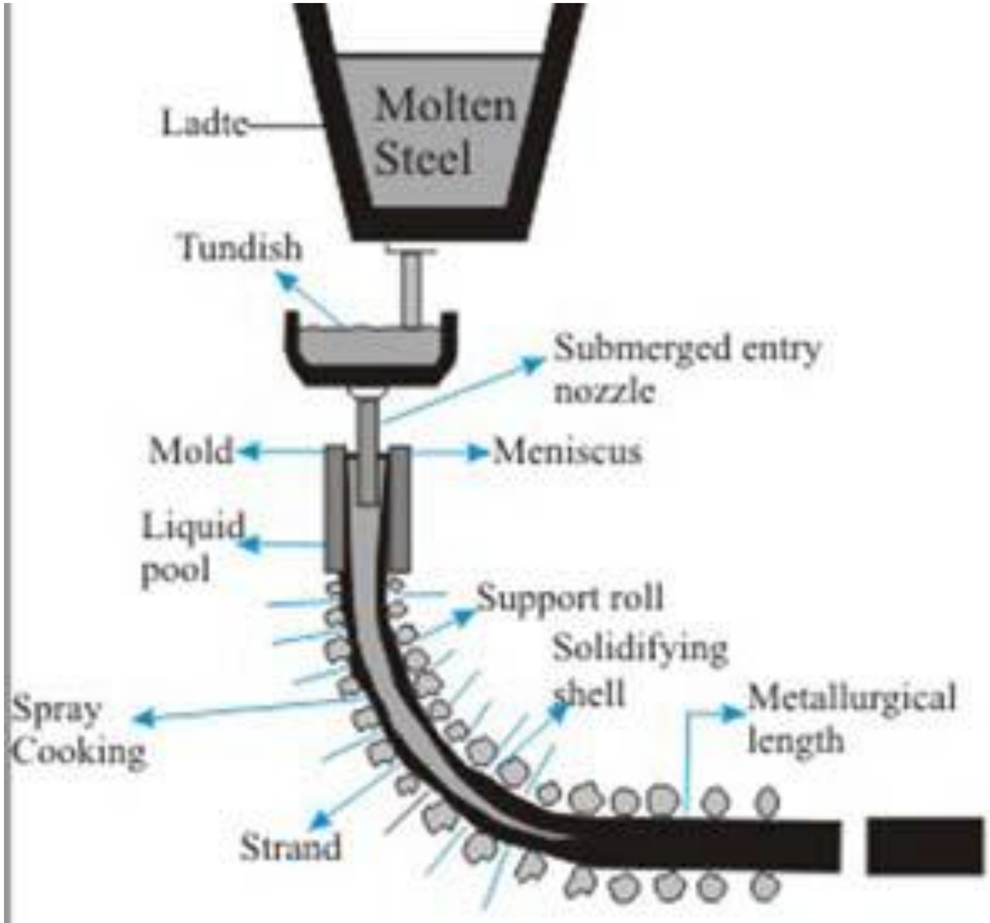
CONTINUOUS CASTING OF STEEL

- **Introduction**
- In the continuous casting, molten steel is poured from the tundish in the water cooled mold and partially solidified bloom/billet or slab (hereafter called strand) is withdrawn from the bottom of the mold into water spray so that solidified bloom/billet or slab is produced constantly and continuously.
- Continuous casting is widely adopted by steelmakers. The advantages of continuous casting over ingot casting are

- Quality of the cast product is better
- No need to have slabbing/blooming or billet mill as required when ingot casting is used.
- Higher extent of automation is possible
- Width of the slab can be adjusted with the downstream strip mill.
- Continuously cast products show less segregation.
- Hot direct charging of the cast product for rolling is possible which leads to energy saving.

HOW CASTING IS DONE CONTINUOUSLY?

- The essential components of a continuous casting machine are tundish, water cooled mold, water spray and torch cutters.
- Tundish, mold and water spray are arranged such that molten stream is poured from tundish to mold and solidified strand (billet/bloom/billet) is produced continuously.
- The required length of the strand is cut by torch cutter. In figure, the arrangement of tundish, mold and water spray is shown.


Ladte
Molten Steel
Tundish
Submerged entry nozzle
Mold
Meniscus
Liquid pool
Support roll
Solidifying shell
Spray Cooking
Metallurgical length
Strand

Curved

- *Tundish*
- Tundish is a refractory lined vessel. Liquid steel is usually tapped from ladle into tundish. The stream is shrouded as it enters from ladle to tundish. The functions of the tundish are:

RESERVOIR OF MOLTEN STEEL

- Tundish acts as a reservoir for molten steel. It supplies molten steel in presence of a slag cover to all continuous casting molds constantly and continuously at constant steel flow rate.
- The flow rate is maintained constant by maintaining a constant steel bath height in the tundish through teeming of molten steel from the ladle.

- The number of mold is either one or more than one.
- Normally bloom and billet casting machines are multi-strand i.e. number of molds are either 4 or 6 or 8. Slab casters usually have either single or two molds.
- During sequence casting and ladle change- over periods, tundish supplies molten steel to the molds.

DISTRIBUTOR

- Tundish distributes molten steel to different molds of the continuous casting machine at constant flow rant and superheat which is required for stand similarly with reference to solidification microstructure.
- Control of superheat is required in all the moulds to reduce break-out.

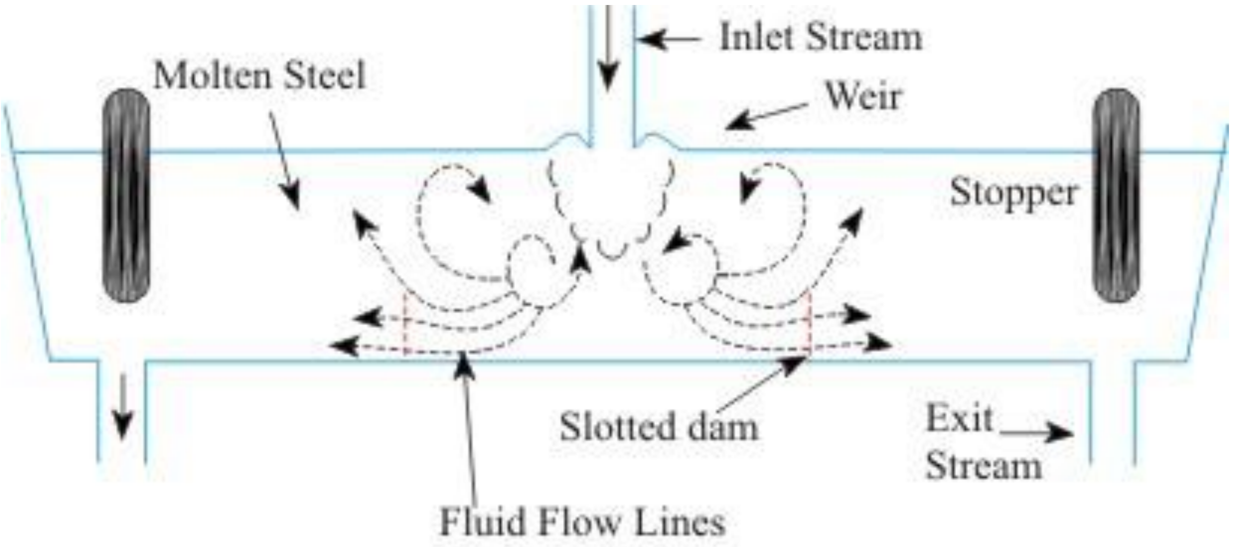
- Location of ladles stream in the tundish is important.
- It may be located symmetric or asymmetric to the centre of the tundish depending on the number of mold.
- For single strand machines, molten stream enters from one side and exits the other side of the tundish.
- In multi-strand tundishes, ladle stream is either at the centre of the tundish or displaced to the width side of the tundish.

INCLUSION REMOVAL

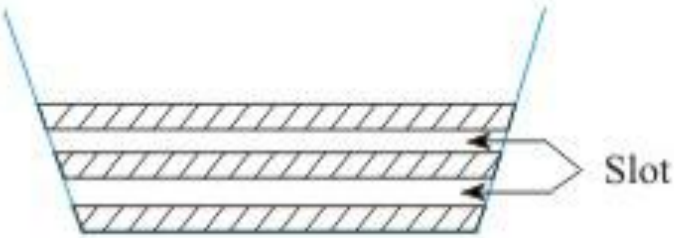
- Tundish helps to remove inclusions during the process of continuous casting.
- For this purpose liquid steel flow in the tundish is modified by inserting dams, weirs, slotted dams etc.
- The whole idea is to utilize the residence time available before steel leaves the tundish.

- For example, if capacity of tundish is 40 tons and casting speed is 5 tons/min, then the average residence time of molten steel in the tundish is 8 minutes.
- During this average residence time., inclusion removal can be exercised .

- For this purpose flow of steel melt in the tundish has to be modified so as to accelerate the inclusion removal.
- The Inclusion removal is a two step step unit operation, namely floatation and absorption by a flux added on the surface of the tundish.
- Flux is usually rice husk, or fly ash or some synthetic powder.



(a)



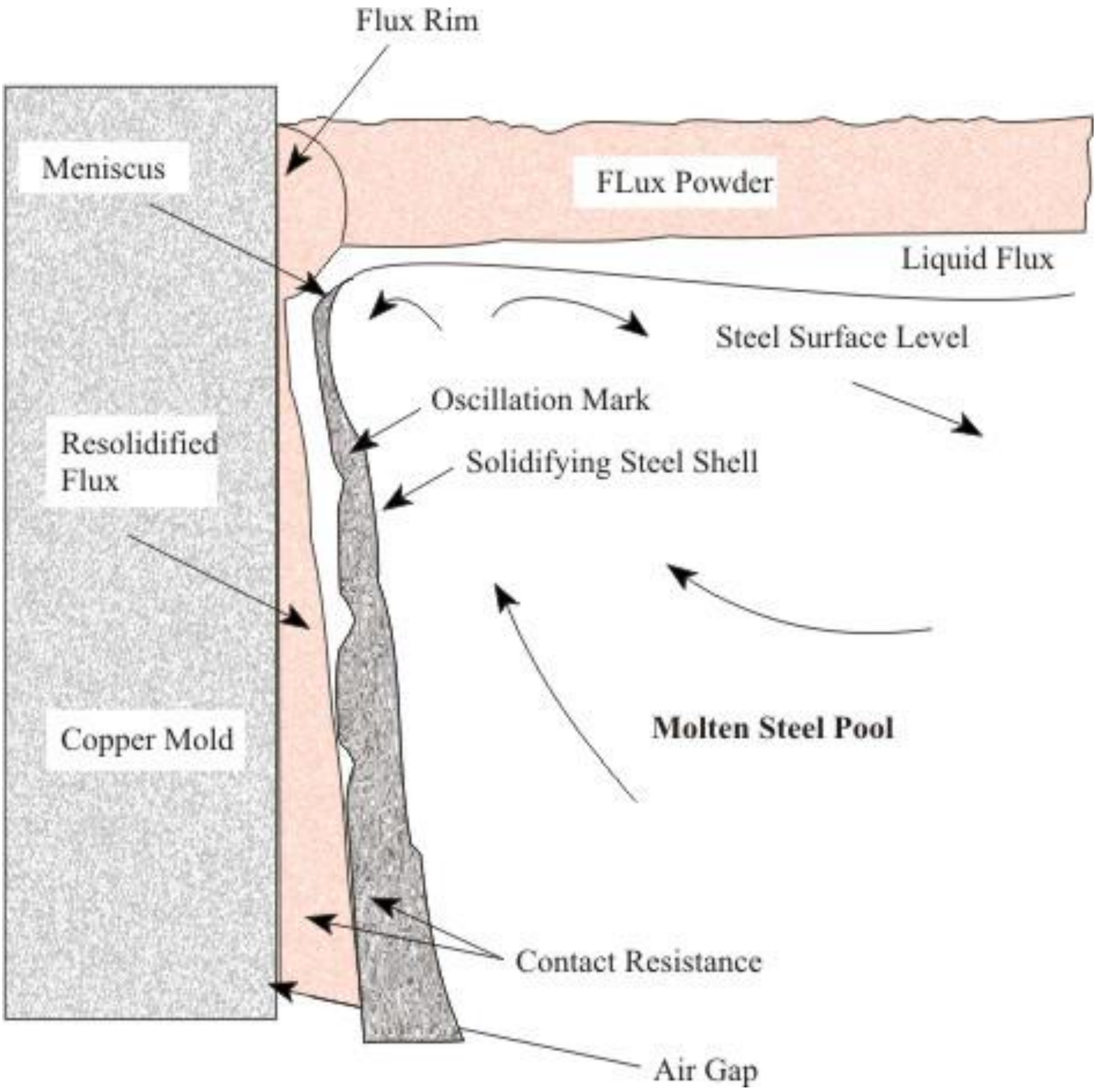
End view of tundish
showing Slotted dam

(b)

MOLD:

- Mold is the heart of continuous casting. In the water cooled mold, molten stream enters from the tundish into mold in presence of flux through the submerged nozzle immersed in the liquid steel.
- Solidification of steel begins in the mold. The casting powder is added onto the top of molten steel in the mold. It melts and penetrates between the surface of mold and the solidifying strand to minimize friction as shown in figure

- Control of height of molten steel in the mould is crucial for the success of the continuous casting machine. The solidification begins from the meniscus of steel level in the mould. Mold level sensors are used to control the meniscus level in the mould.


Flux Rim
Meniscus
FLux Powder
Liquid Flux
Steel Surface Level
Oscillation Mark
Resolidified Flux
Solidifying Steel Shell
Copper Mold
Molten Steel Pool
Contact Resistance
Air Gap

- As seen in the figure, flux melts and enters into the gap between mold surface and solidified strand.
- Molds are made of copper alloys. Small amounts of alloying elements are added to increase the strength.
- Mold is tapered to reduce the air gap formation. Taper is typically 1% of the mold length.

- For 100mm X 100 mm cross section of mold the taper is about 1mm for 1m long mold. The cross section of the mold is the cross section of the slab/bloom/billet.
- Length of the mold is around 0.75-1.4m and is more for large cross sections. Mold cross section decreases gradually from top to bottom. Mould extracts around 10% of the total heat.
- The mold is oscillated up and down to withdraw the partially solidified strand (strand is either billet or bloom or slab).

- The oscillated frequency can be varied. At Tata steel slab caster frequency is varied in between 0 and 250cycles/min and the stroke length from 0 to 12mm.
- Steel level in mould is controlled, that is the meniscus for smooth caster operation. Sensors are used to control the meniscus level.

THE FUNCTIONS OF MOLD FLUX ARE.

- Inclusion absorption capability.
- Prevention of oxidation.
- Minimization of heat losses.
- Flux on melting enters into the air gap and provides lubrication.

