of slag comprises SiO2 (55%–60%), MnO (12%–16%) CaO (7%–10%) and FeO (12%–20%). The slag typically floats over metal and acts as thermal insulating layer reducing heat losses from melt surface.

De-oxidation: The oxidised bath is de-oxidised before pouring into a transfer ladle. Otherwise, the oxides would form again and may go into the final products. Once the first slag is removed the power is switched off. De-oxidation is carried out using specific de-oxidisers with a high affinity towards oxygen in the bath as compared to iron. The most common de-oxidisers include ferro-alloys, that is, ferro-manganese or ferro-silicon. Aluminium is typically added at the end which is the most powerful de-oxidising agent as compared to the ferro alloys.

Tapping of liquid steel: Once the required temperature is achieved (usually about 1650 °C), a sample is drawn from the bath to ascertain the desired chemistry of the molten bath. Finer corrections are made to the chemistry, if required. The molten steel is poured into a pre-heated ladle either by tilting or by EBT mechanism. Any slag entering in the ladle is removed by adding adequate quantities of lime. On the completion of pouring, the slag door is cleaned of solidified slag, repairs if any are done, and electrodes are inspected for damages.

2 KEY PERFORMANCE INDICATORS OF THE EAF SECTOR



Key Performance Indicators of the EAF Sector

A Key Performance Indicator (KPI) is a measurable value that shows how effectively a system or sector is performing. The KPIs indicate the potential for improvement with respect to the best performance values. This section provides details of the various KPIs related to the EAF sector in India.

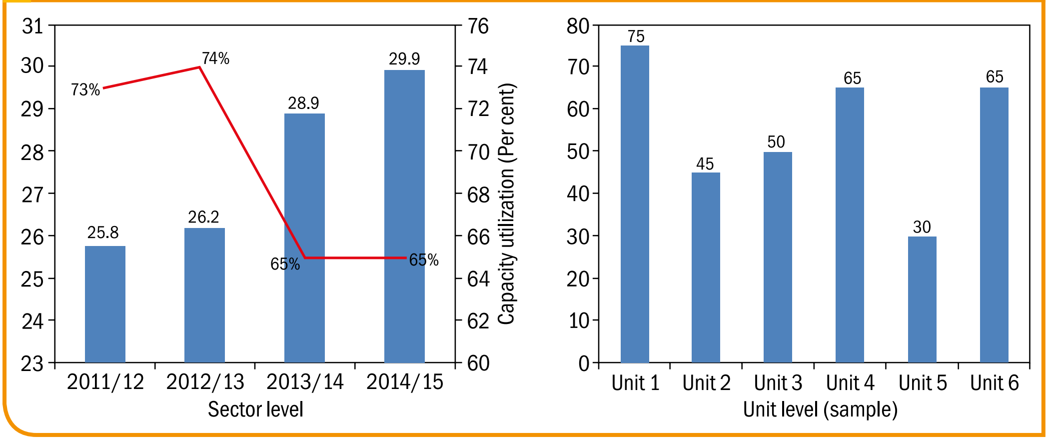
2.1 Capacity utilisation

The performance of the EAF sector is dependent on the overall utilisation of the capacity existing in the sector. The EAF sector accounts[5] for about 28% of total steel production in India, whereas the IF route and BF-BOF route contribute for about 30% and 42% of total steel production, respectively. The production[6] through the EAF route during 2014–15 was 19.44 mt registering about 65% capacity utilisation of the sector. Although there is a steady raise in the installed capacities of EAFs over the years, the production levels have largely remained constant. According to the Ministry of Steel, Government of India, the BF-BOF route is expected to have a share of 60%–65% of the crude steel capacity and production with the remaining 35%–40% by the EAF and IF routes in 2030–31. The capacity utilization of the representative units also shows that the average capacity utilisation is hovering around 30% –75 %.

2.2 Yield

The yield of an EAF unit is defined as the share in per cent of liquid metal with reference to the quantity of raw materials charged. Higher the ratio of liquid metal, higher will be the yield and vice versa. The yield of an EAF is primarily dependent on the quality of scrap and share of input raw materials, such as DRI, scrap, pig iron, and returns. The degree of metallisation of the raw materials varies, thus the ratio of different raw materials is an important parameter in deciding the net yield of EAFs. The yield can vary significantly based on grades of steel

Capacity utilisation of the EAF sector



Furnace capacity vs. yield of sample EAF units

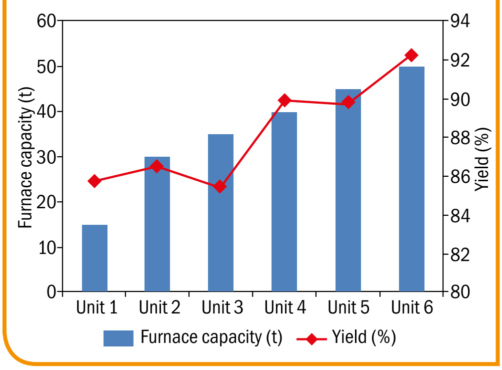


Illustration of SEC evaluation

Parameter	Unit	Value
Raw material feed	tonne per heat	55.7
Yield	%	91.6
Electricity consumption	kWh per heat	22,640
Specific energy consumption	kWh/ t melt	443

Source: Energy audits of EAFs supported by UNDP, 2017

produced in the EAF. The typical yield[7] of the EAF was found to vary from 85% to 92%. The yield of the EAF plant generally increases with furnace capacities.

Yield $= (Q_{lm}/Q_{rm}) \times 100$

Q_{lm} : Quantity of liquid metal (tonne per heat)

Q_{rm} : Total quantity of raw materials added in the furnace (tonne per heat)

2.3 Specific energy consumption

The major energy form used in an EAF unit is electricity followed by chemical energy. The Specific Energy Consumption (SEC) of the EAF is defined as the ratio of the total energy consumed by the furnace to the production of liquid steel. The SEC level is an important indicator of the EAF that shows how effectively the furnace is performing. The energy consumption in an EAF is monitored for each heat on a tap-to-tap basis. A few EAF units in India have installed oxy-fuel burner systems which provide additional thermal energy through gas firing along with electrical energy input. In this case, the overall SEC of the EAF would include both electricity and fuel consumption.

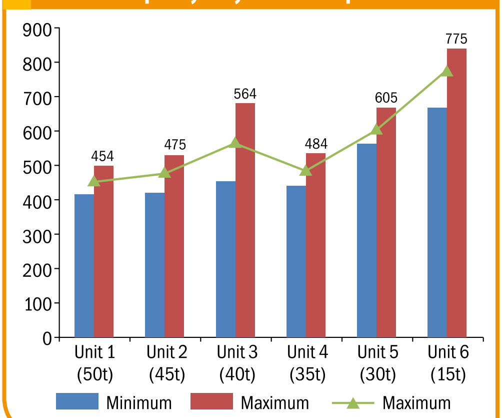
SEC = Ein/Qlm

Q_{lm}: Energy input (kWh per heat)

Q_{rm}: Total quantity of raw materials added in the furnace (tonne per heat)

Wide variations can be observed in the SEC levels of the EAF units in India. The SEC of the electric arc furnaces was observed to be in the range of 420 to 775 kWh per tonne of liquid steel. Large variations in the SEC level may be attributed to numerous factors, such as the grade of steel produced, composition of raw materials, size of the furnace, capacity utilization, temperature of liquid metal, and operating practices. The SECs of the furnaces have a tendency to decrease with an increase in capacities and vice versa. Moreover, any deviations of tapping temperature from set temperatures can lead to a substantial increase in SEC levels for the same product. On-line measurements and the control of key operating parameters and associated control systems are important to optimise SEC levels in EAFs.

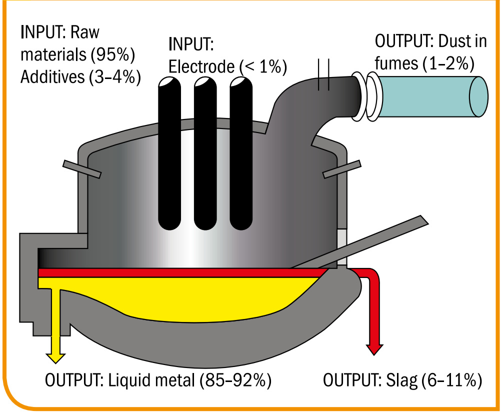
Furnace capacity vs. yield of sample EAF units



2.4 Material balance

The input of the material balance are three fold: firstly, the metallic raw materials comprising pig iron, DRI, light and heavy scrap and plant returns; secondly, additives such as limestone, dolomite, coke, CPC, ferroalloys, aluminium ingots and deoxidizers; finally, the electrode consumed during the EAF operation. The world average use of pig iron in EAF is about 5%, which may go up to 60% with scarce availability of scrap. The pig iron usage in the EAF typically varies between 5%–30% depending on the grade of steel produced, cost of pig iron and scrap, etc. The EAF units in India are predominantly scrap-melting units. The quantity of scrap used in EAF units in India is about 40%–80% and the DRI usage goes up to 30%. The quality of scrap used is one of the important factors in the overall yield (liquid metal) of the furnace. The output predominantly includes liquid metal (85%–92%), slag (6%–11%) and off-gases (1%–2%) generated through chemical reactions.

Material balance of EAF



2.5 Energy balance

The energy balance of the EAF is a method to evaluate the efficiency of the system and compare relative energy losses. It is based on the total energy inputs and outputs to the EAF over the entire tap-to-tap cycle. The energy distribution in an EAF is mainly dependent on the raw material quality and its costs and is unique to the specific unit operation. The oxygen provided to the EAF will react with a number of elements in the bath, such as aluminium, silicon, manganese, phosphorus, carbon and iron, and forming oxides of respective elements. These reactions are exothermic providing additional heat.

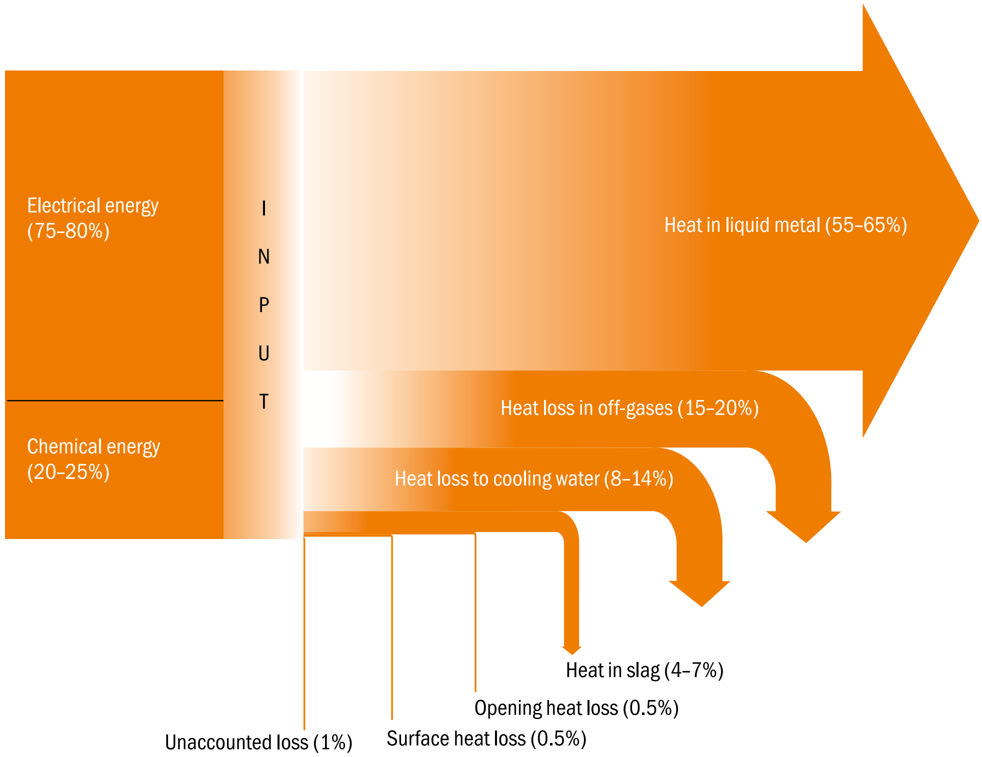
The assessment of the energy balance is based on measurements and analysis of the data collated from representative industries during energy audits. The portable instruments used for measuring key operating parameters are shown below.

The major heat losses include sensible heat in off-gases (15%–20%) which are generated during various reactions occurring inside the furnace during operation. Another significant heat loss in an EAF is heat carried by cooling water (8%–14%). The quantum of heat losses in EAF clearly shows that there exist a significant potential to reduce energy consumption by reducing various heat losses.

Instruments	Application
Power analyser	Power (active, reactive, apparent), PF, current, voltage, harmonics
Ultrasonic flow meter	Cooling water flow rate
Flue gas analyser	Carbon monoxide, oxygen
Pyrometer	Temperature of furnace and openings
Infrared thermometer	Temperature of surfaces
Differential pressure meter	Off-gas velocity

In addition to the EAF, the other energy-consuming areas include cooling water systems (pumps and cooling tower) and fumes extraction system (primary-and secondary-induced draft fans). There is a significant potential for energy saving through the adoption of energy-efficient technologies and practices in these areas as well.

Energy balance of an electric arc furnace



2.6 Energy performance assessment

This section describes the basic methods for quantification of energy losses and performance assessment of the EAFs. The plant personnel may use this methodology to conduct the performance assessment of the furnace periodically. The assessment of furnace and its associated auxiliaries should be conducted at normal plant-load operation. Ideally, all heat inputs to the furnace should be utilised towards the melting of metal; however, in practice, a number of energy losses occur within the system, leading to deviations in system performance. These losses are summarised below.

Heat loss in off-gases: The off-gases resulting from various chemical reactions occurring inside the furnace exit at quite high temperatures (900 -1100°C), which account for major heat loss in an electric arc furnace.

Heat loss in off-gases =m ×Cp ×(Tg-Ta)

m: Quantity of off-gases (kg/heat)

Cp: Specific heat of gases (kcal/kg °C)

Tg: Temperature of off-gases (°C)

Ta: Ambient temperature (°C)

Heat loss in cooling water: The furnace needs to be cooled continuously during the operation in order to maintain the sidewall and roof temperatures within the permissible limits. Any increase in the temperature of furnace walls can lead to refractories being damaged. Further, the temperature of off-gas needs to be brought down using cooling water before entering into bag filters, where temperature is a limiting factor.

Heat loss in cooling water=m ×(Tout-Tin)

m : Quantity of cooling water (kg/heat)

Tout : Outlet temperature of cooling water (°C)

Tin : Inlet temperature of cooling water (°C)

Heat in slag: The melting operation forms a sizeable quantity of slag. The slag comprises oxides of Si, Mn, Ca, Fe, and Al along with other impurities present in charge material. This slag is removed at very high temperatures leading to substantial heat losses.

Heat loss in slag = [m×Cp×L×(Tm-Ta)]+(m×L)+[m×Cp×L×(Ts-Tm)]

m: Quantity of slag (kg/heat)

Cps: Specific heat of solid slag (kcal/kg °C)

CpL: Specific heat of liquid slag (kcal/kg °C)

Tm: Melting point of slag

Ts: Temperature of slag (°C)

Ta: Ambient temperature (°C)

L: Heat required for phase transition (kCal/kg)

Heat losses through openings: Radiation and convection heat losses occur from openings present in the furnace and through air infiltration due to furnace draft. The main opening in furnace is slag door, which is kept open throughout the heat in most units.