- For the above functions the flux should have the following properties.
  - Low viscosity
  - Low liquidus temperature
  - Melting rate of flux must match with the speed of the continuous casting.

SECONDARY COOLING

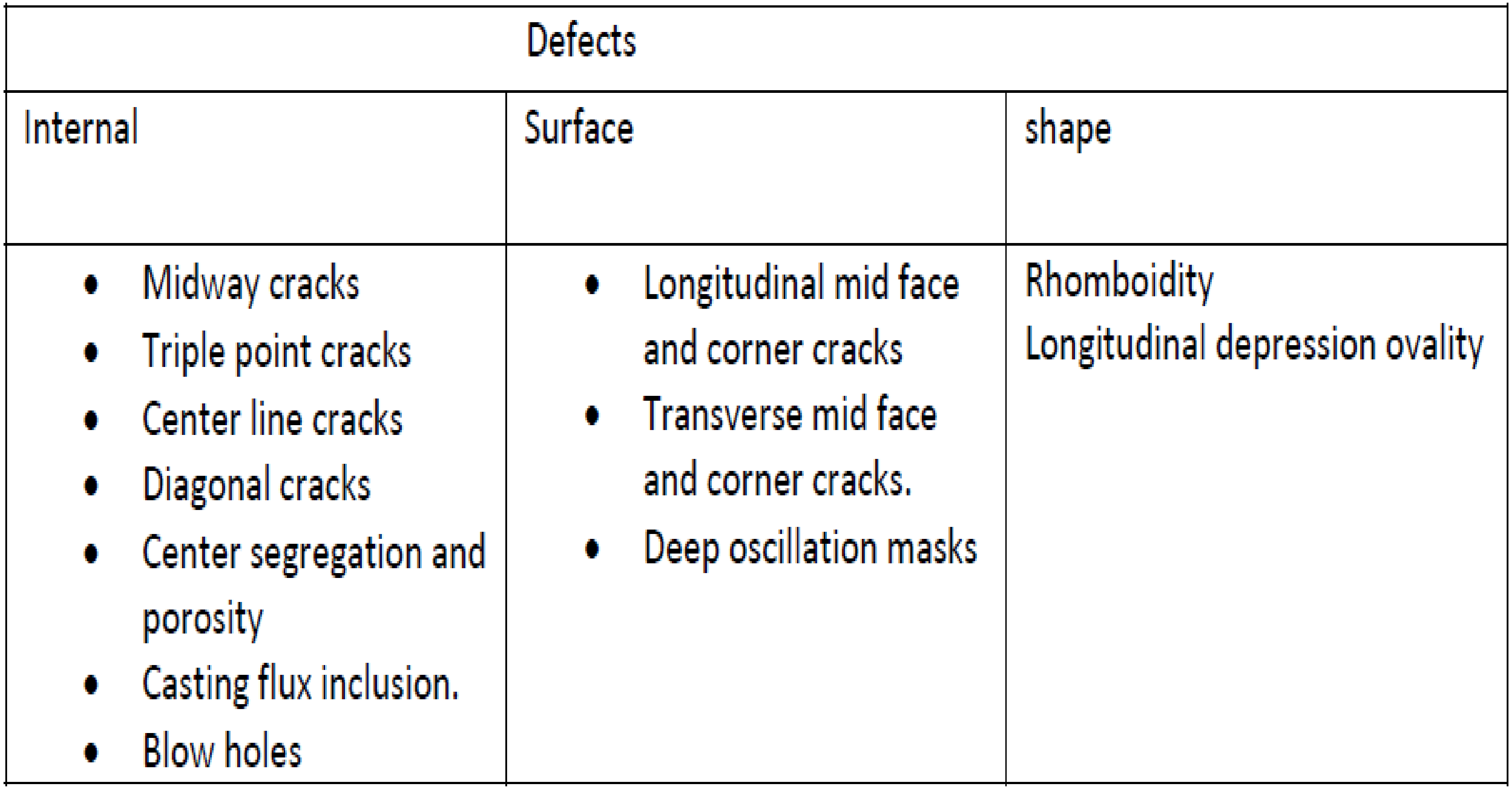
- Below the mold partially solidification strand is water sprayed to complete the solidification. Parameters affecting the heat extraction are:
  - Water drop flux
  - Mean drop size
  - Droplet velocity hitting the strands
  - Wetting effects

- Spray cooling essentially involves boiling heat transfer. A water vapour blanket forms on the strand surface which prevents direct contact of water droplets with strand surface
- Velocity of droplets should be such that droplet can penetrate the vapour layer so that droplets can wet the surface and cools the surface.
- In secondary cooling, number of nozzles is distributed over the surface of the moving strand. Overlapping of spray may occur, distance between the nozzle is important.

Products and casting defects

Presently killed steels are cast continuously into slab for flat products and bloom and billet for structural products.

Defects in continuous casting originate from several factors like mould oscillation, mould flux, segregation coefficient of solute elements; phase transformation etc. In the following, a brief presentation is given on defect formation.



Defects		
Internal	Surface	shape
• Midway cracks • Triple point cracks • Center line cracks • Diagonal cracks • Center segregation and porosity • Casting flux inclusion. • Blow holes	• Longitudinal mid face and corner cracks • Transverse mid face and corner cracks. • Deep oscillation masks	Rhomboidity Longitudinal depression ovality

- Cracks are originated in the cast product due to mechanical and thermal stresses. Material factors are also responsible
- Mechanical stresses are created due to
  - Friction
  - Ferro static Pressure
  - Bending and Straightening operation
  - Roll Pressure

- Mechanical stresses can be reduced by improving mold practices like:
  - Controlling powder feed rate
  - Resonance in mold
  - More accurate strand guidance
  - Casting powder

ELECTRIC ARC FURNACE

ELECTRIC ARC FURNACE:

An **Electric Arc Furnace** (**EAF**) is a furnace that heats charged material by means of an electric arc.

Arc furnaces range in size from small units of approximately one ton capacity (used in foundries for producing cast iron products) up to about 400 ton units used for secondary steelmaking

TEMPERATURE RANGE

- Industrial electric arc furnace temperatures can be up to 1,800 °C, (3272 °F) while laboratory units can exceed 3,000 °C. (5432 °F)
- Arc furnaces differ from induction furnaces in that the charge material is directly exposed to an electric arc, and the current in the furnace terminals passes through the charged material.

HISTORY

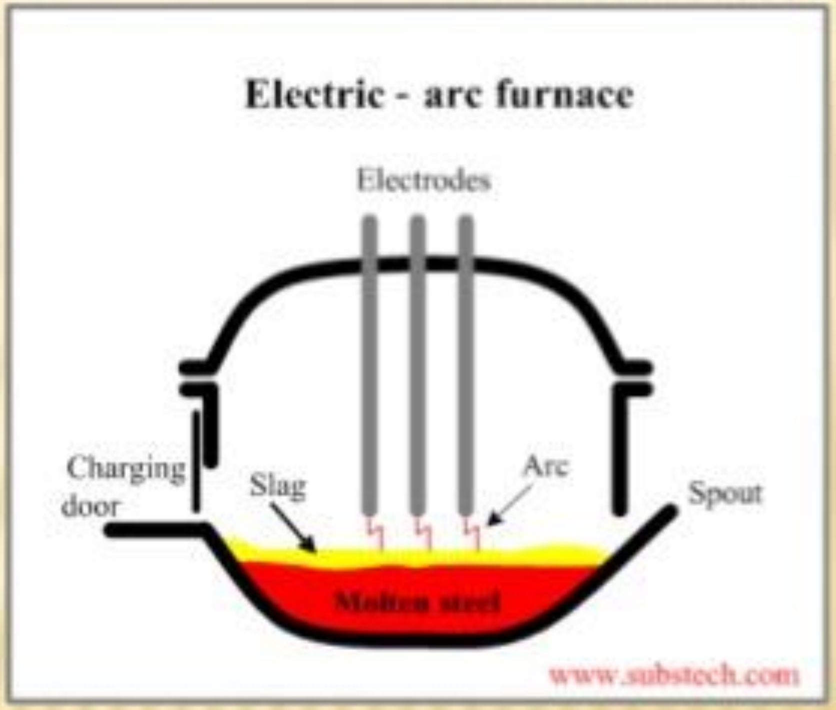
- The first electric arc furnaces were developed by Paul Héroult, of France, with a commercial plant established in the United States in 1907.
- The Sanderson brothers formed The Sanderson Brothers steel Co. in Syracuse, New York, installing the first electric arc furnace in the U.S.
- This furnace is now on display at Station Square, Pittsburgh, Pennsylvania.

TYPES OF EAF

- Two kinds of electric current may be used in Electric Arc Furnaces:
- direct (DC) EAF
- alternating (AC) EAF
- Three-phase AC Electric Arc Furnaces with graphite electrodes are commonly used in steel making.

CONSTRUCTION

- The furnace consists of a spherical hearth (bottom), cylindrical shell and a swinging water-cooled dome-shaped roof.
- The roof has three holes for consumable graphite electrodes held by a clamping mechanism.
- The mechanism provides independent lifting and lowering of each electrode.


Electric - arc furnace
Electrodes
Charging door
Slag
Arc
Spout
Molten steel
www.substech.com

- The charge door, through which the slag components and alloying additives are charged, is located on the front side of the furnace shell.
- The charge door is also used for removing the slag (de-slagging).

REFRACTORY LINING OF AN EAF

- Refractory linings of Electric Arc Furnaces are made generally of resin-bonded magnesia-carbon bricks.
- When the bricks are heated the bonding material is coked and turns into a carbon network binding the refractory grains,preventing wetting by the slag and protecting the lining the from erosion and chemical attack of the molten metal and slag.

OPERATION/WORKING

- The scrap is charged commonly from the furnace top.
- The roof with the electrodes is swung aside before the scrap charging.
- The scrap arranged in the charge basket is transferred to the furnace by a crane and then dropped into the shell.

- Lower voltages are selected for this first part of the operation to protect the roof and walls from excessive heat and damage from the arcs.
- Once the electrodes have reached the heavy melt at the base of the furnace and the arcs are shielded by the scrap,
- the voltage can be increased and the electrodes raised slightly, lengthening the arcs and increasing power to the melt.

CHEMICAL AND PHYSICAL PROCESSES IN AN EAF

- *Melting*
- Melting process starts at low voltage (short arc) between the electrodes and the scrap.
- The arc during this period is unstable.
- In order to improve the arc stability small pieces of the scrap are placed in the upper layer of the charge.
- The electrodes descend melting the charge and penetrating into the scrap forming bores.

- The molten metal flows down to the furnace bottom.
- When the electrodes reach the liquid bath the arc becomes stable and the voltage may be increased (long arc).
- The electrodes are lifting together with the melt level. Most of scrap (85%) melt during this period.

Temperature of the arc reaches 6300ºF (3500ºC).

OXIDIZING STAGE

- At this stage excessive carbon, phosphorous, silicon and manganese oxidize.
  The process is similar to that in Basic Oxygen Furnace.
- Basic oxidizing slag composed of lime (CaO) and ion ore (FeO) is used during the oxidizing period.
  Gaseous oxygen may be blown into the melt for additional oxidizing.

REDUCING STAGE

- New slag composed mainly of lime (CaO), CaF2 (as slag fluidizer) is added at this stage for formation of basic reducing conditions.
- The function of this slag is refining of the steel from sulfur and absorption of oxides, formed as a result of deoxidation ("killing").
- The excessive oxygen dissolved in the melt during oxidizing period is removed by metallic deoxidizersMn, Si, Al:

$[Mn] + [O] = (MnO)$

$[Si] + 2[O] = (SiO_2)$

$2[Al] + 3[O] = (Al_2O_3)$

Basic reducing slag is favorable for desulfurization in accordance to the reaction:

$[S] + (CaO) = (CaS) + [O]$

Oxide and sulfide non-metallic inclusions are absorbed by the slag

- Iron oxide causes increase of Oxygen content in the molten steel according to the reaction:
  (square brackets [ ] - signify solution in steel, round brackets ( ) - in slag, curly brackets {} - in gas)

  $(FeO) = [Fe] + [O]$

  Oxygen dissolved in the melt oxidizes carbon, phosphorous, silicon and manganese:

  $[C] + [O] = \{CO\}$

  $[Si] + \{O_2\} = (SiO_2)$

  $[Mn] + 1/2\{O_2\} = (MnO)$

  $2[P] + 5/2\{O_2\} = (P_2O_5)$

  Carbon monoxide partially burns in the atmosphere:

  $\{CO\} + \{O_2\} = \{CO_2\}$

ADVANTAGES OF ELECTRIC ARC FURNACE

- The use of EAFs allows steel to be made from a 100% scrap metal feedstock.
- This greatly reduces the energy required to make steel when compared with primary steelmaking from ores
- . Another benefit is flexibility: while blast furnaces cannot vary their production by much and can remain in operation for years at a time,

- EAFs can be rapidly started and stopped, allowing the steel mill to vary production according to demand.
- During the peak of global financial meltdown in 2009, an estimated quantity of only 1 million tonne was produced in USA employing EAF technique.
- Although steelmaking arc furnaces generally use scrap steel as their primary feedstock,

- if hot metal from a blast furnace or direct-reduced iron is available economically, these can also be used as furnace feed.

- A typical steelmaking arc furnace is the source of steel for a mini-mill, which may make bars or strip product. Mini-mills can be sited relatively near to the markets for steel products, and the transport requirements are less than for an integrated mill, which would commonly be sited near a harbour for access to shipping.

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- Steelmaking in electric arc furnace has emerged as an important steelmaking process in recent years.
- The flexibility and easy adoptability of EAF steelmaking to accommodate the fluctuating market demand have evolved into the concept of mini steel plants to produce different grades of finished products (long or flat or mixed) of plain carbon or alloy steels from scrap and other metallic charge materials.

- Although scrap is the preferred raw material but sponge iron and iron carbide are being used regularly in most plants because of shortage of steel scrap and to dilute the concentration of tramp elements.
- Several developments in the design and operation have made EAF steelmaking to contribute significantly to the overall total production of steel in the world.
- According to an estimate, the proportion of electric steel is around 40 to 45% in the total world steel production.
- It must be noted that EAF consumes lot of electric energy and hence the cost and availability of electrical power are important issues in electric steel development.

TYPE OF ELECTRIC FURNACES

- In principle an electric arc is formed between the electrode and the metallic charge and charge is heated from the arc radiation.
- Electric arc furnaces are of two type (a) alternating current and (b) direct current.
- In alternating current, furnace operates by means of electric current flowing from one electrode of three to another through the metallic charge.
- In direct current, the current flows from carbon electrode, which acts as cathode, to an anode embedded in the bottom of the furnace.

CONSTRUCTION OF AC ELECTRIC ARC FURNACE

- The furnace consists of a steel shell, lined with suitable refractory materials and is mounted on the tilting mechanism.
- The shell thickness is around 0.005 times the shell diameter.
- Three electrodes enter through the roof. The hood may be swung away for charging.
- Heat is generated by the hot area formed between the electrodes and the charge.

HEARTH

- The hearth contains metal and slag.
- The hearth lining consists of backing lining and working lining. The backing lining is few layers of high fired magnesite bricks on which working lining is rammed with either dolomite or magnesite mass.
- Permeable blocks or porous refractory elements are introduced through the bottom to inject inert gas for stirring.
- The EAF steel bath is shallow.

ROOF

- The roof is exposed to more heat than other furnace elements.
- Its lining is also subjected to radiant heat reflected from the walls and slag.
- High alumina bricks and magnesite – chromite bricks are used for roof lining.
- The roof lining is water cooled which increases the life of refractory lining to at least 10-20 times more than without water cooling.
- The roof has three holes to allow insertion of the electrodes.

ELECTRODE

- A typical alternating current operated EAF has three electrodes.
- Electrodes are round in section, and typically in segments with threaded coupling, so that as the electrodes wear, new segments can be added.
- Graphite electrodes are preferred over carbon electrodes because of better electrical conductivity.
- The electrodes are automatically raised and lowered by a positioning system.

- Electrode consumption depends on
  - Oxidation of the surface of the electrode
  - Mechanical losses due to fracture
  - Dissolution in slag during carbon boil
- The diameter of the electrode should correspond to the current supplied; if current density is excessively high, electrodes will be heated and oxidized vigorously.
- The electrode current could vary from 12 to 16Acm2/ for 400 to 600 m electrode diameter. Larger electrode diameter increases electric energy consumption.

- The electrodes are positioned at apexes of an equilateral triangle.
- The diameter of the circle passing through the centers of electrodes is called the diameter of the electrode spacing.
- If the electrodes are placed close to each other and far from furnace walls, the charge at the furnace banks will be heated belatedly.
- With large spacing diameter, electric arcs will burn near the walls, which will result in rapid wear of the lining.

- The electrode spacing diameter for the bath diameter could be 0.45 for small furnaces, 0.35 for medium- sized and large furnaces, and still lower for super- powerful furnaces.
- For a bath diameter of 5560 mm of a 100 ton furnace the electrode spacing diameter would be 0.35×5560=1900mm.

SIDE WALLS

- The side walls refractory materials should be able to withstand thermal shock and corrosive action of slag.
- Hot spot is formed on the side walls due to the radiation from arc flames, reflected from bath surface during power input.
- The side wall is lined with magnesite, dolomite or chrome magnesite bricks up to the slag line.
- The side wall thickness is usually 450 to 500mm for 10 to 50 ton furnaces and 550 to 650mm for 100 to 200 ton furnaces.

TRANSFORMER POWER

- Electric furnaces are powerful consumers of electric energy.
- The operating voltage of a furnace is 100-800V and the current may reach several thousand amperes.
- The furnace transformer transforms high voltage energy into low voltage.
- The melting process consists of two periods: melt-down and refining period.
- In melt down period higher electric energy is required as compared with the refining period.

- In small furnaces, the power consumption for melting is about 600kWh/ton and it falls to 450kWh/ton in big furnaces.
- Additional 150 to 400 k Wh/ton power is required during refining depending on the practice.

- Large transformers are required to run electric arc furnaces.
- During melting more power is required than during refining.
- The transformer capacity is designed to suit melting requirements.
- The capacity of the transformer is usually 470-650 KVA per tonne of furnace capacity.
- In terms of hearth area, the transformer capacity is in the range of 750-900 KVA per square meter

CHARGING MATERIALS

- Steel scrap is the principle raw material. It may constitute 60 to 80% of the charge.
- In some practices sponge iron and or pig iron is also used for chemical balance.
- In basic furnaces slag formers like limestone, fluorspar, sand, and quartzite are used to form a slag to refine the metal.

- For decarburization oxygen lancing is used. Iron ore is also added.
- Ferro-manganese, ferrosilicon or aluminium are used for deoxidation.
- To produce alloy steels, alloying elements are added.

PLANT LAYOUT

- Layout of an electric arc furnace steelmaking shop varies from plant to plant due to difference in the quality of the product and the scale of production.
- Some plants have just one EAF while others have two.
- The variation is also due to whether the shop is provided with oxygen lancing and carbon injection facilities, gas cleaning equipments and finished castings or ingots.

BROADLY ELECTRIC FURNACE STEELMAKING SHOP COMPRISES OF THE FOLLOWING:

a) Electric furnace
b) Transport facilities for ladle
c) Scrap charging
d) Auxiliary injection facilities
e) Electrode movement mechanism
f) Charging of raw materials and weighing system
g) Slag disposal.

In an ideal layout, all the above facilities should be arranged so as to ensure smooth input and output of materials.

ARC FURNACES OPERATION

- It consists of charging, melt down period and refining. The large baskets containing heavy and light scrap are preheated through the exit gas.
- Burnt lime and spar are added to help early slag formation. Iron one or mill scale may also be added if refining is required during melt- down period.
- The roof is swung off the furnace, and the furnace is charged. Some furnaces are equipped with continuous charging. Hot metal is also charged as per the requirement.

- In the meltdown period, electrodes are lowered and bored into the scrap.
- Lower voltages are selected in order to protect the roof and walls from excessive heat and damage from the arcs.
- Once the arc is shielded by scrap, voltage is increased to form molten metal pool to reduce the meltdown period.
- During meltdown period, silicon, manganese and carbon oxidizes.
- Also oxidizing and limy slag is produces which promotes dephosphorization as well.

MELT- DOWN TIME DEPENDS ON

  - Arc conditions: larger arc requires lower current and lower heat losses
  - Deep or shallow bath: deep bath shortens the meltdown period.
- Refining continues even during melting. Removal of phosphorus must be complete before the rise in temperature and carbon boil.

- The single oxidizing slag practice is employed when removal of sulphur is not required.
- When both P and S are required to be removed double slag practice is used.
- In double slag practice, oxidizing slag is removed and reducing slag is formed after deoxidation with ferrosilicon or ferromanganese or aluminum.

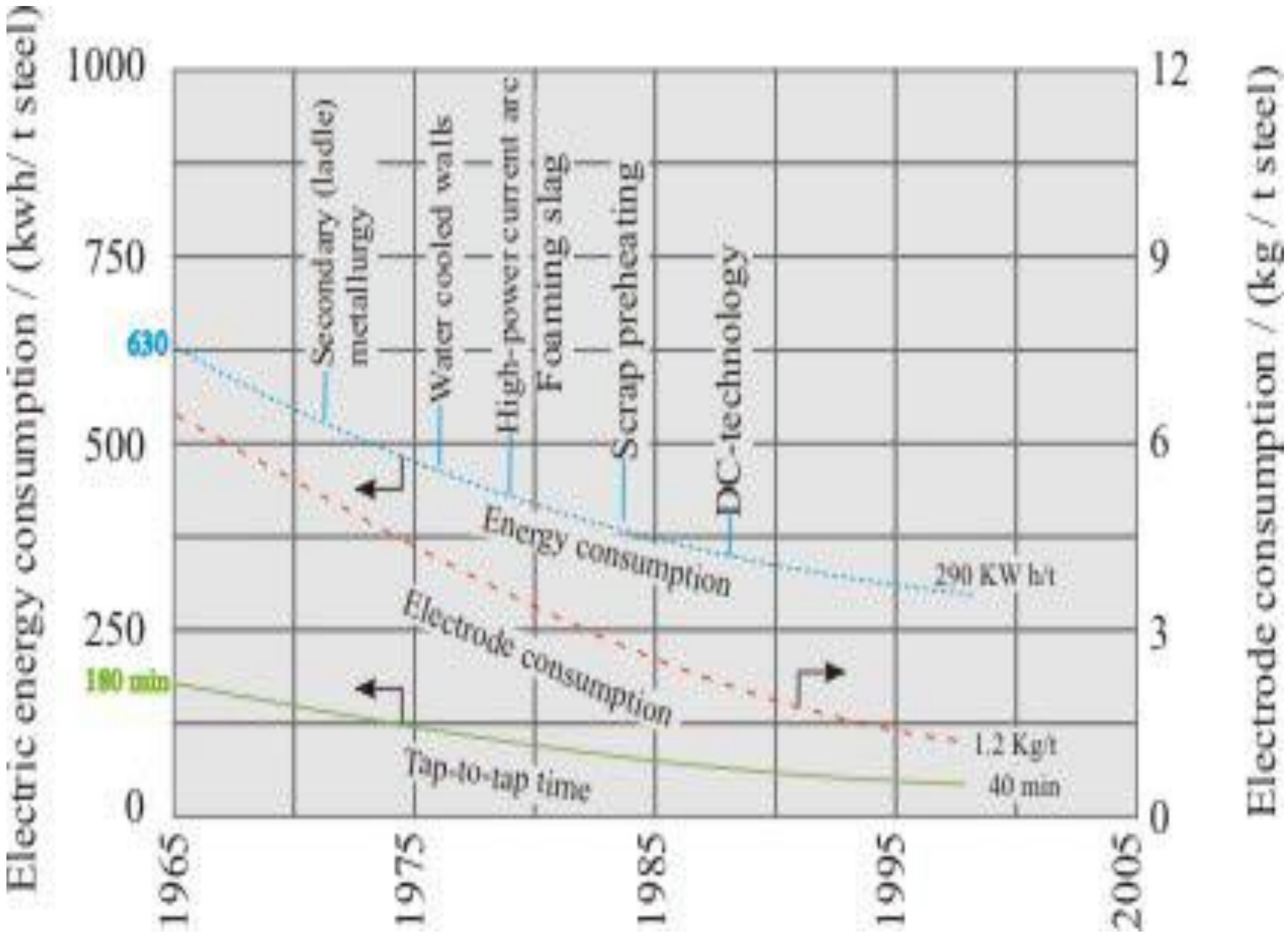
- Reducing slag helps to avoid loss of alloying elements
- Once the bath chemistry and its temperature are attained, heat is deoxidized and finished for tapping

COMPARISON WITH OXYGEN STEELMAKING

	EAF	Oxygen steelmaking
Source of energy	Electric + chemical energy	Chemical energy; Autogeneous process
Iron containing raw material	Hot metal + directly reduced iron + scrap in the suitable proportion as per practice	Hot metal + 20 – 30% scrap
Operating procedure	Oxygen lancing is to promote decarburization, scrap melting and post combustion.	Oxygen supply is continuously done to refine hot metal to steel. A three phase dispersion of slag/metal/gas forms to accelerate the refining rates.
	Slag foaming is induced to shield refractory lining from the heat of arc.	
	Carbon injection is done to induce foamy slag practice	

MODERN DEVELOPMENTS IN ARC FURNACE

- The growth of electric steel production around the world has been driven by lower investment, higher operational flexibility and easy adoptability to market demand on long or flat products of either plain carbon or alloy steels.
- Growth has been supported by updating installations and technologies to reduce the electric energy, electrode consumption and tap to tap time.


Electric energy consumption / (kwh/ t steel)
1000
750
630
500
250
180 min
0
12
9
6
3
0
Electrode consumption / (kg / t steel)
1965
1975
1985
1995
2005
Secondary (ladle) metallurgy
Water cooled walls
High-power current arc
Foaming slag
Scrap preheating
DC-technology
Energy consumption
290 KW h/t
Electrode consumption
1.2 Kg/t
Tap-to-tap time
40 min

- Figure shows the developments in electric steelmaking technologies.
- Developments in EAF technologies are strongly supported by secondary steelmaking. One can note in the figure that the power consumption has decreased from 630
- Kwh/ton of steel to 290kWh/ton. Similarly tap tp tap time has decreased from 180 minutes to 40 minutes and electrode consumption has decreased from arounf 6.2 kg/ton to as low as 1.2 kg/ton within the periods of representation in the figure.
- This became possible with the several simultaneous developments in the secondary steel-making method. Table shows the various developments

DEVELOPMENT IN EAF

Furnace design	Process operating technologies	Chemical energy	Charge materials
Split shell design	Bottom stirring	Oxidation reaction	Directly reduced iron, hot metal
Transformer power	Foamy slag practice	Post combustion oxy fuel burner	
DC arc furnace	Scrap preheating	Carbon injection	

FURNACE DESIGN (1)

- Construction of hearth and lower side section of the shell of larger diameter than the top opening. This leads to increase in shell volume which results in larger tonnage charge, lower heat losses and improved thermal efficiency.

(2)

- In the split shell design, shell structure is constructed in two sections: lower section which contains hearth and free board allowance for slag, and upper section containing side wall and roof. The two sections are coupled such that the upper section can be repaired easily. This reduces the downtime and increases furnace availability.

(3)

- High powered transformers are the current trends. Most modern furnaces operate at 500k VA/ton and the trend is towards ultra high power ranging in between 700k VA/ton to1000k VA/ton.
- Developments are in progress to install transformer with 1500k VA/ton capacity.
- It is claimed that a 120 tons operating at 180 MVA transformer capacity and by using refining combined burner technology through oxygen gas and carbon injection, it is possible to increase capacity by up to 50%.
- The largest transformer in AC EAF corresponds to a rated power 0f 240 MVA for 300 ton furnace.

(4)

- Eccentric bottom taping reduces tap times, temperature losses and slag carry over into ladle. The strip producing plants are equipped with eccentric bottom tapping in electric arc furnaces.