Heat loss through opening =Fb ×E ×F ×A

E : Emissivity of the surface

Fb : Black body radiation at furnace temperature (kcal/kg/cm^2/hr)

F : Factor of radiation

A : Area of opening (cm^2)

Surface heat loss: The heat from furnace surfaces, such as sidewalls, roof, etc. are radiated to the atmosphere. The quantum of surface heat losses are dependent on the type and quality of insulation used in furnace construction. The surface heat loss per m^2 area can be estimated using:

$$Q = [a \times (T_s - T_a)^{5/4}] + [4.88 \times E \times \{(T_s/100)^4 - (T_a/100)^4\}]$$

a : Factor for direction of the surface of natural convection ceiling

T_s : Surface temperature (K)

T_a : Ambient temperature (K)

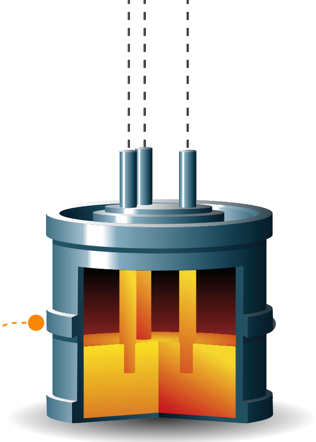
E : Emissivity of external wall surface of the furnace

The total energy losses are the sum of all the losses occurring in the furnace.

Furnace efficiency: The efficiency of furnace is evaluated by subtracting various energy losses from the total heat input. For this, various operating parameters pertaining to different heat losses must be measured, for example, the energy consumption rate, heat generated from chemical reactions, temperature of off-gases, surface temperatures, etc. Data for some of these parameters can be obtained from production records while others must be measured with special monitoring instruments.

Furnace efficiency = Total heat input – Total energy losses

3 ENERGY EFFICIENT TECHNOLOGIES FOR THE EAF SECTOR



Energy Efficient Technologies for the EAF Sector

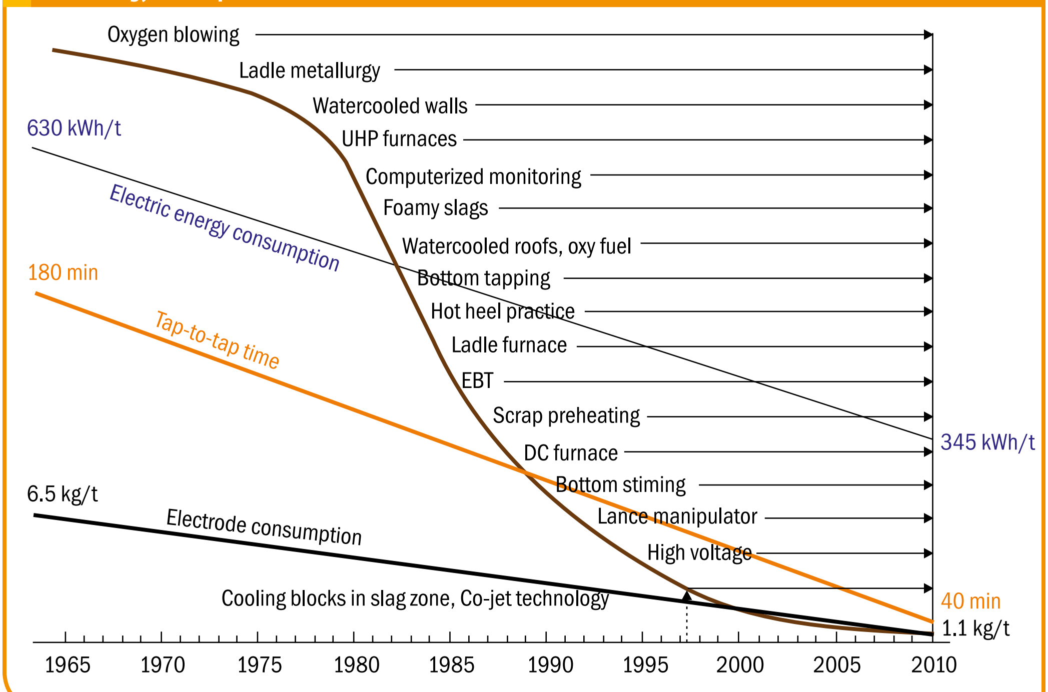
3.1 Energy-efficient technologies

The key performance indicators (KPI) of Indian EAFs shows that the specific energy-consumption levels are significantly higher than the international benchmark offering significant potential for improvement. The other KPIs such TTT and electrode consumption are also showing a higher trend which further calls for improvements. The improvements in performance at the international level have been achieved through constant innovation and upgradation in technology and practices.

The technology use in the sector indicates that there is scope for improvement in energy efficiency and productivity. The present level of specific energy consumption of the furnaces further confirms that energy efficiency can be improved by adopting a range of energy-efficient technologies and best operating practices.

The energy balance diagram of EAFs operating in India shows that a major energy input (75%–80%) is met through electrical energy and the balance (20%–25%) in the form of chemical energy. About 55%–65% of energy is used in melting. Of the

Technology development in international EAF sector



balance energy lost in various forms, off-gases account for about 15%–20% of heat input, indicating there is a potential to recover and re-utilise the heat. The other major form of energy loss is heat removed by cooling water (8%–14%).

The technology compendium on 'Energy-Efficient Technology Packages on Electric Arc Furnace' focuses on energy-efficient technologies and best practices pertaining to EAF and its associated auxiliaries that are relevant for the Indian EAF sector. The compendium has been prepared by TERI based on detailed energy audits of the representative EAF units, scouting of energy-efficiency interventions at national and international levels and stakeholder consultations.

The identified EE technology packages for the Indian EAF sector are categorised into (1) furnace design (2) furnace operation and practices (3) charge management (4) auxiliary systems, and (5) future technology options.

1. Furnace design

- Ultra-high power transformer
- High-impedance operation
- Aluminium electrode arm
- Improve regulation control
- Oxy-fuel burners
- Coherent jet

2. Furnace operation and practices

- Bottom stirring – inert gas purging
- Foamy slag practice
- Use of chemical energy
- Mist cooling for electrodes
- Water-cooled electrical cables
- Copper-based water cooled panel
- Improved refractories
- Nitrogen as carrier in Al-mix injector
- Waste heat recovery: preheating boiler feed water

3. Charge management

- Scrap processing
- Scrap preheating system
- Hot metal charging

4. Auxiliary systems

- Variable frequency drive for primary ID fan
- Intelligent control system for off-gas cooling
- Fibre-reinforced plastic fan blades for the cooling tower
- Thermostatic controller for cooling tower fan
- Energy-efficient centrifugal pumps

5. Future technology options

- Shaft furnace
- DC arc furnace
- Bottom stirring – electro-magnetic system
- Single-bucket charging system
- Tapper shell furnace
- Neural network for process control

This section provides an overview of the existing technology status, gaps, potential EET options, their salient features, and cost benefit analysis.

3.2 Furnace design

The major energy-efficient technologies in furnace design include: (1) ultra-high power transformer (2) high impedance system (3) aluminium electrode arm (4) improved regulation control (5) oxy-fuel burner, and (6) coherent jet.

3.2.1 Ultra High Power transformer

Background

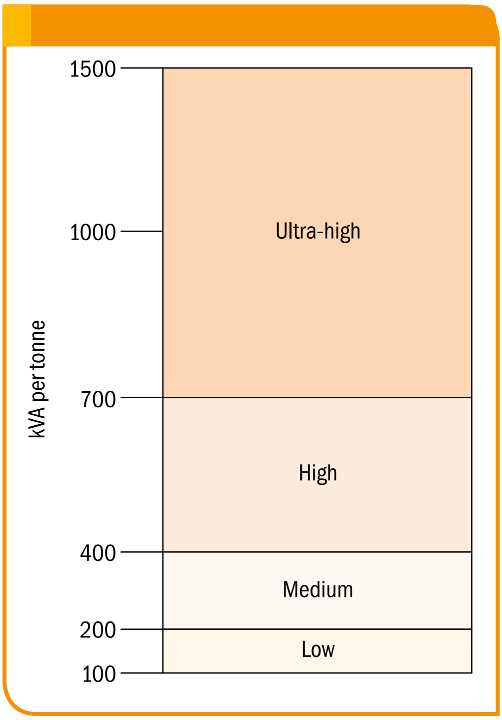
A majority of EAFs in India were installed before the 1980s. The power ratings of the transformers used in the units were limited to a maximum of 500 kVA per tonne. This has resulted in higher tap-to-tap time hence increasing the SEC levels. The overall energy loss due to use of low power rating transformer

Power ratings of transformers		
Furnace capacity, t	**Transformer rating, MVA**	**Ratio, kVA/t**
5.0	2.0	400
10.0	5.0	500
15.0	7.5	500
30.0	15.0	500

can be as high as 7%. The energy losses occurring in a transformer is a function of age, size, and input electrical power quality.

EE technology

The inefficient transformers can be replaced with Ultra-High Power transformers (UHP) in EAF units, which will help in reducing energy losses and shorter tap-to-tap time. This would reduce fixed losses of the EAF. By definition, in EAFs, if the input power is above 700 kVA per tonne, the transformer is termed as UHP. Although UHPs are typically available in the range 700–1,500 kVA, transformers with 1,000 kVA per tonne capacity are commonly used in developed countries. Development and advancements for using 1500 kVA per tonne rating transformer are also in progress. The major benefit of UHP transformer include (i) substantial increase in productivity, (ii) reduction in electrode consumption and (iii) energy saving.



Savings, investments, and GHG reduction

The average energy savings with UHP transformers is estimated to be about 5%. Typically, for a 50-tonne furnace, the investment requirement on a UHP is about ₹400 lakh with a simple payback period of about 2 years. The GHG emission reduction potential is about 3,690 tonne of CO_2 per year.

In a French plant equipped with two EAFs, the HP transformers were replaced with UHP transformers. The baseline energy consumption, electrode consumption, and productivity were established through measurements, monitoring, and verification. For every MW power increase, the energy consumption and electrode consumption came down by about 1.1 kWh and 0.3 kg, respectively.

UHP transformer		
Parameter	**Unit**	**Value**
Existing transformer rating	MVA	50
Old transformer	kVA/t	500
New transformer	kVA/t	1000
Productivity enhancement	%	40.0
Reduction in electrode consumption	%	10.0
Reduction in energy consumption	%	5.5
Investment	₹lakh	400
Simple payback period	Years	1 – 2
Source: Ernst Worrell, et.al. "Energy Efficiency Improvement and Cost Saving Opportunities for the U.S. Iron and Steel Industry", Oct 2010		

3.2.2 High-impedance system

Background

Traditionally, EAF operation was focussing on short arcs and high currents to transfer maximum power into the furnace, which resulted in high electrode consumption. The development of foamy slag practice led to the use of longer arc operation. This also led to lower operational currents and reduced electrode consumption. However, this practice has brought challenges, such as higher flickers and harmonics, particularly during the bore down period, thus leading to unstable operation as well as stress on feeding power supply system. This resulted in greater stress on mechanical components due to increased vibrations

EE technology

The shortcomings in EAF operations can be minimized with 'high-impedance operation'. It will help in a more stable and smooth furnace operation. With low-current and long-arc operation, it is important to select an appropriate power factor and a suitable system reactance for stable operation. Use of high- impedance system helps in operating the furnace close to the maximum power point of a given tap and lowers the sensitivity of power changes versus current changes. High impedance is achieved by adding a reactor on the primary side of the transformer. Also, the voltage taps on the secondary side of the transformer is raised to compensate for the voltage drop in the reactor. The major advantages of maintaining a high-impedance system include the following:

- Reduction in electrode tip consumption and breakage
- Less mechanical forces acting on the electrodes and electrode arms
- Less flickers and lower harmonics distortions on the supply network
- Stable-arc operation
- Potential to use lower electrode diameter due to lower current which will substantially reduce oxidation losses

Savings, investments, and GHG reduction

The average energy savings with high-impedance operation is estimated to be about 1%-2%. Typically, for a 50-tonne furnace, the investment requirement for a reactor is about ₹170 lakh with a simple payback period of about 3 years. The GHG emission-reduction potential is about 740 tonne of CO_2 per year.

The effect of impedance can be illustrated by considering the following three cases: (a) traditional design (b) same-arc power, but with lower electrode current and (c) same-arc power and arc length, but with a slightly lower power factor to stabilize the arcing condition. The furnace can be operated with 'long arc' for about 75% of 'power ON' time, with this assumption the effect of high impedance on operating characteristics of an EAF is given in the following box. Although case 2 and case 3 indicate similar results, the advantage with case 3 is stable arcing operation.

Particular	Unit	Case 1	Case 2	Case 3
Secondary voltage	V	800	1025	1100
System reactance	m Ω	3.3	6.1	7.1
Electrode current	kA	65.3	50.4	50.4
Active power	MW	73.7	71.5	71.4
Arc power	MW	67.8	67.7	67.6
Power factor		0.84	0.83	0.78
Arc voltage	V	363	461	460
Electrode saving	%	-	15	15
Energy saving	%	-	1.5	1.5

Source: Kjell Bergman, Danieli CentroMet, "High impedance for stable and smooth EAF operation", Steel Times International May 1993, Vol. 17 No. 3

Moreover, in the UHP transformer-based furnaces, there is an additional risk of tip breakage of electrodes due to high short circuit currents (ISC). The operation at high impedance with slightly lower power factor reduces the short circuit currents by about one-third, thus reducing the tensile stress in tip of electrode by about 50%.

The EAF units installing new transformers are mandated to use UHP transformers along with

Particular	Unit	Case 1	Case 2
Nominal current	kA	65	50
Nominal torque on electrode clamp	$Nm10^{-3}$	3.3	6.1
Tensile stress in electrode	MN/m^2	0.39	0.23
Tensile stress in tip of electrode	MN/m^2	5.46	2.46
Source: Kjell Bergman, Danieli CentroMet, 'High impedance for stable and smooth EAF operation', Steel Times International May 1993, Vol. 17 No. 3			

reactors. Therefore, the overall energy saving would be cumulative of both UHP and high impedance.

3.2.3 Aluminium electrode arm

Background

The electrode current-conducting arm carries power from the transformers to the electrodes. A mild steel support with water-cooled copper cables is the standard material used in EAFs. A copper clad, that is, steel arm with copper bus tubes, is also being used in the furnaces. The copper system (Cu-system) has high strength and conductivity. The overall weight of the Cu-system is quite high; the electromagnetic forces around the copper bus and electrode clamping heads affect the system performance. This increases the system resistance leading to a drop in the power fed to the furnace. The maintenance requirement for a Cu-system is also high.

EE technology

The shortcomings in EAF operations with Cu-system can be overcome with 'aluminium electrode arm'. The aluminium system (Al-system) is lighter than the Cu-system which is also a non-magnetic material. The Al-system comprises aluminium current-conducting electrode arms and columns with guide roll assemblies. The advantages of an Al-system include the following:

- High-arc power
- Increased productivity
- Reduction in maintenance downtime
- Lower weight
- Less mechanical vibrations

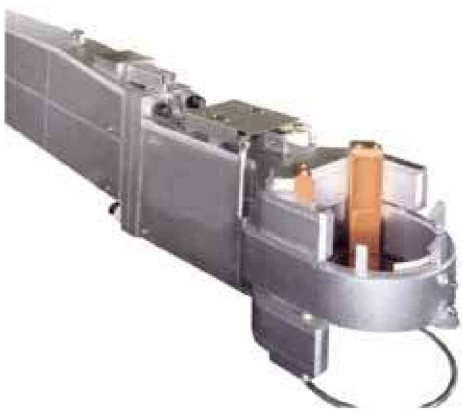
Savings, investments, and GHG reduction

The average energy savings with aluminium electrode arm is estimated to be about 0.7%. Typically for a 50-tonne furnace, the additional

Copper electrode arm

Source: http://www.hammersindustries.com/ ea_furnace_ components.html

Aluminium electrode arm



Source: http://www.kark.de/cms/index.php/en/ aluminium-electrode-arms investment requirement is about ₹70 lakh with a simple payback period of about 1.5 years. The GHG emission reduction potential is about 520 tonne of CO_2 per year.