(5)

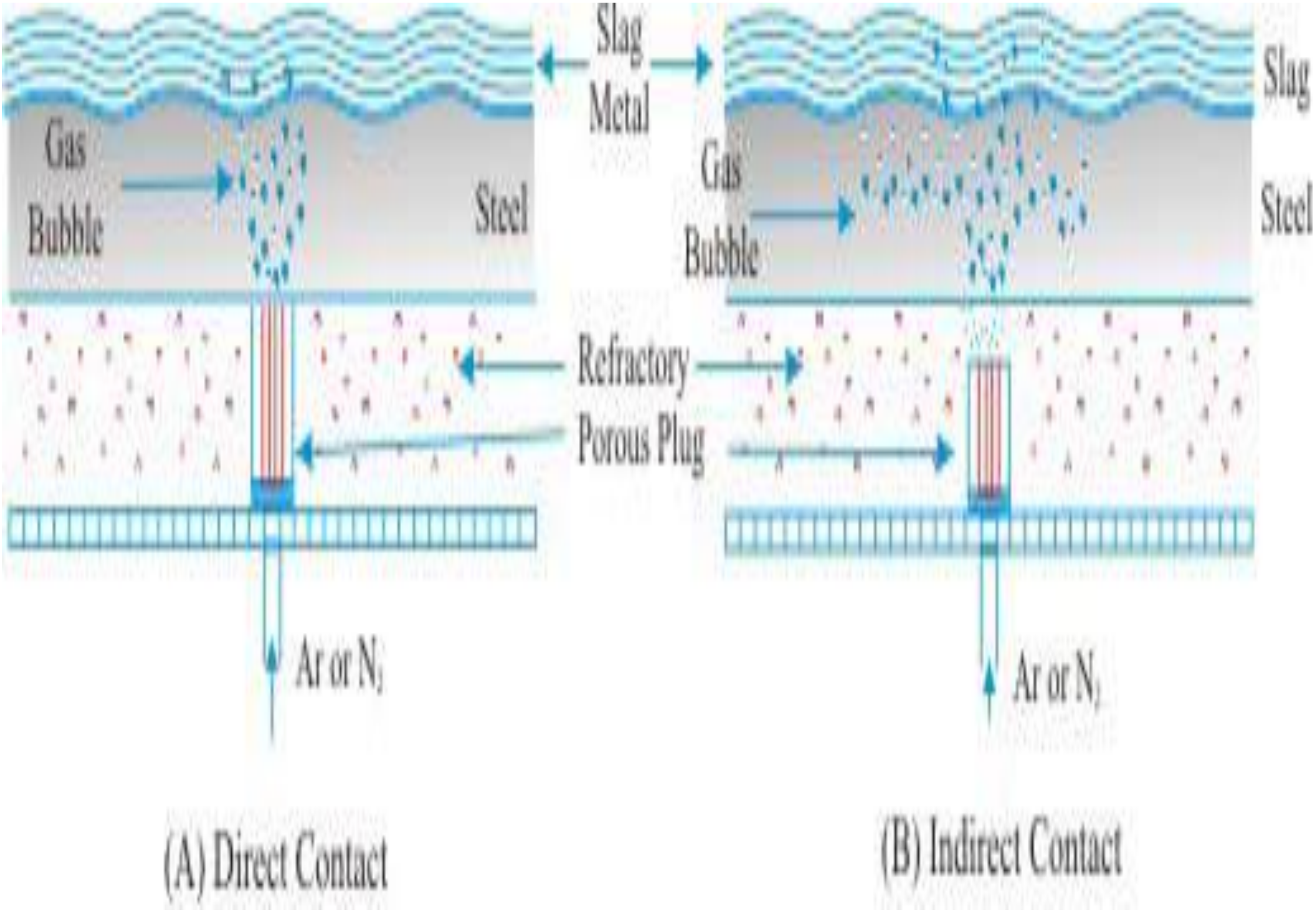
- DC (direct current) arc furnaces represent a different concept in arc furnace design.
- Most DC furnaces are with single electrode where current flows down from the carbon electrode to an anode mounted in the bottom of the furnace.
- Reduced electrode consumption of the order of 50 to 60 % is the major benefit of a dc furnace compared to a convectional three- phase arc furnace.

- Noise levels for the dc furnaces are lower.
- Lower maintenance costs are claimed and refractory costs are less for sidewall but more for the furnace bottom.
- A dc arc furnace requires an addition of the bottom electrode (anode), a dc reactor, and a thyristor all of which add cost to a dc furnace.
- The electrode technology limits diameter to a maximum of 700 mm allowing a dc current of 100kA and 70 MVA power for single electrode furnace. Furnace size is limited to 200 tons.
- Further developments are in progress.

PROCESS OPERATING TECHNOLOGIES

- Most of the developments in process operating technologies are in AC- electric arc furnaces as these furnaces are popular.

- i) Bottom stirring
- In convectional arc furnaces there is little natural electrical turbulence within the bath. Due to absence of stirring large piece of scrap can take a long time to melt and may require oxygen lancing. Argon or nitrogen stirring
  - Eliminates temperature and concentration gradients
  - Shortens tap-to-tap times
  - Reduces refractory, electrode and power consumption and
  - Improves yield of iron and alloys



(A) Direct Contact

(B) Indirect Contact

- Industrial systems for bottom stirring are either with direct contact plug or with indirect contact plug. In direct contact plug, the plug is in contact with molten metal, whereas in indirect one the plug is embedded in a porous bottom refractory.
- In the indirect contact, the plug is not directly in contact the molten metal. The gas enters the bath via the porous refractory hearth which results in stirring over a large area when compared with direct plug as shown in the figure.
- Figure shows the direct contact and indirect contact plug for bottom stirring. Note that in indirect contact large area of the bath is stirred as compared with direct contact plug.

II) FOAMY SLAG PRACTICE

- In EAF steelmaking, progressive melting of scrap increases the irradiative heat transfer from arc to the side walls of the furnace. By covering the arc in a layer of slag, the arc is shielded and more energy is transferred to the bath. The foaming slag during this period is beneficial.
- The effectiveness of slag foaming depends on slag basicity, FeO content of slag, slag temperature and availability of carbon to react with either oxygen or FeO of slag.

- Slag foams in steelmaking due to entrapment of gas bubbles. Gas producing reactions in steelmaking are:

a) Reaction between FeO of slag with carbon

- (FeO) +C=[Fe]+{CO} ------------------------(1)

b) Between carbon and oxygen dissolved in metal

- [C]+[CO]={CO} --------------------------------(2)

c) Between chromium oxide and carbon:

- $Cr_2\,O_3+3C=2Cr+3CO$ ----------------------(3)

- Reactions 1 and 2 are important in carbon steelmaking whereas reaction 3 is important in stainless steel making.
- Injection of carbon and oxygen at several places in the bath assures slag foaming practice, when carbon content of the bath is insufficient.
- Typically carbon injection rates for slag foaming are 2.5 to 5 kg/ ton of steel. In high powered furnaces carbon injection is 5-10 kg/ton of steel.

SCRAP PREHEATING

- Preheating of scrap brings thermal energy into the furnace. Preheating of scrap to 540°C brings 81kwh/ton of additional energy. Scrap preheating gives the following advantages:
  - Reduction in energy consumption by 40-60 kwh/ton depending on the scrap preheat temperature
  - Electrode consumption reduces by 0.3 to 0.36 kg/ton
  - Refractory consumption decreases by 0.9 to 1.4 kg/ton
  - Tap to tap time reduces by 5 to 8 minutes.

- It is important to note that scrap preheating technology needs to be developed. Thermal energy is required to preheat the scrap and is economical only when the waste heat from the furnace is utilized.

FUTURE OF EAF STEELMAKING

- The EAF needs a metallurgical reactor that has the largest growth potential both in terms of production capacity and technology evolution.
- Future EAF will be equipped with all modern technologies- like Ultra high power input (up to1500 kVA/t), latest oxygen and carbon injection technology and design features- like ultra high shell design, heavy mill type components

- This combination leads to an Electric Arc Furnace where the tap to tap times can be extremely short and the corresponding productivity reaches the level of larger furnace sizes or converter plants.
- The two main reasons for this are:
  - The possibility of a higher electrical power input and
  - A far higher efficiency of chemical energy, decarburization and scrap preheating compared to the same size (tap weight) standard furnace.

IT IS INTERESTING TO COMPARE A CONVENTIONAL 120TON EAF WITH THE ULTIMATE 120 TON EAF.

Conventional 120 ton EAF	Ultimate 120 ton EAF
2- bucket charge Scrap bucket 130 m^3 Furnace volume 145 m^3	1-bucket charge Scrap bucket 185 m^3 Furnace volume 210 m^3
Transformer design upto 1,000kVA/t, 120MVA for 120 ton tapping weight, Secondary voltage up to 1,200V	Transformer design upto 1,500kVA/t, 180MVA for 120 ton tapping weight, Secondary voltage up to 1,500V
Utilization of chemical energy 3 oxygen gas burners 3 refined combined burners (RCB) 2 carbon injectors	Utilization of chemical energy 3 oxygen gas burners 5 refined combined burners (RCB) 4 carbon injectors 4 post combustion injectors

- Refined Combined Burner (RCB) technology combines a conventional oxy/gas burner with a supersonic oxygen injection lance and is designed to optimize the injection of carbon and oxygen into EAF. It supplies chemical energy through chemical reactions of fuel and gas, oxygen, and carbon injected into the furnace.

GASES IN STEEL (NITROGEN)

- Except a small proportion of steel wherein the hardening influence of extra nitrogen content is made use of in developing

GASES IN STEEL (OXYGEN)

- Oxygen is supplied for refining iron and hence, a certain fraction is inevitably left over as dissolved oxygen in liquid steel at the end of refining.
- Several useful deoxidisers have been found to effectively deoxidise liquid steel is to obtain sound ingots on solidification.
- The use of deoxidisers, unless it forms gaseous product of deoxidation reaction, tends to decrease cleanliness of the steel.

- Where cleanliness is of prime importance and where oxygen is to be reduces to a lower level than that attainable by normal deoxidation practice, liquid steel has to be treated under vaccum prior to solidification.

DEOXIDATION: INTRODUCTION

- Refining of hot metal to steel is done under oxidizing atmosphere.
- During refining oxygen dissolves in steel.
- Solubility of oxygen in steel is negligibly small.
- During solidification of molten steel, excess oxygen is rejected by the solidifying steel.
- This excess oxygen produces defects like blow holes and non- metallic oxide inclusion in solidified casting.
- Defects have considerable effect on mechanical properties of steel.

- Therefore, it is necessary to remove oxygen from steel; removal of oxygen is called Deoxidation.

- **Sources of oxygen in steel**
  - Rust on steel
  - Oxygen blowing
  - Steelmaking slag
  - Atmospheric oxygen dissolved in steel during teeming
  - Oxidizing refractories

- At 1600°C solubility of oxygen in liquid steel is 0.23% which deceases to 0.003% in solid steel during solidification. According to the degree of deoxidation, carbon steels may be subdivided into three groups:

i. Killed steel: Oxygen is removed completely. Solidification of such steels does not give gas porosity (blow holes).

ii. Semi –killed steel: Incompletely deoxidized steels containing some amount of oxygen which froms CO during solidification.

iii. Rimming steel: Partially deoxidized or non-deoxidized low carbon steels evolving sufficient CO during solidification. These steels have good surface finish.

DEOXIDATION OF STEEL

- Deoxidation can be carried out either by single element such as Si,Al,Mn etc or by mixture of elements such as Si+Mn,Ca–Si–Al etc.
- De oxidation by single element is known as simple deoxidation, whereas deoxidation by a mixture of elements is known as complex deoxidation.

- In both simple and complex deoxidation, oxide is formed; hence it is also termed precipitation deoxidation.
- Deoxidation is also carried out by carbon under vacuum; which is called vacuum deoxidation.
- Elements are added in the form of Ferro-alloys Fe− Si,Fe−Mn or Fe Si + Fe Mn etc.

- Simple deoxidation can be represented by

$$a[M]+b[O]=(M_a\ O_b)\ \text{------}(1)$$

- If deoxidation product is pure then activity of $(M_a\ O_b=1)$ and if elements are in dilute solution

$$[W_M]^a[W_O]^b=K_m\quad \text{---------}(2)$$

- Where K_M is deoxidation constant and equals to $1/KM_1$ where KM_1 is equilibrium constant.

$$\log K_M=-X/T+Y\ \text{----------}(3)$$

- Where X and Y are constants and T is temperature. Increase in T increases K_M.
- Using equations 2 and 3 one can calculate the variation of W_O with W_M when W_M is in small quantity.
- In complex deoxidation where a mixture of Si+Mn,Ca+Si,Ca+Si+Al is used, the following advantages are reported as compared with simple one:
  - The dissolved oxygen is lower.
  - Due to formation of liquid deoxidation product agglomeration of the product into large size can be obtained easily and can be floated easily.

- According to equation 2

$$[W_O]^b=K_M[W_M]^a \text{ ----------(4)}$$

- Equation 4 indicates that weight percent oxygen in steel depends on value of K_M for small concentration of deoxidizers. At 1600°C the value of Km is 2.4×10^{-5} for the reaction
- $Si+O_2=SiO_2$ and for the reaction

- 2 Al+3O=Al_2O_3 the value of $K_M=3.32\times10^{-14}$.

- Similarly for the reaction Ca+O=CaO, $K_M=9.84\times10^{-11}$.
- The value of K_M indicates the deoxidizing ability of an element.
- For the above reaction, calcium is the most efficient deoxidizer and Si is not so efficient as compared to calcium. Aluminum is also a strong deoxidizing element when compared with silicon.

- Though calcium and aluminum are very efficient deoxidizers, but they oxidize very fast and moreover, their density is much lower than steel.
- Also Ca has a boiling point 1485°C which means calcium is gaseous phase at the steelmaking temperature. Suitable injection methods or addition methods are to be developed.

KINETICS OF DEOXIDATION

- Total oxygen in steel equals to dissolved oxygen + oxygen present in deoxidation products (SiO2,Al2O3,MnO etc). Even if the dissolved oxygen is low, deoxidation products (also called inclusions) have to be removed, otherwise steel is not clean (clean steel refers to number and size of inclusions in steel). Kinetics of inclusion is concerned with deoxidation reaction and separation of deoxidation products as well.

THE DEOXIDATION PROCESS CONSISTS OF THE FOLLOWING STEPS

- Dissolution and homogenization of de oxidizer. Mechanism of dissolution depends on melting point. Ferro alloys melt at around 1500°C. Aluminium is expected to melt faster due to its much lower point. Intensity of agitation will govern the homogenization of deoxidizer in steel melt for faster kinetics of reaction between oxygen and deoxidizer.
- Nucleation of solid product becomes easier if interface is present. Deoxidation by Al produces solid Al2O3 and as such Al2O3/steel interface is useful for nucleation.

- Growth of the de oxidation product: It depends on the state of the product. A liquid product can coalesce easily as compared with the solid product. Deoxidation with single elements like Al,Si etc. produce solid deoxidation product at the steelmaking temperature. Deoxidation with ferro silicon+ ferro manganese produces liquid deoxidation product. Boron, titanium zirconium are also quite effective deoxidizers. Manganese and silicon are used in the ratio 7:1 to 4:1 in order to obtain a thin liquid slag.

- Removal of deoxidation product: Removal of de oxidation product is equally important. It is achieved by floatation and absorption into a slag. Following steps are important for removal of de oxidation products from steel:

  i. Growth of de oxidation product
  ii. Movement through molten steel to surface
  iii. Absorption of inclusion by a suitable designed synthetic slag.

- Floatation of an oxide product depends among physical properties of steel, on the size of the product. The rate of rise of a spherical particle in a quiet fluid or in a fluid of laminar flow (i.e. at very low Reynold’s number) can be described at steady state by Stoke’s law :

$$V_t = \frac{gd^2 \Delta\rho}{18\,\eta}$$

- Where,

- Vt= terminal velocity (m/s)of the inclusion,
- g is acceleration due to gravity (m/s^2),
- Δρ= differnce in density of steel and deoxidation product and
- η is viscosity of steel (kg/m.s).