The operational experience of an aluminium electrode arm by one of the units in USA operating a 100 tonne, 85 MVA EAF shows improvement in the average power input and productivity. The unit was operating the furnace with 'long arc' for 60% of the time. The short circuit test on the Cu-system and Al-system shows that the resistance of the aluminium electrode arm is about 4.6% lower than the Cu-system. The average power input increased by about 0.7% and the productivity improvement by 3.2%. The unit further claimed that the downtime due to maintenance of electrode arms had come down by about 80%.

Particular	Unit	Cu-system	Al-system	Change
Reactance (short circuit)	mΩ	3.02	2.88	- 4.6%
Reactance (foamy slag)	mΩ	3.31	2.93	- 11.5%
Power foamy slag	MW	82.1	82.6	+ 0.6%
Power normal	MW	76.6	77.3	+ 0.9%
Power melt down	MW	75.5	75.9	+ 0.7%
Power ON time	min	41	39.7	- 3.2%

Source: 'Operational experience with aluminium electrode arms', Metallurgical Plant and Technology International 2/2004

3.2.4 Improved regulation control

Background

The degree of transformation of electrical power into thermal energy is pivotal for the efficient operation of the EAF. This depends on regulation of the transformer, which, traditionally, use following methods: (i) changing the number of turns in primary winding (ii) star to delta switching in primary side of the transformer (this is not applicable for UHP transformers as regulation is done through on-load changer) (iii) use of auto transformers, and (iv) booster transformer. One of the major issues with a conventional regulation system is that it is a complex-structure contact on-load changer, which increases the switching time (3–5 seconds). Further, the on-load changers operate in a high-intensity mode (frequent changes ~500–800 per day) leading to high wear and tear thereby, decreasing the operational reliability.

EE technology

The shortcomings in conventional regulation systems (analog/electro-hydraulic) can be addressed with "high pressure hydraulic digital regulation". The digital system would allow minimum delays for switching from one melting stage to another. This system can be linked with 'Level-2 or 3' automation for dynamic production control. The main advantages of digital based regulation system are the following:

- Reduction in tap-to-tap time
- Increase in productivity
- Increase in operational reliability

Savings, investments, and GHG reduction

The average energy savings with improved electrode regulation is estimated to be about 3%. Typically for a 50-tonne furnace, the investment requirement is about ₹75 lakh which includes hardware and software and associated hydraulic systems. The simple payback period is about 6 months. The GHG emission-reduction potential is about 2,210 tonne of CO_2 per year.

The case of a 40-tonne EAF fed by a 36 MVA transformer illustrates the effects of a installation of state-of-the-art electrode regulation system on energy consumption, electrode consumption, and productivity improvement. The installed electrode regulation system had led to an energy saving of 3.3%, electrode saving of 3.1%, and productivity improvement by 1.6%.

Particular	Unit	Base case	EE technology
Furnace capacity	t	40	40
Transformer rating	MVA	36	36
SEC	kWh/t	426	412
Power ON time	min	49.7	48.9
Electrode consumption	kg/t	3.51	3.40
Monetary benefit	₹/t	-	81
Investment cost	₹lakh	-	250
Simple payback period	Years	-	0.52
Source: TERI energy audit study in EAF unit, 2016			

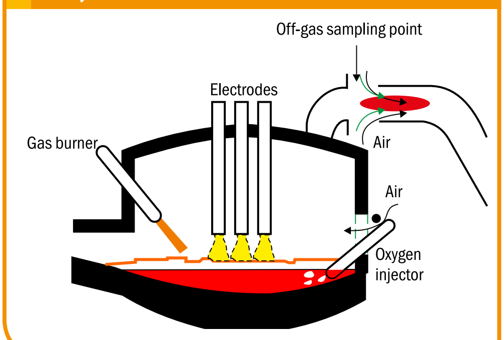
The units wherein the digital electrode regulation system is already in place can achieve additional energy saving with fine-tuning of the software with reference to their respective scrap quality. Moreover, the software would require updation whenever there is significant changes in the input scrap quality.

3.2.5 Oxy-fuel burner

Background

An EAF operation is characterised by a pattern of hot and cold spots across the furnace cross section. The cold spots exist generally in the areas lying between electrodes on the peripheral areas of furnace bottom. The creation of cold spots within the EAF would lead to an increase in TTT time thereby increasing the specific energy consumption. It is, therefore, important to eliminate cold spots from the furnace. Oxygen injection—either lancing or oxy-fuel burner would help in addressing the issues related to cold spots.

Oxy-fuel burner



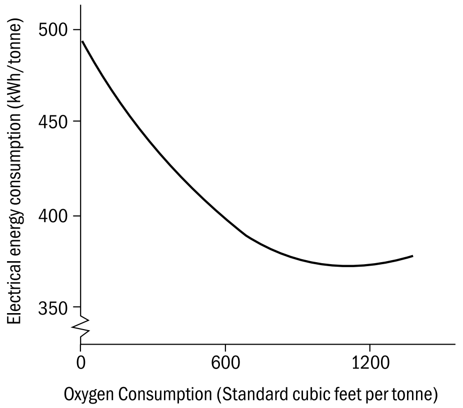
EE technology

The state-of-the-art EAFs are equipped with oxy-fuel burners and mounted on the sidewalls. Natural gas, LPG, etc. are used in oxy-fuel burners. The oxy-fuel burners are used to provide additional energy-to-cold spots, thereby ensuring the homogeneity of liquid bath temperature leading to a more uniform melting. Upon the formation of a liquid metal pool, oxygen can be directly lanced into the molten bath to accelerate oxidation of various solutes, starting with carbon in the bath and iron.

During this process, silicon, manganese, and phosphorus present in the raw material also get oxidised and are removed as slag. These reactions are exothermic, thereby providing additional thermal energy for melting. The reaction of oxygen with carbon in the bath forms carbon monoxide (CO). The CO either burns in the furnace if sufficient oxygen is available or gets exhausted through a fume-extraction system wherein it is combusted and sent to a pollution-control system. The CO escaping from the bath produces 'carbon boil' in the melt, which helps in: (i) heat transfer by agitating the molten bath (ii) cleansing the bath of retained oxides during de-slagging (iii) accelerating reactions at the gas metal interface, and (iv) aiding in the removal of hydrogen and nitrogen formed during the reactions.

Modern EAF units widely use wall-mounted oxy-fuel burners and a combination lance burners. These burners operate in a burner mode at the beginning of melting. Upon the formation of liquid metal, the burners change over to lancing mode. Some of the important advantages of using an oxy-fuel burner include:

Electricity consumption vs. oxygen use (100 t EAF)



Source:http://infohouse.p2ric.org/ref/10/09047.pdf

- Lower electricity consumption[8]
- Reduction in tap-to-tap times (3-6 minutes).
- Enhancement of yield by about 1%

Savings, investments and GHG reduction

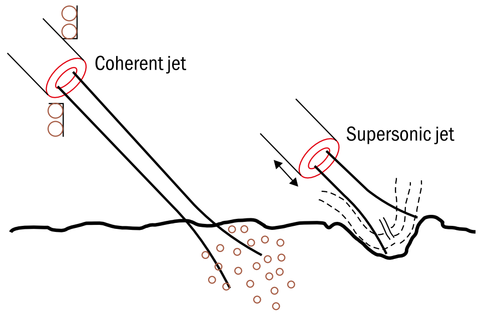
The average energy savings by installation of oxy-fuel burners is estimated to be about 3%. Typically for a 50 tonne furnace, the investment requirement is about ₹400 lakh with a simple payback period is about 2 years. The GHG emission reduction potential is about 2,210 tonne of CO_2 per year.

3.2.6 Coherent jet

Background

The oxygen injection system in traditional electric arc furnace is used to improve productivity by utilizing the chemical energy. The typical oxygen injection is in the form of a supersonic jet which creates splash and leads to formation of cavity in the liquid metal bath. Moreover, the penetration of supersonic stream is not very effective and splashing leads to higher refractory consumption.

Coherent jet vs. supersonic jet



Coherent jet vs. supersonic jet

Source: Praxair CoJetTM Technology

EE technology

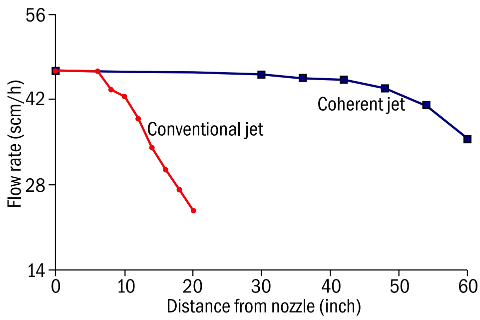
The shortcomings in supersonic jet are overcome with use of coherent jet technology (CoJet).[9] The coherent jet system comprises up to four numbers of CoJet injectors, which are mounted on furnace side walls, depending on size and process requirement. These CoJet injectors are multi-purpose systems which acts as burner, lance and also post-combustion device. The CoJet has capability of compact lancing and decarburising without any splash. This is achieved by keeping the oxygen stream coherent i.e. retaining its original diameter and velocity over longer distances.

Its performance can be further enhanced using programmable logic controllers.

The major advantages of CoJet injectors over conventional injectors are as given below:

- Better penetration of liquid metal bath (80% more than traditional lance)
- Supplies precise amount of oxygen to liquid metal bath
- Less splash and cavity formation
- Lower refractory consumption
- Improves slag foaming with less carbon
- Decreases air infiltration as the slag door can be kept closed

Conventional vs. coherent jet



Source: Praxair CoJet™ Technology

Savings, investments, and GHG reduction

The average energy savings with use of coherent jet injectors is estimated to be about 2%. Typically for a 50-tonne furnace, the investment requirement in co-jet burners is about ₹300 lakh with a simple payback period of about 2.5 years. The GHG emission-reduction potential is about 1,480 tonne of CO_2 per year.

A unit in western India has installed an oxy-fuel system with 3 numbers of CoJet injectors in a 50 t EAF fed by 40-MVA transformer. The energy consumption, electrode consumption, and productivity were monitored before and after the installation. The energy consumption came down by 6.4%, whereas the reduction in electrode consumption was about 9.4%; at the same time, the TTT is reduced by 10.6%, thus improving the productivity. The savings correspond to oxy-fuel burners using Co-Jet technology.

Particular	Unit	Conventional	CoJet
Capacity	tph	27.1	28.8
Tap-to-tap time	min	114	102
SEC	kWh/t	485	454
Electrode consumption	kg/t	3.2	2.9
Investment	₹lakh	-	100
Simple payback period	Years	-	0.5

Source: Energy audits of EAF units supported by UNDP, 2017

3.3 Furnace operation and practices

The energy efficiency improvements in furnace operation and practices include (1) bottom stirring, (2) foamy slag, (3) use of chemical energy, (4) mist cooling for electrodes, (5) water cooled electrical cables, (6) copper based water cooled panel, (7) improved refractories, (8) N_2 as carrier in Al-mix injector and (9) waste heat recovery for other applications.

3.3.1 Bottom stirring—Inert gas purging

Background

The molten metal in the arc furnace may not be of homogenous mass or uniform quality across the cross section. This may result in increased TTT time and energy consumption. Moreover, it can lead to a high rejection level. Homogenisation of the liquid metal bath is required to overcome the issues and enhance productivity.

EE technology

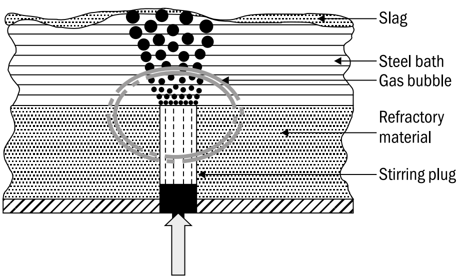
The bottom stirring of liquid bath in an EAF is a potential solution for better homogenisation and

Bottom purging system in EAF

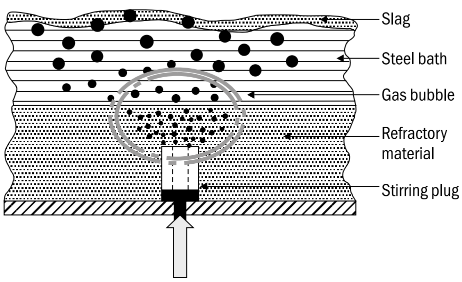
ensures uniform quality. The mechanism used at present for bottom stirring is inert gas injection, mostly used in developed countries. In an inert gas-stirring system, the stirring of liquid metal is accomplished using inert gases such as argon or nitrogen. Bottom-stirring systems based on inert gas injection are available either as a single tube or multi-hole plugs. These plugs are either buried in the furnace hearth ramming mix or 'indirect purging' or in contact with steel melt or 'direct purging'. Indirect purging arrangement offers improved stirring arrangement due to better distribution[10] of inert gases.

The bottom stirring using inert gases are more suitable for smaller furnaces. Bottom stirring further accelerates chemical reactions between steel and slag. The stirring helps in an increased heat transfer with an estimated energy saving[11] of 12–24 kWh per tonne liquid steel. It further leads to increased metal yield of about 0.5%. However, the use of inert gas would require significant maintenance after every heat. The advantages of inert gas-based bottom stirrer include the following:

- Improved control of the temperature and chemical composition
- Lower consumption of refractory and electrode
- Shorter TTT times
- Improvement in liquid metal yield



Ar or N_2 Direct contact stirring system



Ar or N_2 Indirect contact stirring system

Savings, investments, and GHG reduction

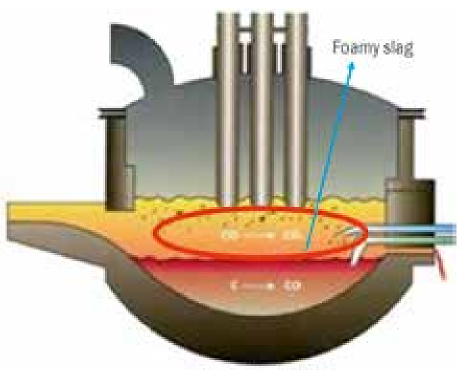
The average energy savings with inert gas based bottom stirring is estimated to be about 3%. Typically for a 50 tonne furnace, the investment requirement is about ₹10 lakh and the payback is immediate. The GHG emission reduction potential is about 2,210 tonne of CO_2 per year.

3.3.2 Foamy slag practice

Background

At the beginning of the melting process, the radiation loss from the arc to the sidewalls is generally observed to be marginal or negligible. This is due to the fact that electrodes are surrounded by scrap which are at low temperatures. In the meltdown phase, the temperature of scrap and melt reaches rises quite high, thereby more heat is radiated to the sidewalls. The increased heat transfer to

Foamy slag in EAF



sidewalls leads to increased surface heat losses and refractory consumption.

EE technology

A layer of slag can be used to cover the arc, thereby shielding it. This would lead to retention of heat, less heat transfer to side walls and hence more effective heat transfer to molten bath. Often, adequate foaming occurs at the beginning of refining process, but gradually decreases towards end of the heat. The process of slag foaming involves reactions that generate and sustain gas bubbles along with proper slag.

The effectiveness[12] of slag foaming depends on slag basicity, FeO content of slag, slag temperature, and the availability of carbon to react with either oxygen or FeO of slag. Slag foam results from the entrapment of gas bubbles in molten bath. The reactions that are involved in gas production inside the furnace include the following reactions. The reactions involving chromium oxide is mainly for stainless steel making.

Reaction between FeO of slag with carbon

$$(FeO) + C \longrightarrow [Fe]+\{CO\}$$

Reaction between carbon and oxygen dissolved in metal

$$[C] + [CO] \longrightarrow \{CO\}$$

Reaction between chromium oxide and carbon

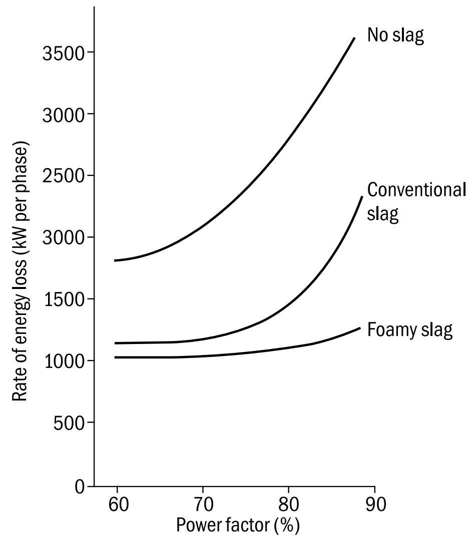
$$Cr_2O_3 + 3C \longrightarrow 2Cr+3CO$$

It is important that the foaming slag needs to be maintained throughout the refining period to minimise energy losses to sidewalls and the efficient use of electrical energy inputs. Injection of carbon and oxygen at multipoints in the bath would ensure and enhance the slag-foaming practice, especially, when the carbon content of the bath is insufficient. It would further help in the protection of the sidewalls and roof from intense heat generated from the EAF.

Slag foaming is done once a flat bath is achieved. In an EAF, oxygen is injected inside along with granular coal or carbon. The carbon reacts with FeO present in the slag and produces carbon monoxide (CO), which foams the slag. In an arc furnace, the slag thickness is typically about 4 inches (about 10 cm). With foaming practice, the slag cover can be increased up to about 12 inches (about 30 cm), which acts as an insulation cover for molten batch, retaining heat as well as increasing the temperature of molten metal bath. Further, with the formation of a deep, foamy slag, there is a potential to increase the arc voltage significantly, which would allow higher power inputs in the furnace.

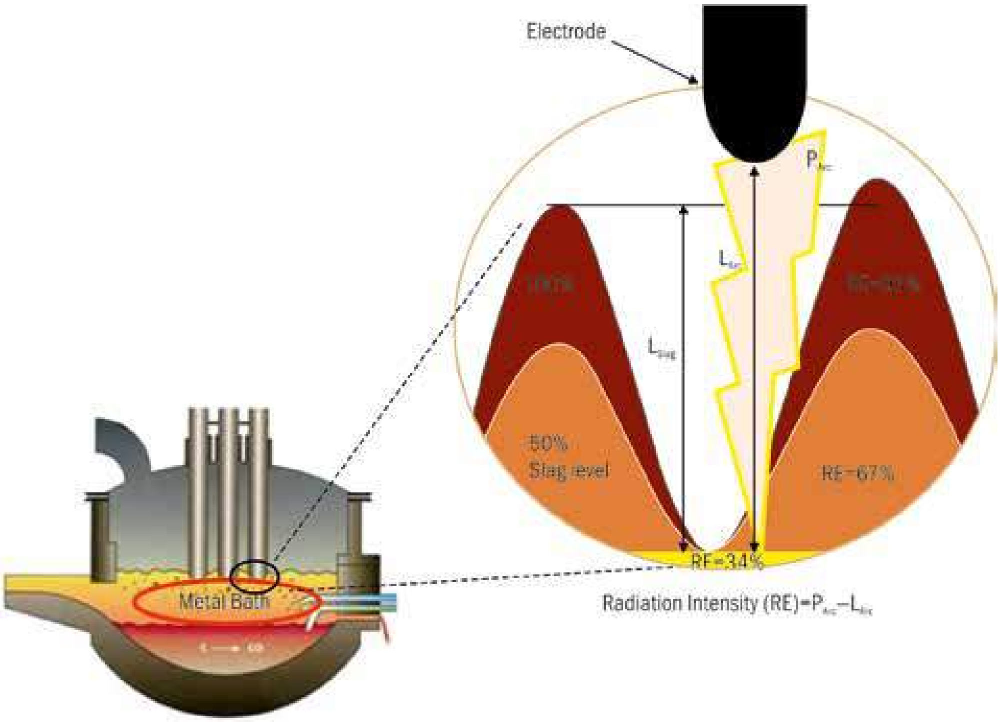
The effect of radiation intensity[13] to the furnace walls is proportional to the length of the arc above the steel bath. The length of arc reduces with an increase in thickness of the slag inside the furnace. Thus when the thickness of foamy slag increases it would tend to cover the electric arc, and hence more heat is radiated to the steel bath rather than lost to furnace walls, thereby increasing the melting rate in the furnace. The major benefits by maintaining foamy slag in the molten metal bath include the following:

Effect of foamy slag on heat losses



Source:http://etech.lwbref.com/Downloads/Theory/Fundamentals%20 of%20the%20EAF%20Process.pdf

Heat losses to side walls of EAF with foamy slag



Source: Joachim D Souza , 3rd India International DRI Summit, Aug 2016

- Enhance heat transfer to the molten bath
- Reduce thermal load radiated to the furnace lining
- Decrease electrode and refractory consumption
- Better electric arc stability during long arc operations
- Minimize arc noise

Slag viscosity plays an important role in maintaining proper foamy slag, as it would determine the retention time of the CO bubbles in foam. Dololime addition using automatic system would help in enhancing the formation as well as the retaining the foamy slag. Suitable training of operators would be required in controlling the foaming practice.

Savings, investments, and GHG reduction

The average energy savings with an enhanced, foamy slag practice is estimated to be about 1.5%. Typically, retrofits required for enhanced foamy slag practice involves oxygen lancing and carbon injection. Most of the units are equipped with the required system for foamy slag; however, the level of foaming is limited to 4–6 inches, which can be further enhanced to up to 12 inches requiring marginal investment with immediate payback. The GHG emissions reduction potential is about 1,100 tonne of CO_2 per year.

3.3.3 Use of chemical energy

Background

The chemical reactions form part of the EAF operation which generate significant quantity of heat during various phases. However, the heat generated is not utilised to its full potential by a majority of the units resulting in significant heat losses.

EE technology

The methods for utilising the chemical energy available from the EAF include post combustion, oxidation reaction, and carbon injections.

(a) Post combustion

The off-gases from EAFs contain a substantial quantity of carbon monoxide (CO) along with hydrogen (H_2). CO is produced in large quantities in EAF both from oxygen lancing as well as from slag foaming process. Since it is not possible for CO to burn to CO_2 inside the furnace, CO will be the predominant gas generated from the process reactions. A large quantity of CO and H_2 is generated at the start of the melting process that include burning of oil, grease, and other combustible materials present in the scrap.

Incomplete reaction carbon and oxygen

$$C + \frac{1}{2}O_2 \longrightarrow CO$$

Cracking of hydrocarbons or reduction of water

$$H_2O + C \longrightarrow H_2 + CO$$

Adequate oxygen is required for the complete combustion of these compounds. As insufficient quantity of oxygen is generally available inside the furnace, it leads to the formation of CO. The heat of combustion further shows that C to CO_2 is about three times higher than heat of combustion of C to CO. Thus, there exists a large potential of energy source in the EAF in the form of CO. 'Post combustion' is a process of utilising chemical energy present in CO and H_2 evolving off the steel bath to heat the steel in the EAF ladle or preheat scrap to (300–800 °C), thereby reducing the electrical energy requirements for the melting process. During the EAF operation, post combustion must be carried out early at meltdown, while the scrap is capable of absorbing the heat

PC can be carried out low in the furnace or in the slag itself. Oxygen is either injected into the furnace above the slag or into the slag before it enters the furnace freeboard. To maximize the CO retention time, the injectors are placed low in the scrap in order to transfer the heat. PC oxygen is generally provided at low velocities into the slag. The usefulness of the heat generated through PC is dependent mainly on the effective heat transfer to steel scrap or liquid metal. If PC oxygen level is more than 15 Nm3 per tonne liquid metal, yield losses may become higher. If additional carbon is not supplied, a yield loss will occur. It may be noted that a yield loss of 1% is equivalent to a power input of 13.2 kWh per tonne. Some of the advantages of adopting PC in EAFs are as follows:

- Savings in electricity consumption[14]
- Reduction in TTT time (3%–11%)
- Improves productivity
- Reduces bag-house emissions
- Reduces temperature of the off-gas system

(b) Oxidation reactions and carbon injection

The main oxidation reactions occurring inside an EAF are the oxidation of iron and carbon besides oxidation of silicon and manganese. Though the oxidation of iron generates more energy than the oxidation of carbon, it would lead to loss in productivity.

Oxidation reaction of iron

$$Fe + \frac{1}{2} O_2 \longrightarrow FeO;\ \text{Heat content } 6.0\,kW/m^3\,O_2$$

Oxidation reaction of carbon

$$C + \frac{1}{2} O_2 \longrightarrow CO;\ \text{Heat content } 3.5\,kW/\,m^3\,O_2$$

Therefore, there is a need to control and manage oxygen injection so that oxidation of iron is kept at a minimum. It may be noted that for bath carbon levels above 0.3%, all the oxygen present reacts with carbon to produce CO. If the level is below 0.3%, the efficiency of carbon oxidation to form CO drops and more and more FeO is generated in the slag. For scrap carbon levels below 0.1%, FeO levels in the slag can become quite high which is an unavoidable yield loss. Carbon injection needs enhancement to control slag FeO levels and prevent excessive refractory losses. Carbon injection is beneficial where 100% scrap practice is being done or carbon content of the bath is insufficient to produce CO for slag foaming.[12]

Savings, investments, and GHG reduction

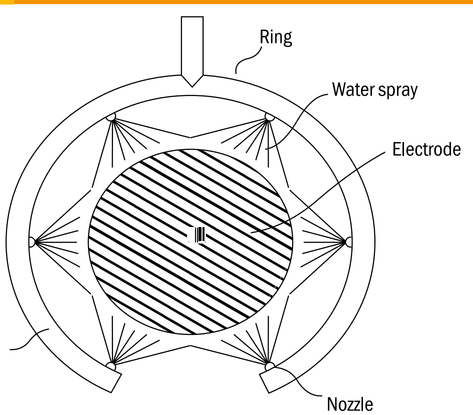
Studies have indicated a reduction in energy consumption[4] of 4.5 kWh per Nm3 of oxygen for PC occurring low in the furnace, or about 3 kWh per Nm^3 of oxygen for PC high in the furnace. PC at slag level typically covers about 20%–30% of CO generated in the furnace, whereas PC in freeboard would cover 80% of CO combustion.

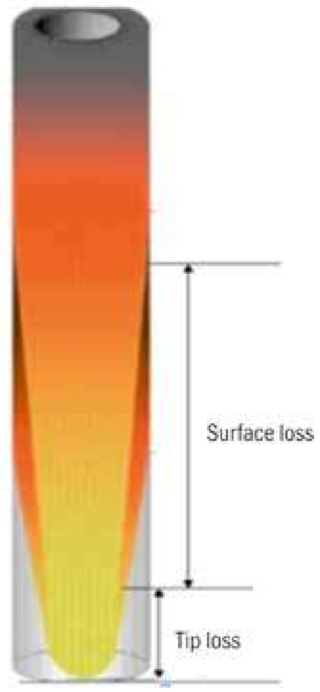
The average energy savings with the proper utilisation of chemical energy is estimated to be about 1%. The investment requirement is marginal and payback is immediate. The GHG emission-reduction potential is about 740 tonne of CO_2 per year.

3.3.4 Mist cooling for electrodes

Background

Typically, graphite electrodes are used in EAFs. The electrodes are clamped by an electrode holder and inserted in the furnace. The electric arc is generated between the tip of the electrodes which produces heat to melt the material in the furnace. The side surface of the electrodes is oxidised and consumed due to the high temperature. During the operation of the furnace, the shape of electrodes changes and at the tip it decreases to as low as 70% of the original electrode diameter.





EE technology

The oxidation loss of the side surface of the electrodes can be reduced by coating the outer surface or by reducing the outer surface temperature of the electrode. A jacket of water mist is created over the outer surface of the electrodes which forms a coating over the electrodes surface, thereby reducing the temperature of the side surface.

Savings, investments, and GHG reduction

When the flow rate of the cooling water is kept optimum, depending on electrode diameters, the electrode consumption reduces by 10%–15%. The corresponding reduction in energy consumption is about 1%. The GHG emission-reduction potential is about 740 tonne of CO_2 per year.

Type of consumption	Value (%)
Consumption due to arcing	40
Side surface oxidation	50
Tip fall down due to thermal shock	10
Source: TERI energy audit study in EAF unit, 2016	

3.3.5 Water-cooled cables

Background

The cables providing electrical power supply to the furnace from transformer are typically water cooled. The resistance of the cables for a 40-tonne furnace with 35-MVA transformer is 90 mΩ during the time of installation. The resistance of the cables increases with the life and usage of the furnace. The resistance of these cables doubles in about 2 years, which is substantial. The units replace the cables generally once in 3–5 years, which results in energy loss.

EE technology

The resistance of the water-cooled cables must be measured periodically (at least twice a year) as part of maintenance practice. When the resistance on the water-cooled cables increases to about 1.5 times of the design, the old cables maybe replaced with new cables of lower resistance.

Water cooled cables

Savings, investments, and GHG reduction

The average energy savings by replacing old, high-resistance water cooled cables with new cables is estimated to be about 0.15%. Typically for a 50 tonne furnace, the investment requirement is about ₹20 lakh with a simple payback period of about 2 years. The GHG emission-reduction potential is about 110 tonne of CO_2 per year.

An EAF unit in India has adopted the regular maintenance practices. The unit has measured the resistance of the water-cooled cables, which indicated a resistance 3.5 times higher than the design value. The unit replaced the high-resistance cables with new, water-cooled cables of lower-design resistance, which resulted in an estimated energy saving of 0.6 kWh per tonne of liquid metal.

Particular	Unit	Old cable	New cable
Furnace capacity	t	40	40
Cable resistance	mΩ	310	90
Energy saving	kWh/t	-	0.6
Investment	₹lakh	-	20
Simple payback period	Years	-	1.5
Source: TERI energy audit study in EAF unit, 2016			

3.3.6 Copper-based water-cooled panels

Background

The water-cooled panels, typically used in the EAFs, are made of mild steel (MS). These MS water-cooled panels usually have low life. Over a period of use, the effectiveness of heat transfer comes down significantly, which would result in higher refractory consumption.

EE technology

The MS-based water-cooled panels can be replaced with copper-based water cooled panels. The

Copper-water cooled panel

advantages of copper-based water cooled panels include: (a) increased life of panels (upto 6 times) (b) reduced number of panel failures, and (c) reduction in refractory consumption.

3.3.7 Improved refractories

Background

The operating parameters and quality of refractory materials used in the furnace are quite important for the overall performance of EAFs. The consumption[15] rate of refractories in an electric arc furnace is about 20–35 kg per tonne of liquid steel for smaller furnace without water-cooled roof and sidewalls. For furnace, with water-cooling system, the refractory consumption is considerably low, about 5–10 kg per tonne of liquid metal. High refractory consumption in an EAF leads to high downtime resulting in lower productivity and higher production costs.

EE technology

The furnace bottom is generally made by ramming with magnesite ramming mass or dead burnt magnesite peas or ready mix and formed as a monolithic layer. The use of a type of magnesite is dependent on the grade of steel to be manufactured. For example, for the manufacturing of high-alloy steel or special steel, high-purity magnesia ramming mass is preferred. The furnace bottom is exposed to high temperature as well as high load conditions. Hence any dent or crevises formed during furnace operations need to be repaired immediately. The repairing of the furnace bottom is carried out if one or more of the following observations are made during the furnace operation: (i) small cracks at the furnace bottoms due to prolonged use (ii) penetration of liquid metal, or (iii) a damaged bottom.