- Deoxidation products are lighter than steel; hence they move up.
- According to Stokes equation the rising velocity is proportional to square of the size of the deoxidation product.
- Larger sizes move faster. Moreover different sizes of de oxidation product will move with different velocities.
- During their movement, they may collide with one another. Stirring of melt may help floating of de oxidation products.

- Degree of stirring in the melt is important. Vigorous stirring may not be of much help since deoxidation product may be circulated in the liquid.
- For the removal of deoxidation product, equally important is the design of synthetic slag to absorb the deoxidation product

DEOXIDATION PRACTICE

- Deoxidation can be carried out during tapping, in ladles runners and even in moulds. Bath stirring is important.
- During tapping, bath is stirred due to potential energy but this subsides towards the end. When deoxidation is carried out in ladle, it is called ladle deoxidation in industrial practice.
- Depending on the extent of deoxidation, killed, semi killed and rimming steels are produced. For carbon content less than 0.15% and enough oxygen in steel, rimming steel can be produced.
- Alloy steels are fully killed to obtain maximum recovery of alloying additions.

DEGASSING PROCESSES

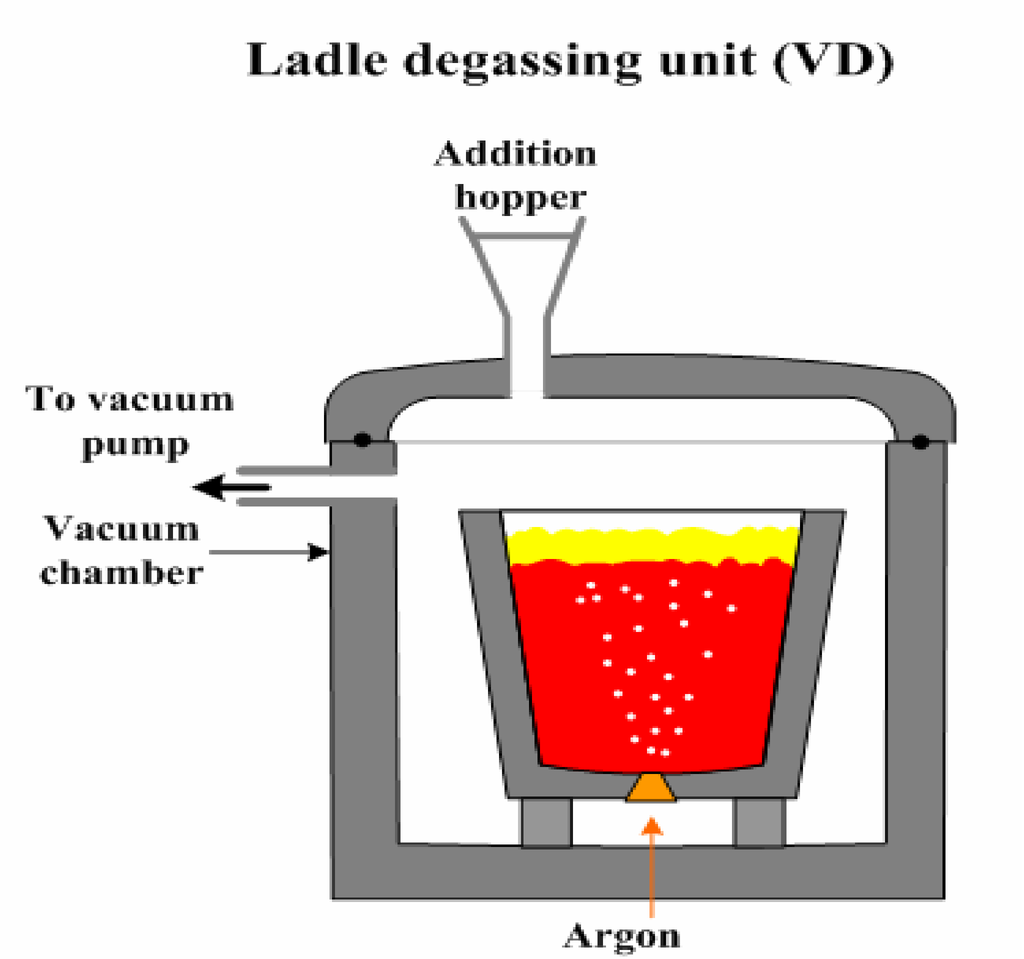
- There are 3 methods of degassing which are in practice:
  - Ladle degassing
  - Stream degassing
  - Circulation degassing
- All these processes are carried out in ladles.

- i) Ladle degassing : Liquid steel is held in a ladle which is put inside a vacuum chamber. steel may be stirred by bubbling an inert gas or by an electro-magnetic stirrer while being exposed to vacuum.

- ii) Stream degassing : Liquid steel flows down in the form of a stream from the furnace or ladle to another ladle or mould during its exposure vacuum.

- iii) Circulation degassing : Liquid steel is either continuously or intermittently circulated during its exposure to vacuum.

LADLE DEGASSING



- Ladle containing molten steel is placed in a chamber which is then evacuated. After a determined time ladle is removed from the chamber and is teemed for casting. Fig. shows ladle degassing unit.

- Ladle is provided with a porous plug at its bottom to purge argon gas as shown in the figure. In a vacuum chamber the ladle is placed.
- The vacuum chamber is equipped with a hopper so as to make additions of elements as and when it is needed.
- For effective degassing of fully killed steel, it is necessary to purge argon through the bottom of the ladle. Stirring the bath enhances rate of gas removal.

- Vigorous removal of gases causes metal splashing too. Therefore ladle is not filled completely and about 25% of its height is kept as freeboard to accommodate the splashed metal droplets.
- Pressure is maintained in between 1mmHg to 10mm Hg for effective degassing. During degassing additions are made for deoxidation and alloying.

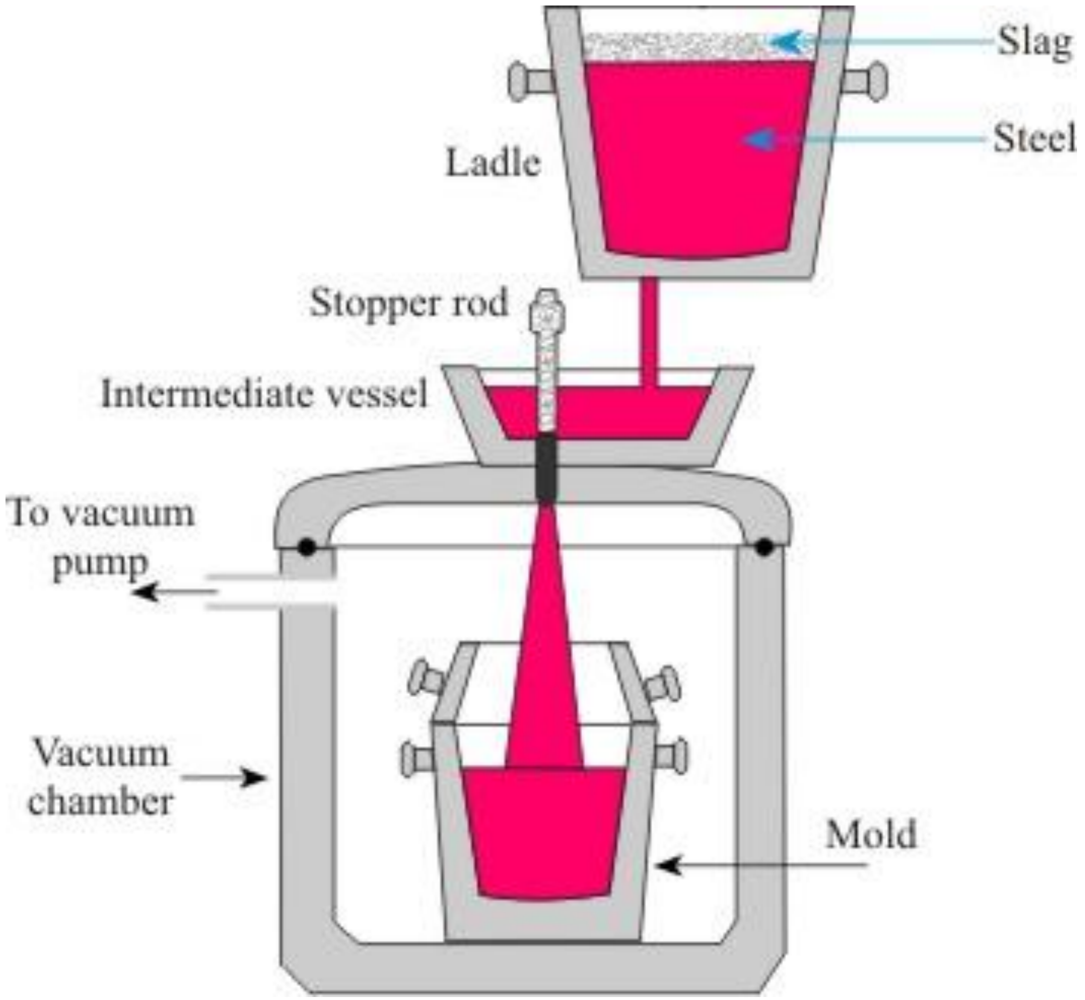
- In certain cases ladle is heated to compensate for the loss of heat during degassing.
- For the effectiveness of degassing , it is necessary that carry-over slag either from BOF or EAF should be as low as possible.
- Carry-over slag contains FeO and since oxygen content of steel is in equilibrium with FeO content of slag, oxygen content of steel increases.

- Stirring gas is introduced either from top through the roof by a submerged refractory tube or through the porous plug fitted at the bottom of the ladle.
- Electromagnetic stirring is employed for degassing. For this purpose ladle has to be made of non magnetic austenitic stainless steel or stainless window could be provided.
- For certain grades of alloy steels, both induction stirring and arc heating are employed for degassing.

- The final content of gas in steel depends on degree of vacuum and time of treatment. Hydrogen is generally reduced to below 2ppm from 4 to 6ppm, nitrogen content of steel is also reduced. The pick-up of nitrogen from the atmospheric air may occur during open pouring of steel, which must be controlled.
- Ladles are generally lined with high alumina bricks at upper part of the ladle while the lower portion is lined with fireclay.

STREAM DEGASSING

- In stream degassing technology, molten steel is teemed into another vessel which is under vacuum.
- Sudden exposure of molten stream in vacuum leads to very rapid degassing due to increased surface area created by breakup of stream into droplets.
- The major amount of degassing occurs during the fall of molten stream. Height of the pouring stream is an important design parameter.


Slag
Steel
Ladle
Stopper rod
Intermediate vessel
To vacuum pump
Vacuum chamber
Mold

STREAM DEGASSING TECHNOLOGY HAS FOLLOWING VARIANTS IN THE PRACTICE

i. Ladle to mould degassing

- Preheated mold with hot top is placed in vacuum chamber.
- Above the chamber a tundish is placed. Steel tapped in the ladle at superheat equivalent to 30°C is placed above the tundish.
- Steel is bottom poured in the tundish. One ingot could weigh around as high as 400tons and several heats from different furnaces are used for casting.

II. LADLE TO LADLE DEGASSING

- In ladle to ladle degassing, a ladle with the stopper rod is placed in a vacuum chamber.
- Ladle containing molten steel from BOF or EAF is placed on top of the vacuum chamber and the gap is vacuum sealed.
- Alloy additions are made under vacuum. Stream is allowed to fall in the ladle where molten steel is degassed.
- Alloy additions are made under vacuum.

- In some plants degassing is done during tapping. In this arrangement molten steel from EAF is tapped into tundish or pony ladle.
- From the pony ladle molten stream is allowed to fall into a ladle which is evacuated.
- Ladle is closed from top with a special cover which contains exhaust opening. Steel with 25°C to 30°C superheat is tapped into ladle.

RECIRCULATION DEGASSING

- In the recirculation degassing technology, molten steel is allowed to circulate in the vacuum chamber continuously by special arrangement.
- In RH degassing technology a cylindrical refractory lined shell with two legs (also called snorkel) is designed such that steel is raised in one leg and falls back into the ladle after degassing through the second leg.
- Top side of the cylindrical shell is provided with exhaust, alloy additions, observation and control window.

- Cylindrical shell is lined with fire bricks in the upper portion, and alumina bricks in the lower portion in order to sustain high temperature.
- The legs are lined with alumina refractory.
- A lifter gas argon is injected at the inlet snorkel in order to increase the molten steel velocity entering into inlet snorkel.
- Figure shows a schematic sketch of a RH degassing unit.

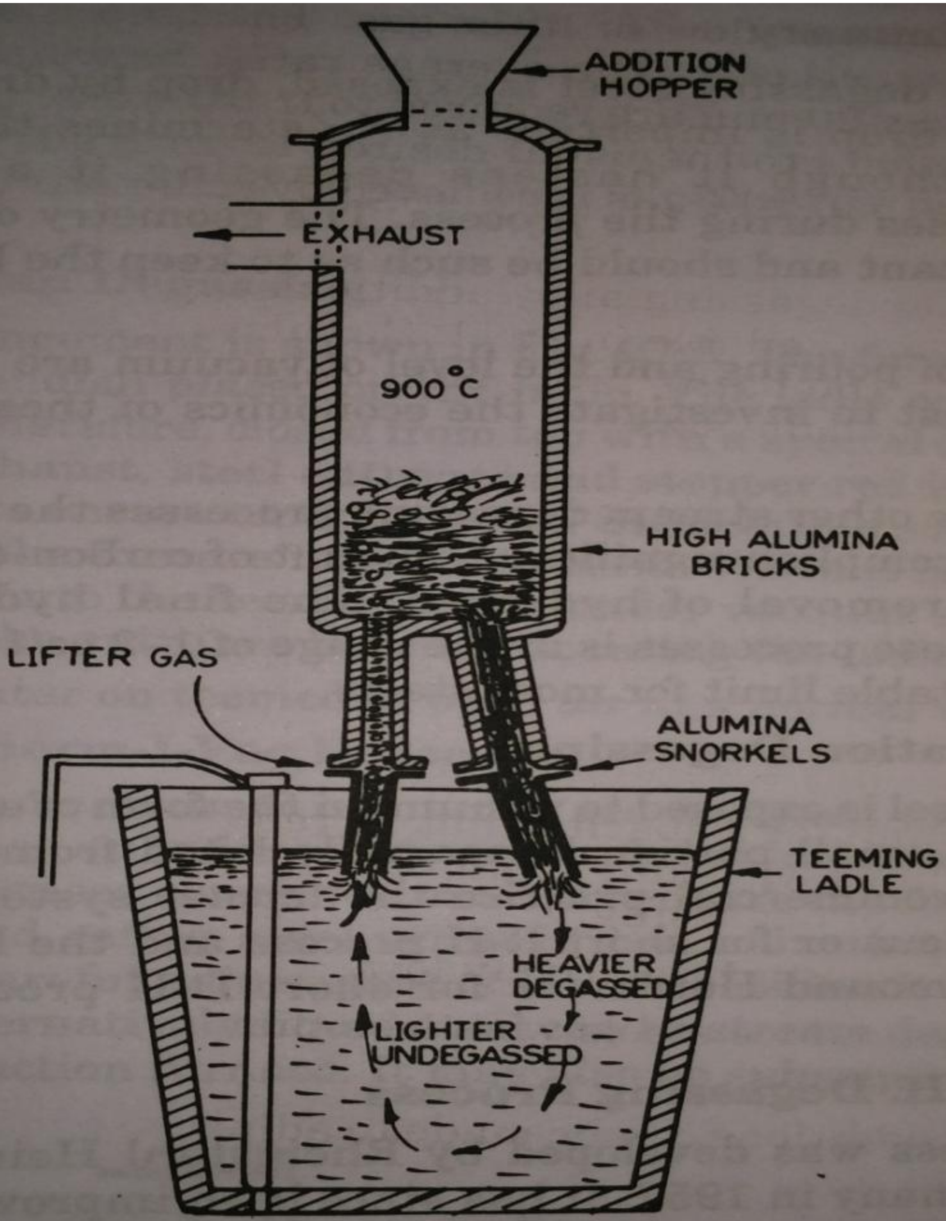


Fig. 27·7. R.H. process of degassing.