Magnesite bricks were being used in construction of sidewalls upto the level of slag line in older furnaces. The modern practice includes the use of 'mag-carb' bricks, which is a composite material having high resistant to corrosion. Carbon addition in the bricks leads to high thermal shock resistance. At high temperatures, the porosity of refractories is reduced which brings down the potential for penetration by slag or molten metal. The slag line is fettled with dry dolomite or gunny mix after every heat.

Savings, investments, and GHG reduction

The use of improved refractories, such as castable alumina and Mag-carb refractories helps in improving the overall life of the furnace; for example, the life of sidewalls with use of Mag-carb refractory is about 200 heats without any repair in the case of continuously operated furnaces. This reduces the furnace downtime and enhances productivity. The average energy savings with the use of improved refractories is estimated to be about 0.2%. The GHG emission-reduction potential is about 150 tonne of CO_2 per year.

3.3.8 Nitrogen as carrier in Al-mix injector

Background

In stainless steel production from EAFs, typically aluminium mix is injected in the furnace, which acts as a reducing agent. This reduces the furnaces yield of liquid metal.

EE technology

In the aluminium mix injector, nitrogen (N_2) can be used as carrier gas in the production of stainless steel. The main advantages of the N_2-based Al-mix system are (i) reduction in Cr_2O_3 in the slag, (ii) yield improvement, and (iii) reduction in energy consumption.

Savings, investments and GHG reduction

The average energy savings with nitrogen as carrier in Al-mix injector is estimated to be about 0.2%. The investment requirements are marginal with immediate payback. The GHG emission reduction potential is about 150 tonnes of CO_2 per year.

3.3.9 WHR for boiler feedwater

Background

The average temperature of melt inside the EAF is about 1650 °C. The waste gases or off-gases from the furnace leave at about 900–1200 °C, which is quite high, wasting significant energy. The waste heat available in off-gases can be effectively recovered and reused which would help in reducing the overall energy consumption of the furnace. In most of the EAF plants in India, at present the off-gases are forced to cool down using cooling water circulation so that the gases can be passed through bag filters having temperature limitations. Although, the best option for utilizing off-gas heat is preheating of scrap material, there may be constraints in existing layout of the plant for installing scrap preheating system.

EE technology

The EAF unit typically uses steam for applications such as vacuum pump operation in vacuum oxygen decarburization (VOD). The steam requirements are presently met through fossil fuel fired boilers. The feedwater required for steam generation is usually drawn at ambient temperatures. The industrial cooling water used for reducing the temperature of off-gases in fumes extraction system to meet the temperature requirements of bag filter can be replaced by boiler feedwater. The sensible heat in off-gases will help in preheating of feedwater, which would result in fuel saving in boiler.

Savings, investments, and GHG reduction

The energy savings for waste heat recovery (WHR) system for preheating boiler feedwater include reduction in FO consumption. Additional electrical energy will be required for pumping of feedwater in WHR circuit. Typical investment required for WHR system is about ₹10 lakh with a simple payback period of about 3 months. The investment would depend on the physical distance between the EAF and the boiler. The GHG emission reduction potential is about 1,510 tonne of CO_2 per year.

Pre-heating boiler feedwater

Parameter	Unit	Value
Steam generation	tph	4.7
Increase in feedwater temperature	°C	45
Furnace oil saving	kg/hr	22
Net monetary benefits	₹lakh	40
Investments	₹lakh	10
Simple payback period	Year	0.2

Source: Energy audits of EAF units supported by UNDP, 2017

3.4 Charge management

The charge management in an electric arc furnace unit includes (1) scrap processing, (2) scrap preheating, and (3) hot metal charging.

3.4.1 Scrap processing

Background

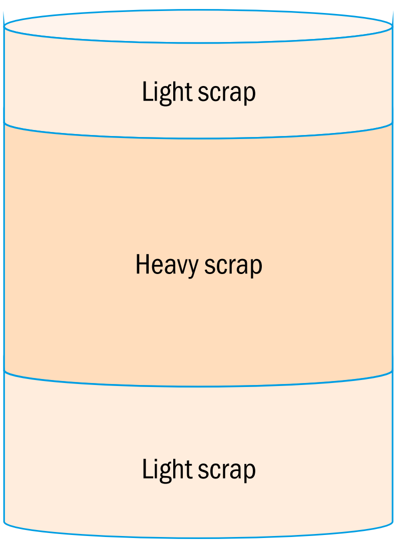
The scrap is an important charge material in electric arc furnace along with pig iron, DRI, and foundry returns. The bulk density of scrap varies largely and affects the duration of melting thus leading to longer tap-to-tap time and higher electrical energy consumption. The EAF units use both heavy scrap and light scrap. The scrap constitutes for almost 40–50% of charge material, about 25–30% being heavy scrap and about 15–20% light scrap. A large number of EAF units do not follow proper procedure for scrap management. Scrap processing and management is one of the key parameters that influence the overall performance of the furnace.

EE technology

Pre-processing of scrap is required to accommodate for variations in bulk density of various types of scrap used by the plant. Scrap processing would comprise shredding, cutting, and bailing/bundling operations. Unwanted foreign material from the scrap is removed and the bulk density of scrap is enhanced by compacting and homogenization.

After pre-processing of scrap, attention must be paid towards preparation of charge bucket that would help in ensuring proper melt-in chemistry and good melting conditions. The charging of heavy scrap at the bottom may lead to damages to bottom refractory lining. Hence, it is preferable that a proper procedure shall be adopted which would not only help in protecting the refractory lining of the furnace but also lead to efficient melting process. The bottom of the charging bucket must be filled with light scrap or less dense material which will be followed by heavy scrap in the middle. Again, the light scrap will be charged at the top to enable faster melting. The key advantages of scrap processing are:

Procedure for scrap charging in bucket



- Ensures proper chemistry of metal
- Enhances melting rate
- Protects refractory lining at the bottom
- It further protects side walls and roof from electric arc

Savings, investments, and GHG reduction

The average energy savings with scrap processing and management is estimated to be about 5–9%. Typically for a 50 tonne furnace, the investment requirement is about ₹350 lakh with a simple payback period is about 1 year. The GHG emission reduction potential is about 5,170 tonnes of CO_2 per year.

Scrap processing in EAF (capacity 90,000 tpy)

Parameter	Unit	Values
SEC - without scrap processing	kWh/t	475
Reduction in power on-time	min	6.9
SEC with scrap processing	kWh/t	445
Annual monetary benefits	₹lakh	195
Investment	₹lakh	350
Simple payback period	Year	1.8

Source: Energy audits of EAF units supported by UNDP, 2017

3.4.2 Scrap preheating

Background

Electric arc furnace involves high temperature melting operation. The average temperature of melt inside the furnace is about 1650 °C. The waste gases or off-gases from the furnace leave at about 900-1200 °C, which is quite high, wasting significant energy. About 20% of input energy is carried away by the off-gases. This waste heat available in off-gases can be effectively recovered and reused which would help in reducing the overall energy consumption of the furnace.

EE technology

One of the major options for WHR is preheating of input scrap. The exact energy savings depend on the type of scrap, size, temperature of off-gases and residence time. The important advantages of scrap preheating include:

- Increased productivity
- Helps removing moisture from scrap
- Reduces electrode consumption
- Reduces refractory consumption.

The most established scrap preheating technologies applicable for EAFs are:

a) Bucket preheating system

b) Continuous scrap preheating system

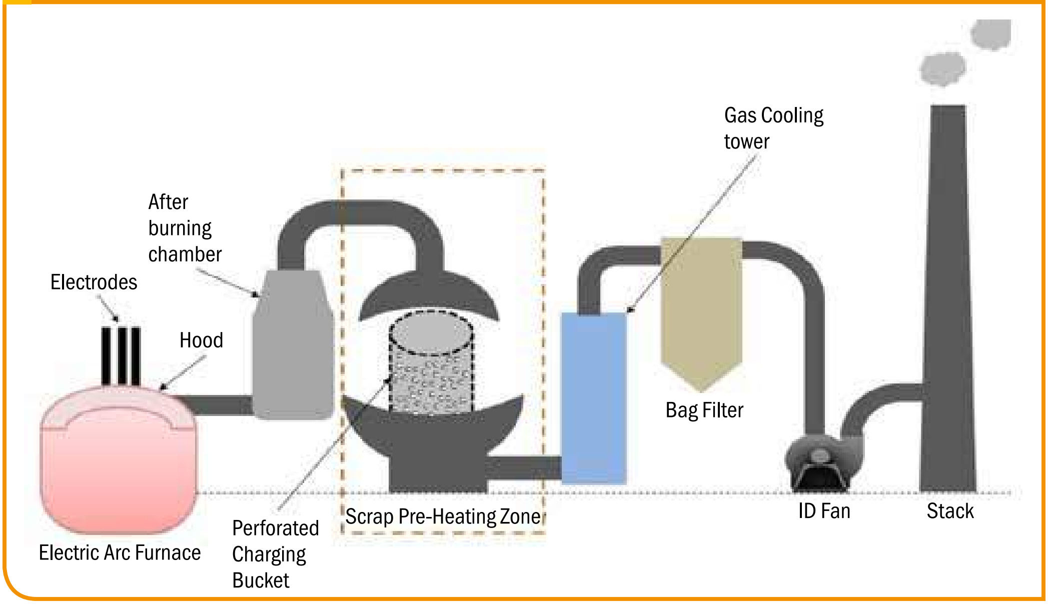
(a) Bucket preheating system

The bucket preheating system was the oldest type of scarp preheating used in EAFs. In this, hot off-gases from the furnace are directed into the scrap charging bucket with a piping and special hood arrangement. The off-gases enter the bucket at about 800 °C, and leave around 200 °C, after imparting sensible heat to the scrap. The scrap can be preheated to about 400 °C. Some of the disadvantages of using bucket preheating system include the following: (a) Inconvenient to operate, for example, scrap sticking to bucket, (b) short bucket life and (c) poor controllability of preheater system. Further, for tap to tap times less than 70 minutes, conventional scrap preheating would lead to minimal energy saving and hence the investment towards bucket type preheating system cannot be justified due to very high payback period.

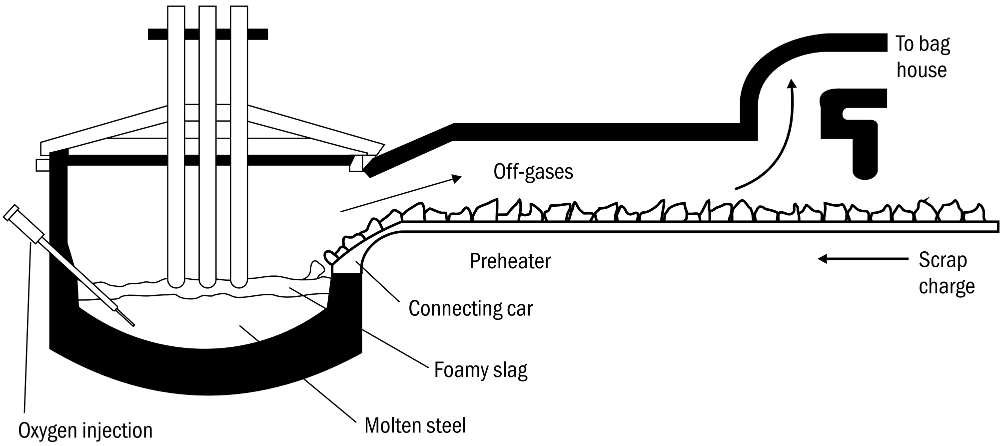
(b) Continuous scrap preheating system

In continuous scrap preheating system, the scrap is put on a conveyor and passed through the preheating section. The off-gases from the EAF are routed through the preheater in a counter flow direction. The preheated scrap fed to the furnace transferred through the conveyor car. Some of the important advantages of this system are:

Bucket type scrap preheater in EAF



Continuous scrap preheating system



Continuous scrap preheating system

Source: http://infohouse.p2ric.org/ref/10/09048.pdf

- Increased productivity
- Low electrode consumption
- Reduced harmonic and flickers
- Reduction in dust generation

Savings, investments, and GHG reduction

The average energy savings with scrap preheating using bucket arrangement is estimated to be about 8%, whereas in a continuous type arrangement it can be as high as 12%. Typically for a 50 tonne furnace, the investment requirement for bucket arrangement is about ₹200 lakh with a simple payback period is about 0.5 year. The GHG emission reduction potential is about 5,900 tonnes of CO_2 per year. The investment required for continuous type scrap preheating system is about ₹400 lakh with a simple payback period of about one year. The GHG emission reduction potential is about 8,860 tonnes of CO_2 per year.

Scrap preheating

Parameter	Unit	Value
Temperature of off-gases	°C	800
Temperature gain by scrap	°C	300
SEC reduction with preheating	kWh/t	41
Annual monetary benefits	₹lakh	268
Investments	₹lakh	200
Payback period	Year	0.7

Source: http://ietd.iipnetwork.org/content/tunnel-furnace-preheating-%E2%80%93-consteel-process

3.4.3 Hot metal charging

Background

Hot metal use is not a common practice among electric arc furnace units in India. A majority of the electric arc furnace units in India use charge materials at ambient temperatures. The units equipped with DRI process along with EAF can charge the hot DRI directly in EAF. The major reason for not using hot metal is improper layout to handle hot charge to feed in the furnace.

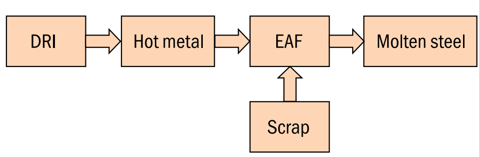
EE technology

Combining a charge of hot metal and scrap to electric arc furnace would help in improving the operating performance of the system. Hot metal with dissolved carbon and silicon is one of the important sources of heat on oxidation. The heat on oxidation along with sensible heat available in hot metal helps in substantial reduction in power consumption of the furnace. Further, hot metal is free of foreign non-metallic materials which would have been removed as slag during iron making process. There is a great potential[16] to charge hot DRI/HBI directly into electric furnaces at a temperature of about 600 °C. However, the EAF units must take care of strong reaction[17] in molten metal due to interactions between oxygen in steel and from lance and carbon in steel, hot metal, and lance. The hot metal can be charged in a controlled manner to take care of carbon content in liquid metal bath.

Different methods used for transfer of hot DRI into EAF include (i) pneumatic transfer, (ii) electro-mechanical conveyor system, (iii) gravity feed and (iv) transport in insulated bottles. Pneumatic and electro-mechanical transfers would require minimum transportation and hence DRI reactors must be located adjacent to EAF. Gravity feed system would also require closer distance between DRI and EAF, and will be elevated at about 20–30 m. The bottle transfer allows more distances compared to others as these are insulated systems. Charging of hot metal can be done in two locations namely, through roof or slag door.

It has been established that hot metal charge[18] of 30–40% is more suitable for electric arc furnaces. Hot metal charging up to 50% has been successfully used in some of the EAFs. However, hot metal charging of more than 50% would result in operational problems as excessive heat is generated through oxidation of elements, such as carbon, manganese and silicon, which can lead to overheating of the furnaces. The

Hot metal charging in EAF



major benefits associated with hot metal charging in EAF include:

- Enhanced productivity
- Improved slag foaming
- Increased carbon content in the charge

Savings, investments, and GHG reduction

The energy savings for hot DRI charging depends largely on the share of DRI in input feed. Typically, furnaces with 50% DRI charging, the energy saving potential is about 150 kWh per tonne of liquid metal, considering a hot DRI temperature of 600 °C. The GHG emission reduction potential is about 22,140 tonnes of CO_2 per year.

3.5 Auxiliary system

The auxiliary system associated with an electric arc furnace unit includes (i) fumes extraction system and (ii) cooling water system. The energy efficiency options in auxiliaries include (1) variable frequency drive for primary ID fan, (2) intelligent control for off-gas cooling, (3) FRP blade for cooling tower fans, (4) thermostatic controller for cooling tower and (5) EE centrifugal pumps.

3.5.1 Variable frequency drives in ID fans

Background

The off-gases generated from various reactions inside EAF are removed from the EAF using a fumes extraction system, which is typically equipped with a high power ID fan. The load on ID fan depends on the operating condition of the furnace. It will be maximum during 'power-ON' period (i.e., arcing) and comes to low during 'power-OFF' period. The power-OFF period generally includes raw material charging, de-slagging, sampling, charge adjustments and un-scheduled outages. The power-OFF period is about 20–30% of the overall operating duration of EAF.

EE technology

The power drawn by the ID fan during power-ON&OFF period is typically same. During the power-OFF duration the speed of ID fan can be reduced to minimum using variable frequency drive (VFD). The use of VFD is generally recommended along with feedback control linked to operation of the furnace. Upon sensing the power conditions of the furnace, the VFD would change the speed (high or low) of the ID fan based on pre-set parameters. Typically with VFD operation, the ID fan is operated at full speed during power-ON period and at about 15-30% of the design speed during power-OFF.

Savings, investments, and GHG reduction

The typical energy savings with VFD application on ID fan of primary fumes extraction system is estimated to be about 10%. Typically for a 50 tonne furnace, the investment requirement is about ₹7.5 lakh with simple payback period of about one year. The GHG emission reduction potential is about 120 tonnes of CO_2 per year.

An EAF unit in India installed variable frequency drive (VFD) on the primary ID fan (400 kW) of fumes extraction system. The VFD system was set to operate the ID fan at 85% of the rated speed (rpm) during power-ON and at 30% during power-OFF. This has helped the EAF unit to bring down the energy consumption in the primary ID fan by about 11%.

VFD application in ID fan

Parameter	Unit	Fixed speed	Variable speed
Power consumption during power- ON	kW	196	196
Power consumption during power-OFF	kW	196	68
Duration of power-OFF	min	17	17
Power consumption per heat	kWh/t	9.15	8.11
Annual monetary benefits	₹lakh	-	7.5
Investment	₹lakh	-	7.5
Simple payback period	Years	-	1

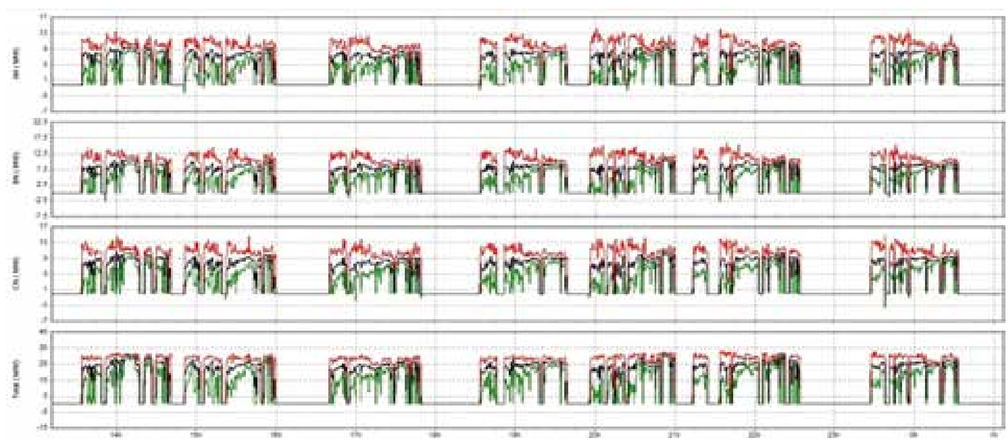
Source: TERI energy audit study in EAF unit, 2016

3.5.2 Intelligent control for off-gas cleaning

Background

Off-gas cleaning is an integral part of EAF operation which however remains as a neglected auxiliary

A sample of loading pattern of EAF



Source: TERI energy audit study in EAF unit, 2016 system. It is often less efficient and offers significant potential for improvement. The gas cleaning is an important aspect in terms of complying with environmental performance standards as applicable.

EE technology

A gas cleaning system in an EAF comprises a number of extraction points from where the off-gases are sucked. In a gas cleaning with intelligent control[19], the system is mapped in mathematical model and loaded into the control unit. The model evaluates required flap settings and flow rates in individual network segments in real time and controls dynamically. The monitoring arrangement at an extraction point will ensure that the flow rate of off-gases do not fall below a certain minimum level, independent of flow rates required at other extraction points. The monitoring function of the control system ensures reliability in long-term planning for operation and servicing of the system.

Savings, investments, and GHG reduction

The typical energy savings with adoption of intelligent control for off-gas cooling is estimated to be about 20% of the fumes extraction system. Typically for a 50 tonne furnace, the saving is in tune of 1–1.5 kWh per tonne of liquid metal. The GHG emission reduction potential is about 210 tonnes of CO_2 per year.

3.5.3 FRP blades for cooling tower fans

Background

The sidewalls, roof, and electrodes of the EAF are water cooled in order to protect the furnace system. The water from cooling tower outlet is pumped to various sections of the electric arc furnace to maintain the temperature. Metal blades (aluminium) are commonly used in cooling tower fans. The metal blades increase the overall weight of the cooling system leading to additional power consumption.

EE technology

The metal blades in cooling tower fan can be replaced with 'fibre reinforced plastic' (FRP) blades, which are lighter. Use of FRP blades would reduce the power consumption of cooling tower system. It further increases the possibility of de-rating or re-sizing the motor capacity of cooling tower fan to a lower sized motor. The other advantages of FRP blade include high reliability and better performance due to lower failure rate.

Savings, investments, and GHG reduction

The typical energy savings with use of FRP fan blades in cooling towers is about 15–25%. Typically for a cooling tower of 1.5 lakh kCal capacity, the energy

FRP fan blades

FRP blades for cooling tower fan

Parameter	Unit	Metal blade	FRP blade
Rated capacity	kW	37.0	22.4
Input power	kW	26.3	19.7
Annual monetary saving	₹lakh	—	2.0
Investment	₹lakh	—	1.6
Simple payback period	Year	—	0.8

Source: TERI energy audit study in EAF unit, 2016 savings is in tune of 0.2 kWh per tonne of liquid metal. The GHG emission reduction potential is about 40 tonnes of CO_2 per year.

3.5.4 Thermostatic controller for cooling tower

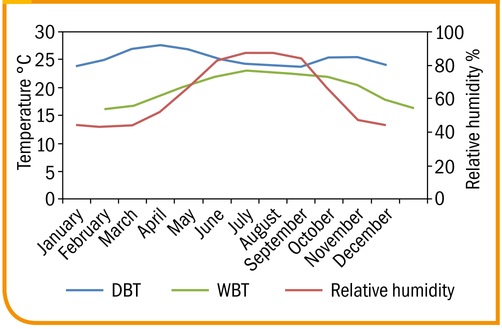
Background

The main function of a cooling tower is to reduce the temperature of incoming water based on wet bulb temperature and relative humidity of ambient conditions. A majority of the cooling towers are not equipped with automatic controls to regulate the fan operation. A few units control the cooling tower operations manually based on outlet temperatures of cooling water. The seasonal variations in ambient temperatures and relative humidity show that the cooling tower requires continuous monitoring of temperatures for effective operation. The maximum possible drop in temperature of cooling water is limited to the wet bulb temperature of the ambient conditions.

EE technology

In place of manual operation, automatic controls are preferred. The most common system used in cooling towers is thermostatic controller. It senses the outlet temperature of the cooling water. The controller switches-on or off the fan automatically based on prevailing level of cooling water temperature.

Seasonal variations in ambient conditions (A location from Western India)



Savings, investments, and GHG reduction

The typical energy savings with installation of thermostatic controllers in cooling water circuit is about 5–10% depending on geographical location. Typically for a cooling tower of 1.5 lakh kCal capacity, the energy saving is in tune of 0.1 kWh per tonne of liquid metal. The GHG emission reduction potential is about 20 tonnes of CO_2 per year.

3.5.5 Energy-efficient centrifugal pump

Background

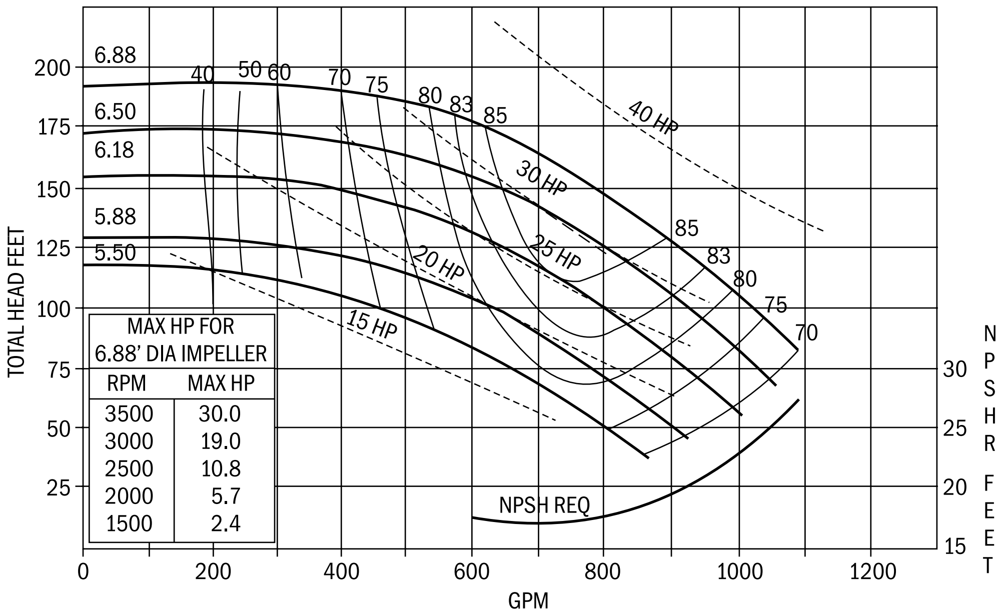
The cooling water system for an electric arc furnace requires pumping for rejecting the heat gained from the EAF operations. Pumps are also used in jacket cooling in primary fumes extraction system. Typically the efficiency of the pumps used in cooling water circuit are lower, in the range of 40–60%. Improvements in energy efficiency of the pumps would help in reducing the overall energy consumption in auxiliary systems.

EE technology

The design of an efficient pumping system depends on a number of factors including water flow rate, piping layout, control techniques, and pump selection. Centrifugal pumps deliver high flow rates, provide smooth and non-pulsating delivery, and regulate flow rate over a wide range. These pumps are compact and can be easily disassembled for maintenance purposes. With a few moving parts, the wear caused by normal operation is minimal in centrifugal pump.

Selection of an energy-efficient pump is based on performance curves. By keeping the operation close to the 'best efficiency point' (BEP), a pump can be operated efficiently while meeting the requirements such as flow rate and head for a particular type of pump and impeller size. To minimize energy consumption, the pump should be selected in such a manner that the system

Characteristic curves for centrifugal pumps



curve intersects the pump curve within 20% of its BEP. The pump impeller should be selected in the mid operating range. The impellers can be further trimmed or replaced to meet the required flow rates.

Savings, investments, and GHG reduction

The typical energy savings with use of EE pumps in cooling water system is about 15–25%. Typically for a 100 hp pump, circulating cooling water to a 50 tonne EAF, the energy saving potential is about 0.5–1 kWh per tonne of liquid metal. The investment requirement is about ₹5 lakh with a simple payback period of 6 months. The GHG emission reduction potential is about 90 tonnes of CO_2 per year.

Energy efficient pump

Parameter	Unit	Existing	EE pump
Flow rate	m^3/h	338	340
Head	m	45	45
Input power	kW	76	56
Pump efficiency	%	54	75
Annual monetary saving	₹lakh	-	8
Investment	₹lakh	-	5
Simple payback period	Year	-	0.6

Source: TERI energy audit study in EAF unit, 2016

3.6 Future technology options

Some of the technologies which are either commercially available or under demonstration in developed countries which can be adopted in EAF sector in India include (1) shaft furnace, (2) DC arc furnace, (3) bottom stirring – electro-magnetic system, (4) single bucket charging, (5) tapper shell furnace, and (6) neural network for process control.

3.6.1 Shaft furnace

Background

Scrap preheating is an important technology for improving the energy performance of an EAF. Typically, scrap preheating is either not in use or a bucket preheating arrangement is used. With this arrangement the improvement in energy efficiency is limited.

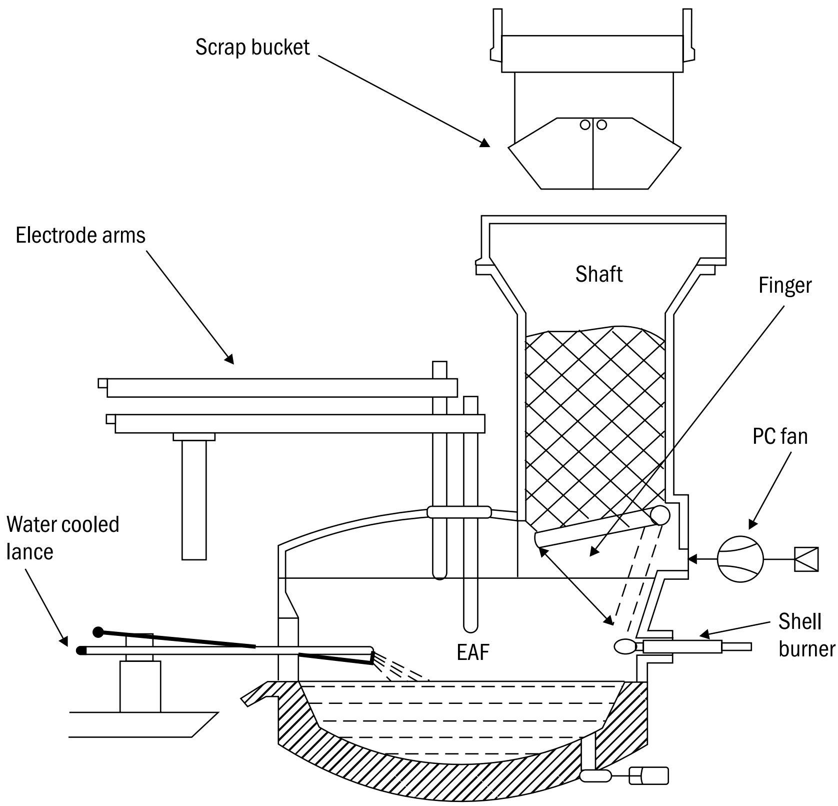
EE technology

Shaft furnace is an alternative to the bucket system, which helps in addressing the issues associated with bucket preheating system, thereby achieving higher heat recovery and hence improved efficiency of EAF system. In a shaft furnace, the preheating arrangement is mounted over the arc furnace itself. Different types of shaft furnaces are used in EAFs include (i) single shaft furnace, (ii) double shaft furnace, and (iii) finger shaft furnace.

A single shaft furnace can handle 50% of the scrap for preheating. A double shaft furnace is an improvement to the single shaft furnace, which consists of two identical shaft furnaces, having twin shell arrangement. A single set of electrode arms caters to the requirements of both the shafts.