THE OPERATION OF RH DEGASSER IS AS FOLLOWS

i) Cylindrical chamber is heated to the desired temperature (varies in between 900°C to 1500°C in different plants).

ii) The chamber is lowered into molten steel up to a desired level.

iii) The chamber is evacuated so that molten steel begins to rise in the chamber. Lifter gas is introduced. This gas expands and creates a buoyant force to increase the speed of molten steel rising into the inlet snorkel.

iv) Molten steel in the chamber is degassed and flows back through the other snorkel into the ladle. This degassed steel is slightly cooler than steel in the ladle. Buoyancy force created by density difference (density of cooler liquid steel is > hot steel) stirs the bath

v) Rate of circulation of molten steel in cylindrical chamber controls the degassing. Circulation rate depends upon amount of lifter gas and the degree of vacuum. A 110 T steel can be degassed in 20 minutes by circulating molten steel at 12 tons/min., amount of argon is around 0.075 0.075 m3/ton.

vi) Alloy additions can be made at the end of degassing depending on the superheat.

vii) Process has several advantages like

- Heat losses are relatively low.
- Alloy additions can be adjusted more closely
- Small vacuum pumping capacity is adequate since smaller volume is to be evacuated as compared with ladle to ladle or stream degassing.

DH DEGASSING

- In DH degassing, a small amount 10-15% of the total mass of steel is degassed at a time. The process is repeated until required level of degassing is achieved. The arrangement of a vessel and the ladle is somewhat similar to figure except the following:
  - In DH unit, the cylindrical vessel has one snorkel .
  - Cylindrical vessel has heating facility.

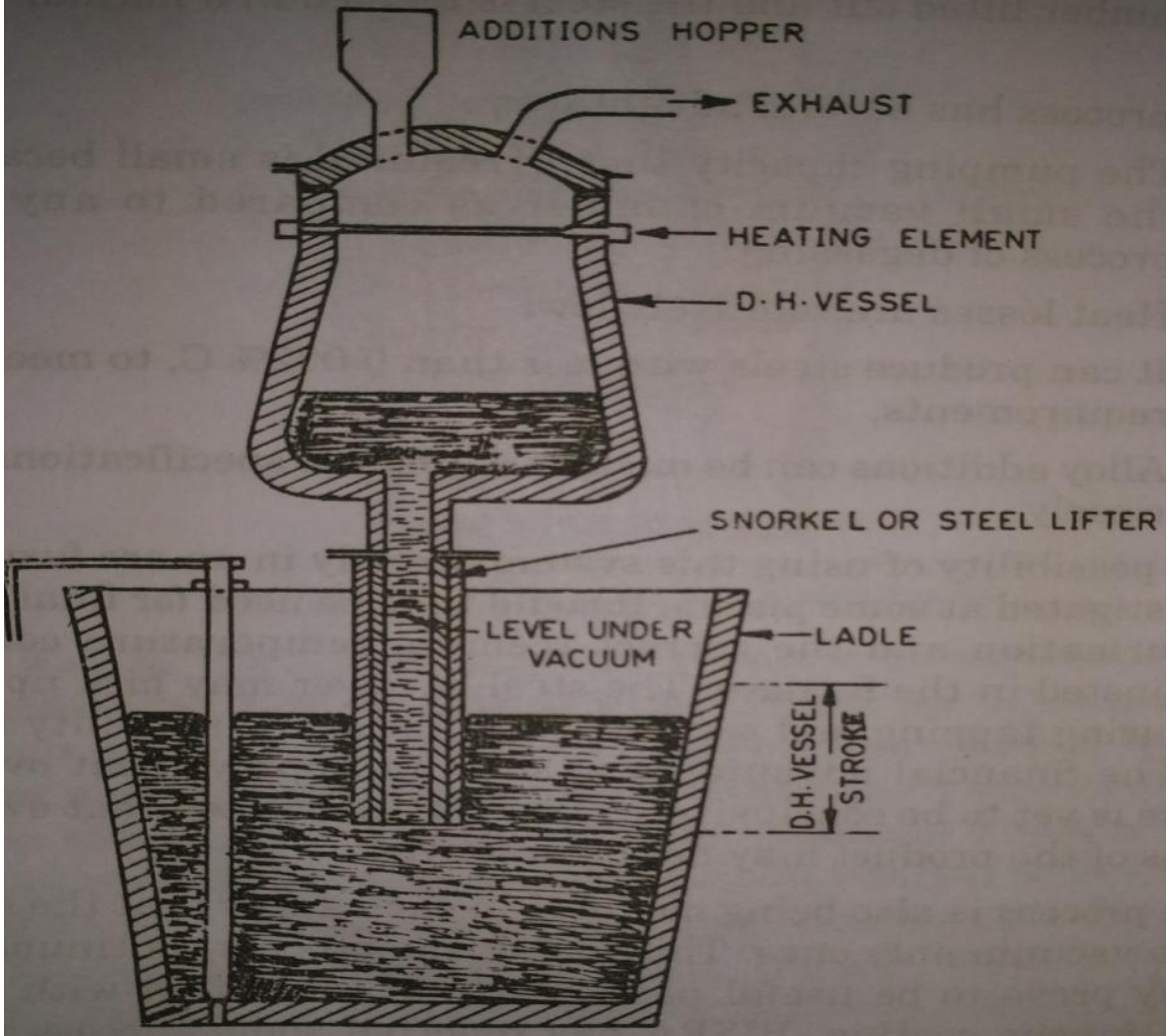


Fig. 27·8. D-H process of degassing.

- The DH chamber is equipped with heating facility, alloying addition arrangement and exhaust systems.
- Bottom of the cylindrical vessel is provided with a snorkel which can be dipped into molten steel.
- The upper portion of the DH vessel is lined with the fireclay and the lower portion with the alumina bricks, snorkel is lined with high quality alumina brick.
- The length of the snorkel is sufficiently large to realize the effect of atmospheric pressure on rise of steel in the snorkel.

THE FOLLOWING STEPS MAY BE NOTED FOR OPERATION

i) DH vessel is preheated and lowered in the ladle so that snorkel tip dips below the molten steel surface

ii) The evacuated chamber is moved up and down so that steel enters the chamber

iii) The chamber is moved for 50-60 times with a cycle time of 20 seconds.

iv) Adequate degassing is possible in 20 -30 cycles.

v) A layer of slag is kept in the ladle to minimize heat losses.

vi) The DH degassing unit can operate with lower superheats compared with RH since DH unit has heating facility

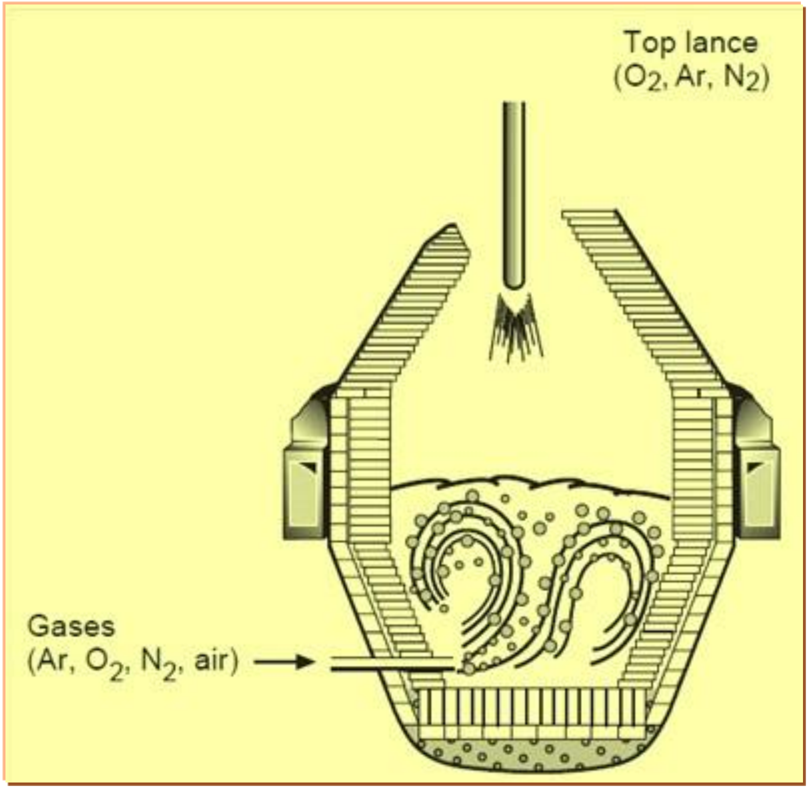
SECONDARY STEEL MAKING

- Secondary steel making is resorted to achieve one or more of the following requirements:

1. Improvement in quality.
2. Improvement in production rate
3. Decrease in energy consumption
4. Use of relatively cheaper grade or alternatively raw materials.
5. Use of alternate sources of energy
6. Higher recovery of alloying elements.

AOD PROCESS

✓**Argon oxygen decarburization** (**AOD**) is a process primarily used in stainless steelmaking and other high grade alloys with oxidizable elements such as chromium and aluminum.



✓After initial melting the metal is then transferred to an AOD vessel where it will be subjected to three steps of refining:

1. Decarburization
2. Reduction
3. Desulphurization

Decarburization:

✓The decarburization step is controlled by ratios of oxygen to argon or nitrogen to remove the carbon from the metal bath.
✓The gases are usually blown through a top lance (oxygen only) and tuyeres in the sides/bottom (oxygen with an inert gas shroud).
✓ In the stages of blowing carbon is removed by the combination of oxygen and carbon forming CO gas.

$$4\ Cr_{(bath)} + 3\ O_2 \rightarrow 2\ Cr_2O_{3(slag)}$$
$$Cr_2O_{3(slag)} + 3\ C_{(bath)} \rightarrow 3\ CO_{(gas)} + 2\ Cr_{(bath)}$$

✓To drive the reaction to the forming of CO, the partial pressure of CO is lowered using argon or nitrogen.
✓The burning of carbon increases the bath temperature.
By the end of this process around 97% of Cr is retained in the steel.

Reduction:

✓after a desired carbon and temperature level have been reached the process moves to reduction.

✓ Reduction recovers the oxidized elements such as chromium from the slag.

✓To achieve this, alloy additions are made with elements that have a higher affinity for oxygen than chromium, using either a silicon alloy or aluminum. The reduction mix also includes lime (CaO) and fluorspar (CaF_2).

✓ The addition of lime and fluorspar help with driving the reduction of Cr_2O_3 and managing the slag, keeping the slag fluid and volume small.

Desulphurization:

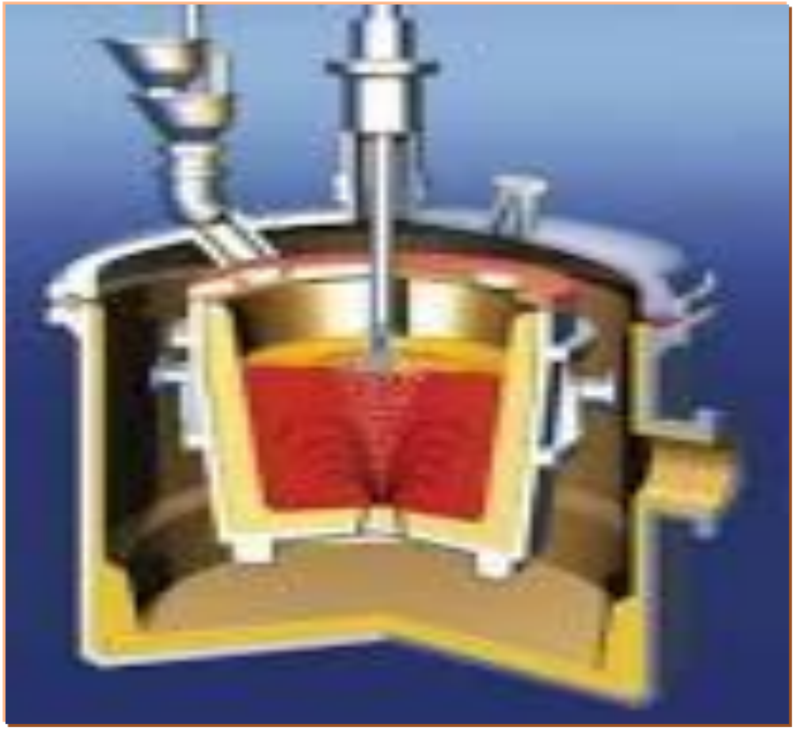
✓Desulphurization is achieved by having a high lime concentration in the slag and a low oxygen activity in the metal bath.

$$S_{(bath)} + CaO_{(slag)} \rightarrow CaS_{(slag)} + O_{(bath)}$$

So, additions of lime are added to dilute sulfur in the metal bath. Also, aluminum or silicon may be added to remove oxygen.

VOD PROCESS

✓Extensive decarburization is achievable with a Vacuum Oxygen Decarburization (VOD) unit.



✓The charge is melted in an arc furnace and the molten metal with around 0.7-0.8% carbon is transferred
To the vod system.

✓This unit is normally used for the deep decarburization of high-alloyed steel grades, usually to remove carbon without affecting the content of chromium in the production of stainless steel grades.