The most efficient shaft-furnace design is the 'finger shaft furnace'. The scrap is charged into the furnace through the shaft. Off-gases pass through the shaft and heat the scrap. One of the major advantages with this design is that it has provisions for a scrap retaining system, which increases the efficiency of heat recovery from off-gases. The finger shaft is water cooled to ensure smooth operation. With the availability of scrap retaining system, preheating of the entire scrap can be accomplished effectively. The advantages of finger shaft furnace[20] are the following:

Finger shaft furnace



Source: http://global.kawasaki.com/en/corp/rd/magazine/140/ne140s01.html

- Offers high energy saving compared to other preheating systems
- Increases productivity by about 20%

Savings, investment, and GHG reduction

The average energy savings with finger shaft furnace is estimated to be about 15–20%. Typically for a furnace of 50-tonne capacity, the investment requirement is about ₹2,500 lakh with simple payback period of about 3–4 years. The GHG emission reduction potential is about 11,070 tonnes of CO_2 per year.

3.6.2 DC arc furnace

Background

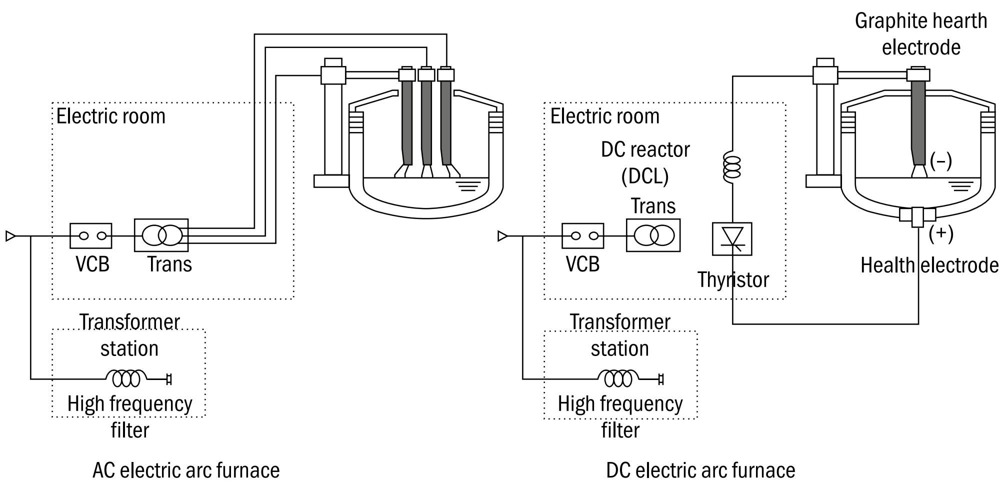
The EAF units in India use AC electric arc furnace. AC arc furnace is characterized by three electrodes, one for each phase. The arc forms between the three electrodes and the melt. AC arc furnaces typically have problems, such as frequent electrode tip breakage and higher radiation loss to side walls due to arcing flash. The consumption of electrode in Indian AC electric arc furnaces varies between 3–6 kg per tonne of liquid melt, which is double the international standards.

EE technology

DC arc furnace is an alternative to the existing AC EAFs, which can reduce the electrode consumption and the refractory damages by arcing flashes. The output of the UHP transformer is converted to DC using a power rectifier usually bridge-connected thyristors. DC furnace has only one electrode which

Parameter	Unit	AC furnace	DC furnace
Electrical losses	%	4.0	5.5
Electrode use			
Tip	kg/t	0.721	0.845
Side	kg/t	0.919	0.398
Breakage	kg/t	0.200	0.100
SEC	kWh/t	410	390

Source: Ben Bowman "Performance comparison between AC and DC furnaces", Steel Times International, Vol. 17 No. 3



Source: Japanese technologies for energy saving/GHG emission reduction, NEDO, 2008 acts as a cathode whereas a return electrode known as anode is at bottom of the furnace for completing the electrical circuit. The major advantages of DC arc furnace over AC arc furnace are as follows:

- High current density and power usage
- Reduction in electrode consumption
- Lower refractory consumption
- Reduction in flickers

The performance comparison of DC and AC arc furnace are as follows: (a) The electrical losses in AC arc furnace are about 4%. The electrical losses in the DC arc furnace are 30–50% higher than AC furnace due to additional reactors and rectifiers in place; (b) The electrode consumption of the DC furnace is substantially lower. The side losses are 1/3rd in DC furnaces as compared to AC furnaces; whereas the breakage loss is only 50%, though there is a slight increase in the tip losses which is primarily due to increase in current; (c) The electrical energy consumption in DC furnace is about 5% less than that of AC furnace for similar capacity.

Shaft arc furnace with DC system: The furnace system consists of EBT lower shell, water-cooled upper shell, and the two identical shafts mounted over the upper shell. The unique design of shaft type DC arc furnace enables uniform pre-heating of the scrap. Water-cooled fingers retain the scrap in the vertical shafts.

Shaft type DC furnace

Parameter	Unit	Value
Furnace rating	t	97
Transformer rating	MVA	78
Oxygen consumption	m^3/t	35.9
Natural gas consumption	m^3/t	6.4
Electricity consumption	kWh/t	280
Investment	₹lakh	2500
Simple payback period	Years	2

Source: Metallurgical Plant and Technology International 2/2016

Savings, investments, and GHG reduction

The average energy savings with DC arc furnace is about 5%. Typically for a furnace of 50-tonne capacity, the investment requirement is about ₹2,500 lakh. The monetary benefits from reduction in consumption of electrodes will be substantial. The simple payback period will be about 2 years. The GHG emission reduction potential is about 3,690 tonnes of CO_2 per year. The saving in shaft type DC arc furnace[21] is estimated to be about 20%.

3.6.3 Bottom stirring – Electromagnetic stirrer

Background

The molten metal in the EAF may not be of homogenous mass or uniform quality throughout the cross-section. As a result, the tap-to-tap time and energy consumption of the furnace would increase. Moreover, it can lead to high rejection level.

EE technology

Bottom stirring of liquid bath in EAF is a potential solution for better homogenization and ensure uniform quality. The electromagnetic stirrer[22] (EMS) is a new generation stirrer arrangement for electric arc furnace. It has a stronger stirring ability and enables to reduce tap-to-tap time in liquid steel production. The stirrer helps in strengthening slag-melt homogenization and increasing yield. The

Electro-magnetic stirrer

Source: ABB

EMS enhances melting of large scraps and reduces stratification as a result of forced convection. The forced convection in the melt is influential in bringing a more homogenous temperature distribution and high melting rate. It leads to increased melt velocity which is almost 10 times higher as compared to natural convection and results in less power-ON time.

Some of the special features of EMS system include (i) low stirring cost, less than 2 kWh per tonne, (ii) low maintenance, and (iii) fully integrated and automated control system. Some of the advantages of electro-magnetic stirrer system are the following:

- Higher productivity
- Higher yield of iron
- Less power on time
- Reduced energy consumption
- Lower consumptions of alloy, lime, refractory, and electrode consumptions.

Savings, investments, and GHG reduction

The average energy savings with electromagnetic based bottom stirring is estimated to be about 5%. Typically for a 50-tonne furnace, the investment requirement is about ₹400 lakh with a simple payback period of about 2 years. The GHG emission reduction potential is about 3,690 tonnes of CO_2 per year.

3.6.4 Single bucket charging system - telescopic roof

Background

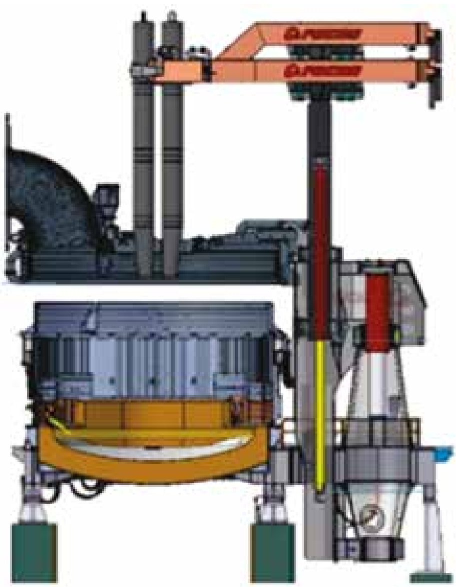
In conventional EAFs, a minimum charge density must be maintained which otherwise would lead to increase in number of bucket charges. This would lead to interruptions in melting process resulting in loss in productivity and poor energy performance. Typically, in Indian EAFs, roughly 10 - 15% time is lost in every heat due to multiple bucket charging.

EE technology

In an EAF with telescopic[23] roof enclosure system, a single bucket system with low charge density can be used without increasing shell diameter and height. The telescopic furnace system allows flexible shell charging volume and the electrode length can be significantly shorter than other single charge type electric arc furnaces of similar capacities. The large distance between top of scrap pile and horizontal portion of the roof allows for initial charge bore down with higher power and larger arcs, thereby increasing average power input.

With the start of scrap melting, the roof along with electrode columns is lowered to follow the reducing height of charge volume. The roof is gradually made to slid down to completely closed position, which leads to overlapping between roof and part of upper shell. The lifting system for roof and electrodes are independent which allows electrodes to continuously track falling height of charge pile. The cycle of telescopic movement between upper

Telescopic roof EAF



Source: https://issuu.com/stahl eisen/docs/int_2016-5 closing position after completion of charging and completely full close position is completed after 30–40% of power-ON time.

The major advantages of single bucket charging system with telescopic arrangement compared to a conventional charging system are as follows:

- Ability to handle low charge density (0.55 tonne per m^3)
- Less tap-to-tap time
- Low power-OFF time
- Lower electrode consumption and breakage

Savings, investments, and GHG reduction

The average energy savings with telescopic roof based single bucket charging system is estimated to be about 10–15%. This type of furnace is presently available for capacity in excess of 100 tonnes. The investment requirement is about ₹3,000 lakh with simple payback period of about 5 years. The GHG emission reduction potential is about 7,380 tonne of CO_2 per year.

3.6.5 Tapered shell furnace

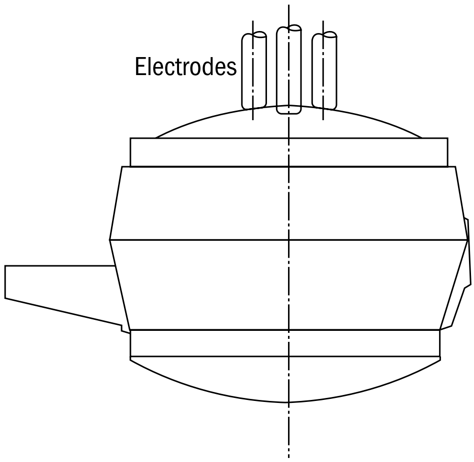
Background

The EAFs have uniform cross-section along the height of the furnace. This would result in hotspots close to side walls leading to reduced lining life of the furnace. It would further increase heat losses to side walls thereby reducing the efficiency of the furnace system.

EE technology

One of the solutions for reducing the hotspots and heat losses to side walls is use of tapered shell design for the furnace. In this design, the furnace volume is increased without increasing the shell height. This is achieved by increasing the shell diameter only midway between sill-line and the top bezel ring. The bezel ring helps in maintaining the shape of the top of the furnace shell. This arrangement is more useful for large capacity furnaces.

Tapered shell furnace



Tapered shell furnace

The associated benefits of tapered shell furnace include:

- Longer life of side wall lining due to larger diameter of the shell at the hotspots
- Reduced heat losses and enhanced heating of the charge material

3.6.6 Neural network for process control

Background

The present control systems for EAF operation through modelling of the dynamic parameters have not yielded optimum results. The existing process control for electrode regulation systems provide energy saving of about 3 per cent. However, there is a further scope for more efficient operation-based on state-of-the-art process control.

EE technology

Recent advancements have led to the use of artificial intelligence-based electrode controllers. Intelligent data processing with neural networks offers a better

Parameter	Unit	Value
Energy saving	kWh/t	20
Electrode saving	kg/t	0.5
Productivity improvement	%	10
Monetary benefit	₹/t	140
Investment	₹lakh	150
Simple payback period	Years	0.5
Source: "The State–of-the-Art Clean Technologies (SOACT) for Steelmaking Handbook", December 2010		

solution for electrode regulation system. These intelligent systems integrate real-time monitoring of process variables, such as liquid metal temperature, carbon percentages, and oxygen lanceing practices.

Savings, investments, and GHG reduction

The average energy savings with neural networks-based electric arc furnace electrode regulation system is estimated to be about 3–5%. Typically for a furnace of 50-tonne capacity, the investment requirement is about ₹150 lakh with simple payback period of about 6 months. The GHG emission reduction potential is about 2,950 tonnes of CO_2 per year.

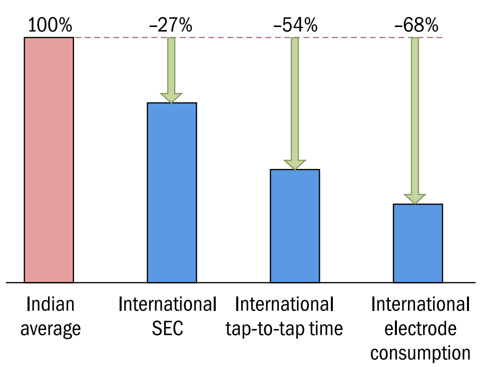
4 SUMMARY OF ENERGY EFFICIENT TECHNOLOGY PACKAGES

Summary of Energy Efficient Technology Packages

The production of iron & steel is highly energy intensive. The secondary sector forms an important link to the overall steel production chain in India. The share of steel production from electric arc furnace (EAF) route is close to 28%. A typical EAF unit uses scrap or mix of scrap and sponge iron (DRI) as the raw material and manufacturers billets or bars. In line with Intended Nationally Determined Contributions (INDC) in iron & steel sector, the CO_2 reduction target for DRI-EAF is 2.6 –2.7 tonnes per tonne of crude steel by the terminal year of 2030. For achieving GHG emission reduction targets, the EAF sector requires consistent efforts to improve energy performance through adoption of EE technologies and best practices. Moreover, the Indian EAF sector should further explore adoption of state-of-art technologies to substantially bring down the energy intensity.

The key performance indicators (KPI) showcasing the operating performance of the EAF include: (i) specific energy consumption (SEC), (ii) tap-to-tap time (TTT), and (iii) electrode consumption. A comparison of Indian EAF sector with the international KPIs of EAF shows a vast potential for improving the performance. The average SEC of the Indian EAFs is about 480 kWh per tonne of liquid metal (410–770) whereas the SEC of international EAFs is about 350 kWh per tonne. The average TTT of EAFs in India is 110 minutes per heat (90–150) against an international average of 50 minutes. The average electrode consumption in Indian EAFs is about 3.5 kg per tonne of liquid metal (2.8–6) and the international consumption level is about 1.1 kg. The improvements in performance at the international level have been achieved through constant innovation and upgradation in technology and practices.

Key performance indicators of EAFs (India vs International)



The technology compendium on "*Energy efficient technology packages on electric arc furnace*" focusses on energy efficient (EE) technologies and best practices pertaining to electric arc furnace (EAF) and its associated auxiliaries that are relevant for Indian EAF sector. The compendium has been prepared by TERI based on detailed energy audits of representative EAF units, scouting of energy efficiency interventions at national and international levels and stakeholder consultations. The identified EE technology packages for Indian EAF sector are categorized into (1) furnace design, (2) furnace operation and practices, (3) charge management, (4) auxiliary systems and (5) future technology options.

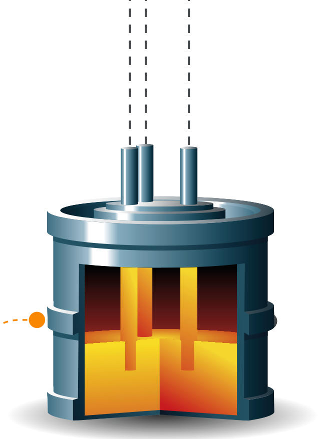
The typical investment, payback and GHG emission reduction potential of EE technologies applicable for a 50-tonne capacity EAF unit with an estimated production of about two lakh tonnes liquid metal per year are summarized below. The payback periods for different EE technologies and practices vary between 'immediate' to 3 years.

Summary of Energy Efficient Technology Packages				
S. No.	**EET packages**	**Investment (₹lakh)**	**Simple payback (Year)**	**GHG emission reduction (tCO_2/year)**
Furnace design				
1	Ultra high power transformer	400	2.0	3,690
2	High impedance operation	170	3.0	738
3	Aluminium electrode arm	70	1.5	517
4	Improved regulation control	75	0.5	2214
5	Oxy-fuel burner	400	2.0	2214
6	Coherent jet	300	2.5	1476
Furnace operation and practices				
7	Bottom stirring – Inert gas purging	10	Immediate	2,214
8	Foamy slag practices	—	Immediate	1,107
9	Use of chemical energy	—	Immediate	738
10	Mist cooling for electrodes	—	Immediate	738
11	Water cooled electrical cables	20	2.0	111
12	Copper water cooling panel	NA†	NA†	NA†
13	Improved refractories	—	Immediate	148
14	N_2 as carrier in Al-mix injector	—	Immediate	148
15	WHR for boiler feed water	10	0.2	1,510
Charge management				
16	Scrap processing	350	1.0	5,166
17a	Scrap preheating - bucket system	200	0.5	5,904
17b	Scrap preheating - continuous	400	1.0	8,856
18	Hot metal charging	NA†	—	22,140
Auxiliary systems				
19	VFD for primary ID fan	7.5	1.0	119
20	Intelligent control for gas cooling	NA†	—	205
21	FRP blades for cooling tower	2.0	0.5	39
22	Thermostatic controller for CT	0.2	Immediate	22
23	EE centrifugal pumps	5.0	0.5	93
Future technology options				
24	Shaft furnace	2500	3.0	11,070
25	DC arc furnace	2500	2.0	3,690
26	Bottom stirring – Electro magnetic	400	2.0	3,690
27	Single bucket charging system	3000	4.0	7,380
28	Tapper shell furnace	NA†	NA†	NA†
29	Neural network: Process control	150	0.5	2,952
† Not Available				

There is a huge potential for the Indian EAFs to upgrade their technologies and adopt best practices that would help in reducing the energy intensity of the sector. Some of the important technology options readily available to the sector include the following. The off-gas heat is not utilized by EAFs in India. Scrap preheating has been identified as one of the best technology options for recovering waste heat from off-gases. Based on the type of scrap preheating technology adopted, the energy saving in EAFs can vary from 8–14 %. The installation of oxy-fuel burners with coherent jet technology will be a significant step for the EAF units to address the problem of cold spots in melting process and achieve energy saving of the order of 3–8%. A shift from the existing analog type electrode regulation to digital system would help in close monitoring and control of furnace operations leading to an energy saving of about 3–5%. Foamy slag, a proven approach to reduce electrode and refractory consumption levels is not fully utilized at present by the Indian industries. Enhanced foamy slag practice would result in about 1–3% energy saving.

There is a considerable gap in technology status between Indian and international EAFs. To bridge this gap, Indian EAFs must adopt state-of-the-art technologies. A few proven state-of-the-art technologies are as follows. Finger shaft furnace provides an integrated solution for the most efficient melting in EAFs with an SEC level of about 280 kWh per tonne of liquid metal. A close control of furnace operating parameters can be achieved through adoption of neural networks based artificial intelligence. This can provide energy saving of 3–5%. The higher consumption levels of electrodes in Indian EAFs and the steady increase in its price can be looked as a motivation to shift towards DC type EAFs, which would result in up to 50% saving in electrode consumption. Achieving homogeneity in liquid metal is a key for maintaining quality of value-added products. One of the latest developments towards this is electromagnetic system for bottom stirring application.

This technology compendium provides a range of EE technologies and best practices applicable for the Indian EAFs. The industry will be able to choose and implement the technologies based on investment required and benefits. A detailed vendors' list for various EE technologies is provided in the compendium as a ready reference.



Annexure: Energy Efficient Technology Vendors

The energy performance improvement in EAF sector would require substantial modifications and adoption of state-of-the-art technologies that are commercially available either in India or at global level. A set of technology vendors providing services pertaining to various aspects of energy efficiency in electric arc furnace and the associated auxiliary systems is provided below.

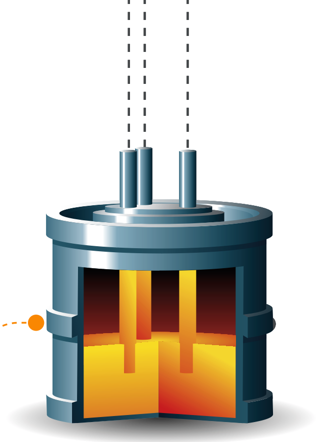
Vendor	**Contact details**
Ultra high power transformer	
ABB India Limited	ABB Ahmedabad office;5th Floor, A-6 Safal Profitaire, Corporate Road, Ahmedabad, Gujarat Tel: +91 96 2436 0600
GE India Industrial Pvt. Ltd.	5th Floor, Building No.7A, DLF Cyber City, DLF Phase-III, Sector 25 A, Gurugram, Haryana – 122002 Tel: (0124) 4808000 Fax: (0124) 4226911 / 4226912
Electrotherm India Limited	Survey No. 72, Village Palodia, Taluka Kalol Palodia, Ahmedabad - 382115, Gujarat, India
High impedance system	
GE India Industrial Pvt. Ltd.	5th Floor, Building No.7A, DLF Cyber City, DLF Phase-III, Sector 25 A, Gurugram, Haryana – 122002 Tel: (0124) 4808000 Fax: (0124) 4226911 / 4226912
SHOO-IN Holding Xi'an Equipment Co. Ltd.	No.1802 Oak Star Building B, Keji Five Road, High-Tech District, Xi'an, Shaanxi, China (710065) Tel: (86 29) 87306978 Fax: (86 29) 87306979
Electrotherm India Limited	Survey No. 72, Village Palodia, Taluka Kalol Palodia, Ahmedabad - 382115, Gujarat, India
Aluminium electrode arm	
Flohe Gmbh & Co. Kg	Rheinstraße 1944579 Castrop-Rauxel, Germany Tel: +49 2305 7003 - 0 Fax:+49 2305 7003 - 199 Email: info@flohe.com Website: www.flohe.com

Vendor	Contact details
Flohe linkwel power pvt.ltd.	Jivdani Industrial Estate No -II Dhumal Nagar , Unique Industrial Complex, Valiv , Vasai (East), Pin :401208. Email: sales@flohe-linkwel.com Email: surendra.chaudhary@flohe-linkwel.com Website: www.flohe-linkwel.com
Improvement of regulation control	
Primemetals Technologies India Pvt. Ltd.	Godrej Waterside, Tower No. 2, Unit Nos. 706. 7th Floor Plot-5, Block DP, Sector - V, Salt lake City, Kolkata - 700091, West Bengal Email: suman.mukherjee@primetals.com Tel: 033-66291133, Fax: 033-66291300
Siemens India Ltd	Registered & Corporate Office Birla Aurora, Level 21, Plot No. 1080, Dr. Annie Besant Road, Worli, Mumbai – 400030, Maharashtra Tel: 022-39677000
ABB India Limited	ABB Ahmedabad office;5th Floor, A-6 Safal Profitaire, Corporate Road, Ahmedabad, Gujarat Tel: +91 96 2436 0600
Oxy fuel burner	
Linde Engineering India Pvt. Ltd.	'Linde House' Opp. VUDA office VIP Road Karelibaug Vadodara 390018, Gujarat Tel: +91.265.3056789 Fax: +91.265.2461757 Email: india@linde-le.com Website: www.linde-engineering.in
Praxair India Private Limited	Mercury 2B Block, 6th. Floor, Prestige Technology Park, Outer Ring Road, Marathahalli, Bengaluru – 560 103, Karnataka Tel: +91 80 3069 1000 - 03 Fax:: +91 80 2844 0156
Nikko systems pvt. Ltd.	A-004, E/2 Highway Park Thakur Complex Kandivli (East) Mumbai - 400 101, Maharashtra Tel: +91-22 28544507 / 28548508 Fax: +91-22 28544509 Email: nikkoind@gmail.com Website: www.nikkoindia.com
Coherent jet	
Praxair India Private Limited	Mercury 2B Block, 6th. Floor, Prestige Technology Park, Outer Ring Road, Marathahalli, Bengaluru – 560 103, Karnataka Tel: +91 80 3069 1000 - 03 Fax: +91 80 2844 0156
Water cooled electric cables	
Southwire Company, LLC	567 Miller Road, Avon Lake, OH 44012-2304 USA Tel: 800-311-8515 email: sales@watteredge.com

Vendor	Contact details
B. B. Electrotechnic	Unit No. G3, N. J. Industrial Estate, Chinchpada, Gokhivire Village, Vasai Road East, Thane - 401208, Maharashtra Tel: 91-250-6458831 / 91-250-6458832
Bottom stirring: Electromagnetic stirring	
ABB India Limited	Luxembourg Branch Route d'Arlon 19-21 Serenity Building Building C, First Floor L-8009 Strassen
Improved refractories	
National Refractories	Vishwakarma Building, SW block, 2nd Floor, 86C Topsia Road. Kolkata-700046, West Bengal Tel: 033-40049801, Email: akc@bmaind.com
Tata Krosaki Refractories Limited	Belpahar Jharsuguda Odisha Tel: 06645-250243/ 258429/258571 Email: hs@trlkrosaki.com/pkn@trlkrosaki.com Website: www.trlkrosaki.com
Ace Refractories	Marketing office Delhi 207, 2nd Floor, New Delhi House,27 Barakhamba Road, New Delhi-110001 Tel : 011-41571131 Email: india@calderys.com Website: www.calderys.co.in
Scrap preheating	
Nikko Systems Pvt. Ltd.	A-004, E/2 Highway Park Thakur Complex Kandivli (East) Mumbai-400 101, Maharashtra Tel: +91-22 28544507 / 28548508 Fax: +91-22 28544509 Email: nikkoind@gmail.com Website: www.nikkoindia.com
Nippon Steel & Sumikin Engineering Co. Ltd.	Osaki Center Building, 1-5-1 Osaki, Shinagawa-ku, Tokyo 141-8604 Japan Tel: +81-3-6665-2000 2nd Floor, Salcon Rasvilas, Saket District Centre, New Delhi - 110017, India Tel: +91-11-4947-8965/8900 Fax: +91-11-4947-8955
Scrap processing	
Primemetals Technologies India Pvt. Ltd.	Godrej Waterside, Tower No. 2, Unit Nos. 706. 7th Floor Plot-5, Block DP, Sector - V, Salt lake City, Kolkata - 700091, West Bengal Email: suman.mukherjee@primetals.com Tel: 033-66291133 Fax: 033-66291300

Vendor	**Contact details**
Nippon Steel & Sumikin Engineering Co. Ltd.	Osaki Center Building, 1-5-1 Osaki, Shinagawa-ku, Tokyo 141-8604 Japan Tel: +81-3-6665-2000 2nd Floor, Salcon Rasvilas, Saket District Centre, New Delhi - 110017, India Tel: +91-11-4947-8965/8900 Fax: +91-11-4947-8955
Variable frequency drives	
ABB India Limited	ABB Ahmedabad office;5th Floor, A-6 Safal Profitaire, Corporate Road, Ahmedabad, Gujarat Tel: +91 96 2436 0600
Siemens India Ltd	Registered & Corporate Office Birla Aurora, Level 21, Plot No. 1080, Dr. Annie Besant Road, Worli, Mumbai – 400030, Maharashtra Tel:: 022-39677000
Energy efficient pump	
KSB pumps limited	KSB Pumps Ltd., KSB House, A-96, Sector IV Dist. Gautam Budh Nagar, Noida 201 301, Uttar Pradesh Tel: +91 120 2541 091 Fax: +91 120 2550 567
Kirloskar Brothers Limited	M-11, 3rd Floor, Middle Circle, Connaught Place, New Delhi - 110 001 Tel: 011 – 41501056 Email: delhi@kbl.co.in
Grundfos Pumps India Pvt. Ltd	118 Rajiv Gandhi Salai, Thoraipakkam, Chennai-600 09, Tamil Nadu Tel. +91 44 4596 6800 Fax +91 44 4596 6969 Toll Free: 1800 345 4555 Email: salesindia@grundfos.com
Cooling tower fan control	
Delta cooling towers p. Ltd.	1st Floor, Bhagwati Sadan, Plot no. 8, Community Centre, BH Block, Shalimar Bagh, Delhi-110088 Tel : +91-11-27495801 / 27495802 / 27495803 Fax : +91-11-27495804 Email : delta@deltactowers.com/delta@nde.vsnl.net.in
Fibre Reinforced Plastic (FRP) fan blades	
Delta cooling towers p. Ltd.	1st Floor, Bhagwati Sadan, Plot no. 8, Community Centre, BH Block, Shalimar Bagh, Delhi-110088 Tel : +91-11-27495801 / 27495802 / 27495803 Fax : +91-11-27495804 Email : delta@deltactowers.com/delta@nde.vsnl.net.in

Vendor	Contact details
Paharpur Cooling Towers Ltd.	Paharpur House 41 Cunningham Road Cross, Bengaluru - 560052, Karnataka Tel: +91-80-2226 5566-7, +91-80-2234 1911 Email: pctblr@paharpur.com
Himgiri cooling tower	2/320, Mahesh Industrial Estate, Opp Silver Park, Mira Road (East), Mumbai, Maharashtra Tel: 02228110937 / 02228118581 Email: yash.bhuva@himgiricooling.com
Shaft furnace	
Inteco Melting And Casting Technologies Gmbh	Wienerstrasse 25 A-8600 Bruck a.d. Mur, Austria Tel: +43 (0)3862 53110 0, Fax: +43 (0)3862 53844 Email: inteco.austria@inteco.at
Primemetals Technologies India Pvt. Ltd.	Godrej Waterside, Tower No. 2, Unit Nos. 706. 7th Floor Plot-5, Block DP, Sector - V, Salt lake City, Kolkata - 700091, West Bengal Email: suman.mukherjee@primetals.com Tel: 033-66291133 Fax: 033-66291300
Siemens Aktiengesellschaft	Werner-von-Siemens-Straße 1 80333 Munich Germany Tel: +49 89 636-00 Fax: +49 69 6682-6664
DC arc furnace	
ABB India Limited	Luxembourg Branch Route d'Arlon 19-21 Serenity Building Building C, First Floor L-8009 Strassen
Tapered shell furnace	
ABB India Limited	Luxembourg Branch, Route d'Arlon 19-21 Serenity Building Building C, First Floor L-8009 Strassen
Copper water cooling panels	
GE India Industrial Pvt. Ltd.	5th Floor, Building No.7A, DLF Cyber City, DLF Phase-III, Sector 25 A, Gurugram – 122002, Haryana Tel: (0124) 4808000 Fax: (0124) 4226911 / 4226912
Neural network for process control	
Primemetals Technologies India Pvt. Ltd.	Godrej Waterside, Tower No. 2, Unit Nos. 706. 7th Floor Plot-5, Block DP, Sector - V, Salt lake City, Kolkata - 700091, West Bengal Email: suman.mukherjee@primetals.com Tel: 033-66291133 Fax: 033-66291300



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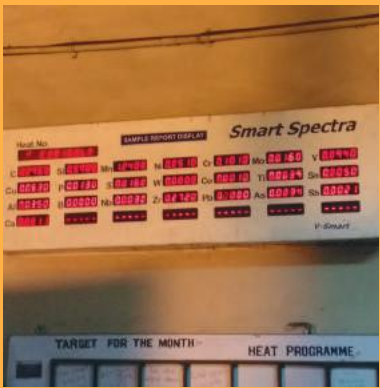
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