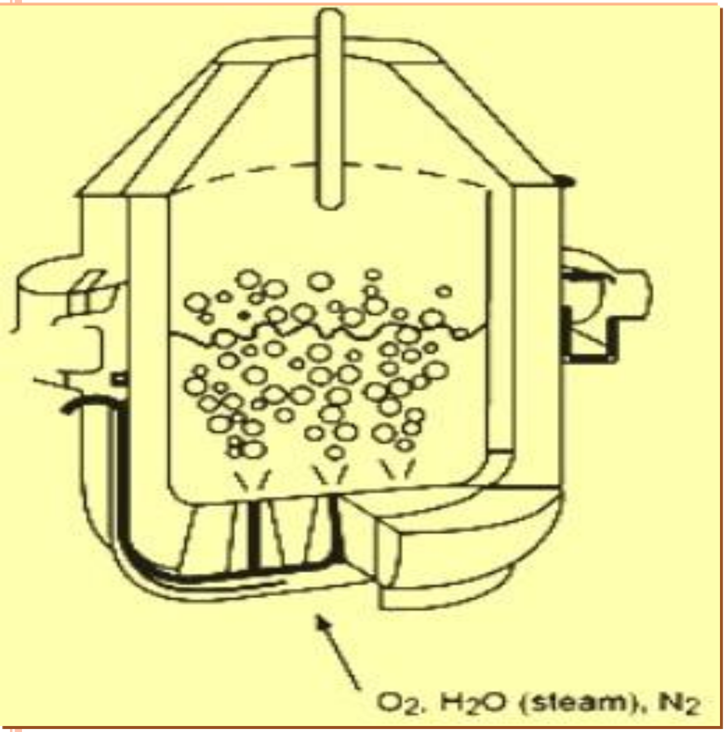
✓The carbon can be lowered to around 0.02% at around 15-18% chromium at a temp. 1600*c. & time taken by vod process is about 2 hr to 2 hr 30 min.

ADVANTAGES:

✓Extensive decarburization with low chromium losses.
✓Flexibility to use high carbon alloying materials of lower cost.
✓High rate of chromium recovery by proper additions.
✓Chemical heating of liquid steel.
✓Improved conditions for desulfurization by proper additions.
✓Improved conditions for Inclusion flotation.

CLU PROCESS

✓CLU process is similar to the AOD (argon oxygen decarburization) process for making stainless steels. CLU refers to the Creusot-Loire Uddeholm process.



✓It also uses liquid steel from an electric arc furnace (EAF) or any other similar primary steel making furnace.
✓ The major development of the CLU process was the idea to use superheated steam as the diluting gas instead of argon (Ar) gas which is used in the AOD process.

✓A mixture of oxygen, steam, argon , nitrogen and air is blown from the bottom. Depending on the chemestry bath.

✓The presence of the steam controlls the temp around 1650-1680*c.
✓Chromium oxidized earlier are reduced back by addition of Fe-Si , Cr-si.

✓$H_2O\ (g) + 241.9\ \text{kJ/mol} = H_2\ (g) + 0.5\ O_2\ (g)$

✓The steam dissociates in the steel, and the hydrogen (H_2) acts as a flushing gas in the same way as Ar in the AOD process, and the O_2 acts as a refining medium.

✓The process the steel bath. This helps in controlling the temperature of the steel bath. of dissociation of steam is endothermic and takes heat from the steel bath. This helps in controlling the temperature of the steel bath.

ADVANTAGES

✓The possibility of controlling the temperature during the decarburization.

✓The cost of dilution gas is low.

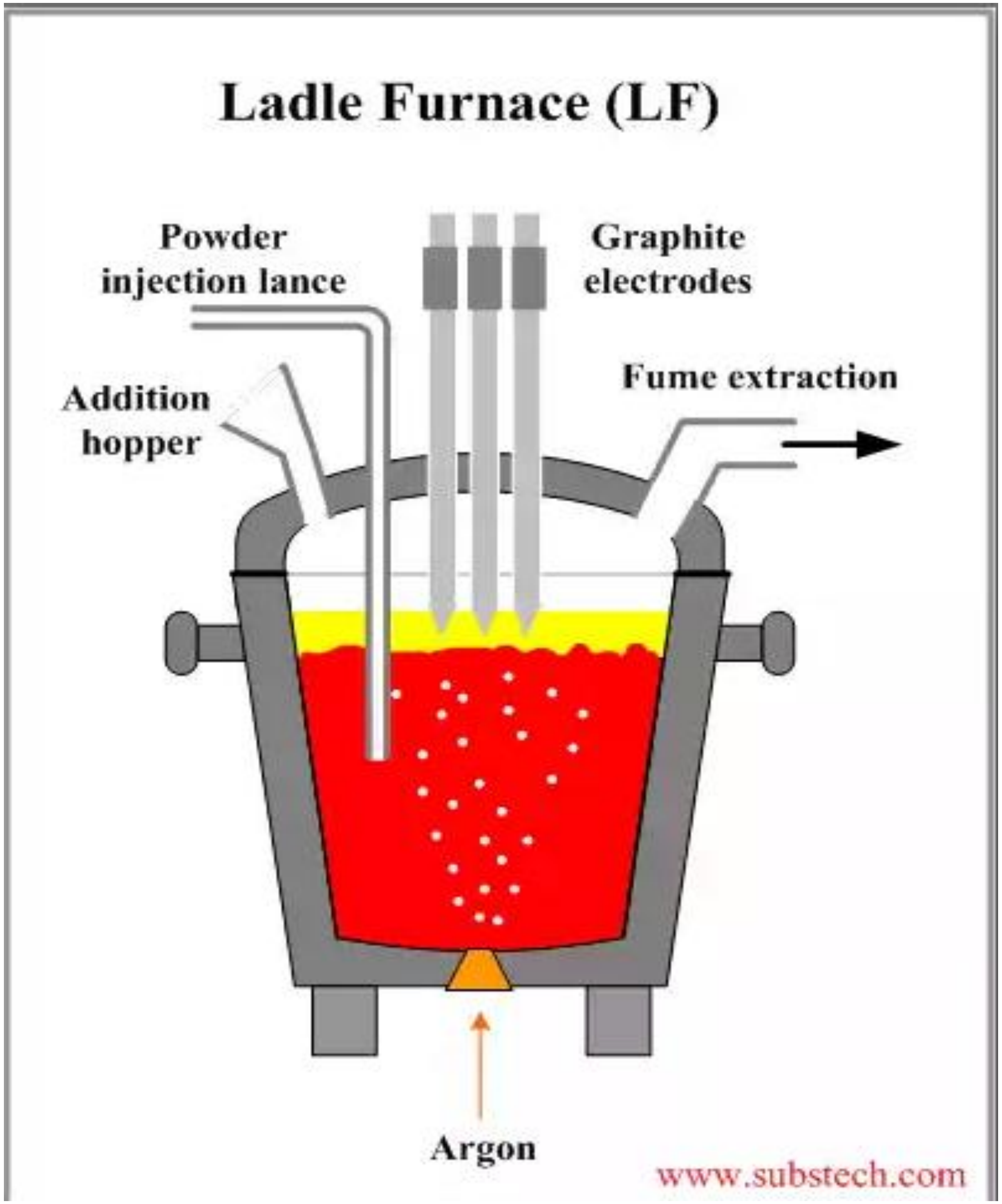
✓The process uses low priced ferrochromium (Fe-Cr) with high Si and C contents.

✓The low operating temperature.

LADLE FURNACE

- Non-metallic inclusions are naturally occurring and typically undesired products that are formed into various types depending on their favourable thermodynamic conditions in almost all treatment practices involving molten steels.
- The equipment and processes are equally varied. Secondary Refining processes are performed at atmospheric pressure or under a vacuum, with or without heating, solids and/or gas injection, and stirring.
- The purposes of secondary refining are many: temperature homogenization or adjustment; chemical adjustments for carbon, sulphur, phosphorus, oxygen and precise alloying; inclusion control; degassing, and others.

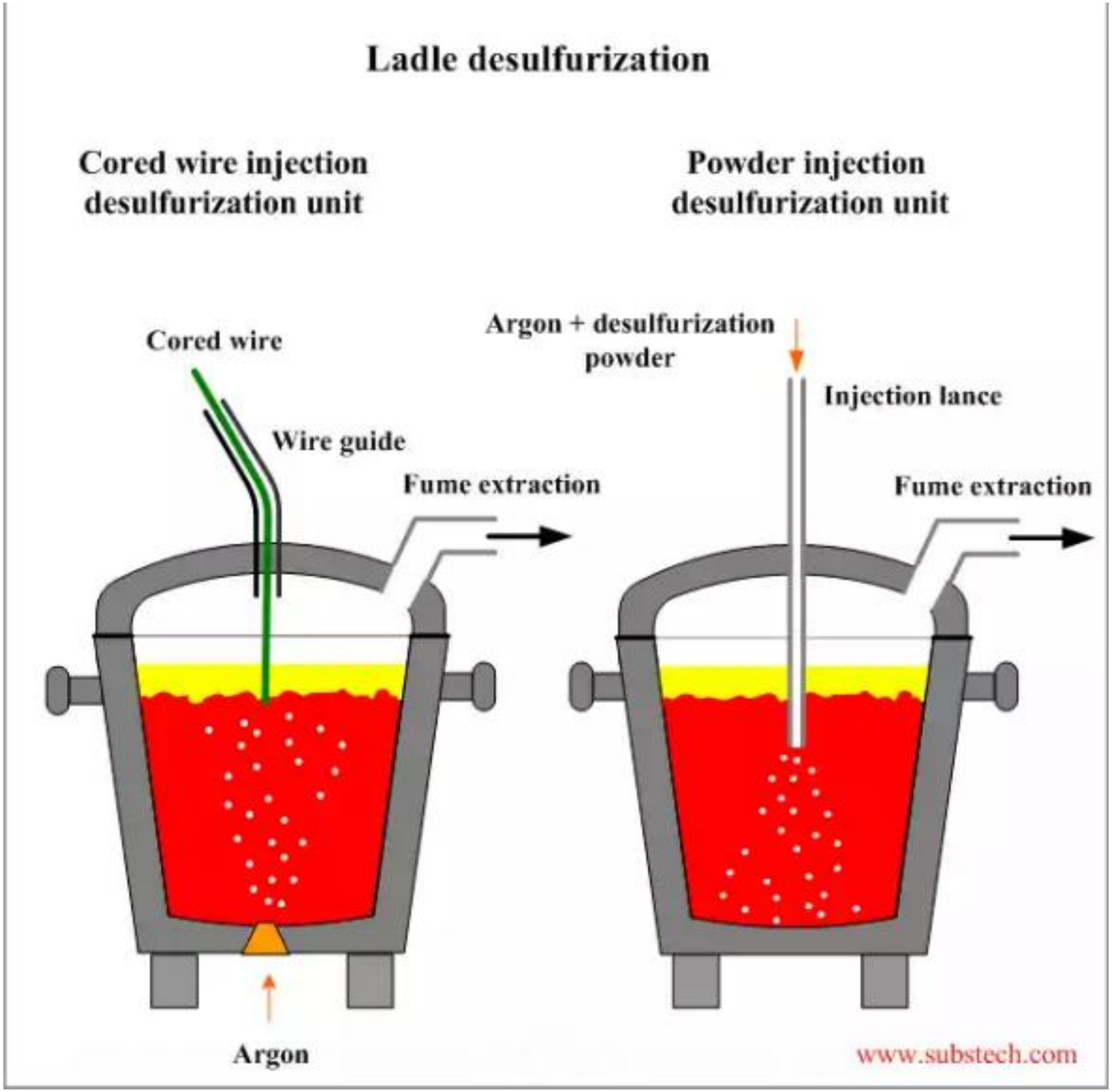
- After tapping from electrical arc furnace, the ladle furnace is put on LF refining position.
- LF refining is conducted through arc heating and argon blowing.
- During this process, the steel deoxidization, desulfurization, the adjustment of steel temperature and chemical composition are completed.
- In primary slag, there is no vacuum function in LF, but room of vacuum device may be obligated in LF zone for future development.


Ladle Furnace (LF)
Powder injection lance
Graphite electrodes
Addition hopper
Fume extraction
Argon
www.substech.com

- A Ladle Furnace is used to relieve the primary melter of most secondary refining operations, and its primary functions are:
  - Reheating of liquid steel through electric power conducted by graphite electrodes
  - Homogenization of steel temperature and chemistry through inert gas stirring
  - Formation of a slag layer that protects refractory from arc damage, concentrates and transfers heat to the liquid steel, trap inclusions and metal oxides, and provide the means for desulphurization

SECONDARY FUNCTIONS

- Alloy additions to provide bulk or trim chemical control
- Cored wire addition for trimming or morphology control
- Provide a means for deep desulphurization
- Provide a means for dephosphorization
- Act as a buffer for down stream steelmaking equipment


Ladle desulfurization
Cored wire injection desulfurization unit
Powder injection desulfurization unit
Cored wire
Wire guide
Fume extraction
Argon
Argon + desulfurization powder
Injection lance
Fume extraction
www.substech.com

SPECIFICATION OF THE LF

- LRF of liquid metal is a proven technology to produce high quality steel. Also used to raise the temperature and adjust the chemical composition of molten metal.
- LRF are used to desulphurise steel, remove other impurities and hold the molten steel for casting operations.
- Costs of extended furnace time, refractory wear and power/fuel consumption can all be reduced using LRFs to perform holding and refining.

- Reduced scrap melting capacity in BOF is another disadvantage of higher tap temperatures. LRFs also acts as a buffer between BOF and EAF and the Continuous Caster, reducing casting costs and allowing greater flexibility in steel making operations.

WORKING OF LRF

- The function stirring of molten metal is to promote homogenization. Normal stirring operations are performed by percolating argon gas through a purge arrangement in the bottom of the ladle.
- A top lance mechanism serves as a back up means for bath stirring in the event the plug circuit in the ladle is temporarily inoperable.
- The gas supply connection to the ladle is automatically when made the ladle is placed on the transfer car.

- Fumes and particulates generated during heating and alloying operations at the LF will exit the water-cooled ladle roof through the various openings in the roof.
- The ladle roof is typically a water-cooled design with a refractory center or delta section and is configured to coordinate with existing ladles such that roof will completely cover the top portion of the ladle when in operating position.

LRFs ARE USED FOR THE FOLLOWING REFINING PROCESS:

- Homogenization
- Inclusion Flotation
- Desulphurization
- Vacuum degassing

renewed after each dip, and can add to costs since they are quite expensive.

16.5 MAJOR INPUTS FOR BOF STEELMAKING

16.5.1 Hot Metal

Hot metal quality is clearly of prime importance in BOF steelmaking. The importance becomes more when high *hot metal ratios* (the proportion of hot metal in the total charge) of the order of 95–99% are used. The reverse is true when scrap (or other coolants) is abundantly available and the hot metal ratio is intentionally lowered to 70–75%. The subject of hot metal composition has already been discussed in Chapter 11 and will not be elaborated further. However, another characteristic of hot metal, viz. its temperature is also of significance in BOF steelmaking. The hot metal temperature has to be high enough to permit easy transfer from the torpedo ladles to the transfer ladle, efficient pre-treatment without giving rise to problems like skull formation on the injection lance, smooth charging into the BOF, etc.

16.5.2 Coolants (IRON ORE/DRI/SCRAP)

In determining the amount of solid charge used in a BOF at any point of time, the primary factors are cost/availability of hot metal, cost/availability of scrap or iron oxide (both are coolants) and the amount of fluxes required. The physical condition of all these solids is also important, since it influences their melting rate during the progress of the blow.

The quality and the composition of scrap are of particular significance in achieving the final composition of the steel tapped. If the scrap charged contains elements like copper, tin and nickel, these elements do not get removed as oxides, and the metals report to steel, resulting even in off-grade products. Another area of concern is the degree of oxidation of the scrap, which may have a significant influence on the *charge balance* (proportion of liquid to solid charge), since

Fe_2O_3 contents as high as 15% may be introduced in this way. A virgin alternative iron source is direct reduced iron (DRI) and with increasing availability of DRI, its usage in the appropriate size (3–15 mm) in BOF steelmaking is also increasing. When calculating the amount of the coolant required, it is important to note that DRI cools 10% more efficiently than scrap for the same weight; whereas, the *cooling factor* of iron ore is 3.0–3.5 times greater. Usage of large amounts of iron ore is often precluded by extensive slopping from the vessel mouth, since the iron ore added is not immediately 'in equilibrium' with the bath. Slopping can be reduced by decreasing the rate of iron ore addition and/or altering the blowing strategy so that the emulsion collapses.

16.5.3 Flux Materials

The quality of fluxes to be used for slag making is an important issue. The flux materials must have sufficient strength to withstand handling during transport to the bins above the converter. Reactivity is another factor that determines the quality of the flux. Insufficient physical strength gives rise to extensive dust generation and carry-over of the flux (as lime powder) into the exit gas, resulting in erroneous basicity of the slag as well as an increase in the p_H level of water in the gas-cleaning plant. This causes deposition of lime in the water treatment section, which has to be avoided to the maximum extent.

16.5.4 Oxygen

This is an important input material whose quality is often not adequately highlighted. The minimum purity of oxygen to allow the production of the full range of carbon steel products should be 99.9%. The final turndown nitrogen and hydrogen contents of steel are dependent not only on the amounts of these elements present in hot metal/fluxes, but also on oxygen.

During the early stages of the oxygen blow, when the rate of carbon monoxide evolution is high, the nitrogen content of the bath decreases, i.e. de-nitrogenisation occurs. However, when the decarburisation rate begins to fall (after 12–15 minutes) the nitrogen content can increase substantially if oxygen of adequate purity is not used.

16.6 PRE-TREATMENT OF HOT METAL PRIOR TO STEELMAKING

Owing to the stringent demands placed in recent years by steel consumers as far as the properties of steel products in terms of their strength, toughness, drawability under extreme forming conditions, etc. are concerned, it has become mandatory to reduce the impurity levels in steel drastically; in some cases, even to a few parts per million (ppm).

Silicon, carbon, sulphur and phosphorus are the elements present in hot metal that have to be removed. At the end of the oxygen blowing period, the carbon level in the bath is normally between 0.03% and 0.04%. For lower carbon levels, vacuum treatment is normally resorted to. As far as silicon is concerned, it gets removed almost completely during steelmaking since this is a thermodynamic precondition for the oxidation of carbon. However, the removal of sulphur and phosphorus are not as straightforward. These elements continue to remain in liquid steel, to various extents, at the end of the blow.

To produce internal crack-free products with acceptable surface quality, it is necessary to lower the levels of sulphur and phosphorus to less than 0.010 percent each (sometimes, even less than 0.005%). To achieve such low values, it is often desirable to charge hot metal containing low amounts of sulphur and phosphorus into the BOF. Otherwise, under the oxidising conditions prevailing during steelmaking, it becomes almost impossible to reduce both sulphur and phosphorus economically. At the same time, owing to factors like decreasing availability of low sulphur coke and the use of high phosphorus-bearing iron ores, it is not always possible to produce low sulphur, low phosphorus hot metal in blast furnaces. Hence, pre-treatment of hot metal to remove sulphur/phosphorus prior to BOF steelmaking has gained worldwide acceptance as an intermediate operation. For this purpose, an extra step (in some cases, more than one step) has to be introduced between the blast furnace and the BOF shop.

The details of the reactions involved in the removal of these elements from liquid iron have been covered in other chapters. Chapter 4 has dealt with the general physicochemical fundamentals, including slag basicity and their capacities to absorb of sulphur/phosphorus. Chapter 5 has discussed the theory of reactions of sulphur, and silicon. Chapter 15 provides an insight into the physical chemistry of steelmaking reactions for silicon, carbon, phosphorus, etc. Hence, these are not being repeated here.

16.6.1 Objectives of Pre-treatment

Hot metal pre-treatment envisages removal of sulphur, and sometimes even silicon plus phosphorus, by the addition of suitable reagents. To increase the surface area so that the reactions occur rapidly, these reagents are normally injected into hot metal in the form of fine powder. While desulphurisation of hot metal has now become standard practice in virtually all plants, in some cases, desiliconisation also becomes necessary, particularly since it is a pre-requisite for the removal of phosphorus. However, desiliconisation automatically decreases the amount of scrap that can be concurrently used in the BOF charge (the extent of heat generation becomes restricted), which is not always desirable from an economical point of view. This is particularly detrimental if the objective is to decrease the hot metal ratio from 92–95% (common in the last few years in countries like Japan owing to excess hot metal capacity) to 82–85% (at times when scrap is relatively inexpensive).

Over and above the ability to produce steel with very low levels of sulphur and phosphorus, there are some additional advantages that accrue from hot metal pre-treatment. These include:

- increased opportunity to recycle steelmaking slags (low in phosphorus) to the blast furnace for recovering iron and manganese units
- possibility of 'slagless' or 'limeless' steelmaking from hot metal low in silicon, sulphur and phosphorus. The advantage of 'slagless' refining is less flux consumption, decreased slopping, increased productivity, and improved hit rates at the end of the blow. The ultimate goal is to use BOFs for decarburisation alone (many Japanese plants have already been successful in achieving this goal).

16.6.2 Removal of Silicon

– by mill scale

– O_2 blowing in another converter

Silicon in hot metal can be removed by injecting an oxidising agent like mill scale (accompanied by lime to help produce a neutral slag), or by taking recourse to a separate step of oxygen blowing in another converter to produce highly siliceous slag (in the presence of lime) before the desiliconised hot metal is transferred to a second converter, for the other reactions to proceed. This type of two-slag BOF operation gives rise to the following advantages:

- Improved dephosphorisation during steelmaking since highly basic slags can be formed early in the blow
- Reduction in the converter slag volume accompanied by an increase in the iron yield (less iron loss in the slag), longer converter campaigns (less attack on the lining from siliceous compounds in the primary slag), etc.
- Lower consumption of ferro alloys because of higher recovery arising on account of the lower levels of dissolved oxygen in liquid steel
- Easier dynamic control of the process to arrive at the desired end point.

Despite these advantages, desiliconisation is not normally practiced essentially because of problems in handling the highly siliceous slag that is produced. Such slags have high temperature and are extremely fluid, thereby causing aggressive attack on most refractories. Instead, efforts have been made to produce low silicon (0.3–0.6%) hot metal directly in blast furnaces to the maximum possible extent, as discussed in Chapter 11.

16.6.3 Desulphurisation

Desulphurisation is better at the hot metal stage rather than at the steel stage because of the reasons given in Table 16.1 (Gupta and Chatterjee, 1995). Desulphurisation of hot metal in blast furnace ladles en route to the steel melting shop has become a standard practice because:

- The productivity of blast furnaces can be improved by 6–8% when sulphur control within the blast furnace is not required, and a leaner slag chemistry as well as lower slag volume can be chosen
- The consumption of coke as well as fluxes decreases, thereby reducing the total energy consumption per tonne of hot metal
- Build-up of alkalis in the blast furnace gets restricted, and
- The production of low silicon hot metal becomes easier.

Table 16.1 Comparison of desulphurisation of hot metal vis-à-vis steel

Parameter	Hot metal desulphurisation	Steel desulphurisation
Oxygen potential	Low (slag FeO = 0.25%)	High (slag FeO = 18–20%)
Temperature	1300–1550°C	Greater than 1600°C
Activity coefficient	4.5–6	1.5
Cost of desulphurisation	Low	High
Desulphurisation efficiency	High	Low
Temperature drop	Can be manipulated	Cannot be manipulated

16.6.4 Dephosphorisation

Theoretically speaking, dephosphorisation of hot metal allows:

- Increased recycling of BOF slag to the blast furnace, thereby reducing the cost of hot metal
- Steel for continuous casting to be tapped at higher temperature without the risk of rephosphorisation
- Control on the extent of segregation of phosphorus during continuous casting
- Lower final sulphur and phosphorus contents in steel, particularly high alloy steel.

However, dephosphorisation is normally not carried out during the production of bulk steels, since from free energy considerations, it can only be done under oxidising conditions, and in the presence of a highly basic slag. This is possible only after the total removal of silicon (dictated by thermodynamics). At the same time, while phosphorus is best removed at low temperature, desiliconisation automatically increases the temperature (the reaction of oxygen with silicon is highly exothermic). The dichotomy of the situation is evident. Therefore, alternative strategies for controlling the phosphorus content of hot metal by choosing appropriate raw materials, or by adopting a modified BOF process (e.g. concurrent injection of lime and oxygen in the converter) to process high phosphorus (1–2%) hot metal, have found favour. However, some Japanese steel plants, which produce very low silicon hot metal (less than 0.3%) in their blast furnaces, have been able to practice simultaneous desulphurisation and dephosphorisation of hot metal.

16.7 REAGENTS USED FOR PRE-TREATMENT

16.7.1 Soda-ash

For DeSi, DeS, DeP

When soda-ash (sodium carbonate) is added to hot metal, dense fumes are generated, which can create environmental problems. Disposal of soda-bearing slags gives rise to ground water contamination. This is the primary reason why the use of soda-ash has been restricted in recent times, though it is an effective reagent for both desiliconisation and desulphurisation.

Sodium carbonate is comparatively stable up to 1200°C, above which it decomposes:

$$Na_2CO_3(l) = Na_2O(l) + CO_2(g) \tag{16.1}$$

A portion of the Na_2O produced dissolves in liquid Na_2CO_3 (m.p. = 851°C) while the remainder decomposes:

$$Na_2O(l) = 2Na(g) + \tfrac{1}{2}O_2(g) \tag{16.2}$$

In hot metal containing carbon and silicon, the following reactions take place:

$$Na_2CO_3(l) + 2[C] = 2Na(g) + 3CO(g) \tag{16.3}$$

$$Na_2CO_3(l) + [Si] = Na_2O.SiO_2 + [C] \tag{16.4}$$

$$Na_2CO_3(l) + 2[C] + [S] = Na_2S + 3CO(g) \tag{16.5}$$

Since the reactions related to the decomposition of Na_2O and Na_2CO_3 to Na (g) proceed rapidly at high temperature, lower temperatures are preferable for desulphurisation (reaction 16.5). Soda-ash is a very effective reagent for desulphurisation and dephosphorisation in the case of low silicon hot metal.

2 : 1

16.7.2 Mixture of Soda-ash and Sodium Sulphate

DeP

The use of sodium carbonate and sodium sulphate together for pre-treatment of hot metal has also been investigated. The incorporation of sodium sulphate helps in dephosphorisation in the following manner:

$$Na_2SO_4(l) + (4/5)P = (2/3)Na_2O(l) = (2/5)P_2O_5(l) + (1/3)Na_2S(l) + (2/3)SO_2 \quad (16.6)$$

A mixture of soda ash and sodium sulphate is advantageous in pre-treating hot metal because of the low melting points of the constituents: Na_2CO_3 (m.p. = 851°C) and Na_2SO_4 (m.p. = 884°C). A mixture of the two in the weight ratio of 2 soda-ash and 1sodium sulphate is considered to be the optimum.

16.7.3 Mill Scale, Sinter Fines, etc.

, O_2, io/mn ore fines → DeSi

Desiliconisation can be carried out by using primary reagents like gaseous oxygen, mill scale, sinter fines, iron ore/manganese ore fines, etc. Along with the primary reagent, an auxiliary agent containing CaO, (CaO + CaF_2), (CaO + CaF_2 + Na_2CO_3) is also added. In several cases, BOF slag is used.

16.7.4 Calcium Carbide and Magnesium Granules

→ DeS

The desired level of sulphur in steel for efficient continuous casting is a maximum of around 0.020%. In the case of special steel plates, the sulphur content has to be restricted to around 0.010% normally. However, there is demand for sulphur levels as low as 10 ppm (0.001%), in the case of steel used in pipe lines (commonly referred to as line pipe steel) that have to be guaranteed against hydrogen induced cracking when sour gas is conveyed. To cater to all such requirements, the sulphur content in hot metal has to be brought down to at least 0.010–0.025%. This is normally achieved by injecting suitable powders like calcium carbide. In actual practice, calcium carbide containing limestone, lime and carbon is used as a mixture as in Table 16.2 (Dutta et al. 1996).

Table 16.2 Typical calcium carbide mixtures used for desulphurisation

Grade	Reagent composition, %			
	CaC_2	$CaCO_3$	CaO	C
CAD 60	48	31	17	4
CAD 70	56	22	19	3
CAD 80	64	14	20	2
CAD 85	68	9	22	1

Lime contributes towards enhancement of the basicity of the micro-slags that are formed, while dissociation of limestone provides carbon dioxide that is beneficial for agitation. On the other hand, carbon in the mixture helps in maintaining the necessary atmosphere at the reaction sites. These mixtures are injected using nitrogen (in some special cases argon) as the carrier gas. Co-injection of carbide and magnesium metal granules (in the ratio of 2.5–7.0 : 1) at injection rates of typically 20–25 kg/min. and 10–12 kg/min. is also resorted to when extremely low levels of sulphur in hot metal (circa 0.010%) are required. The use of magnesium granules helps to reduce the injection time as well as the slag volume. Addition of lime/soda ash during injection is also practised, when it is necessary to bring down the slag raking time or to reduce the metal loss in the slag. External desulphurisation with such mixtures produces very dry slags, in which substantial amount of metal as granules (below 3 mm) tend to get entrapped.

16.7.5 Injection of Desulphurising Agents

A schematic representation of the entire equipment system employed for the injection of powders into melts is given in Figure 16.4 while Figure 16.5 provides a pictorial view of the same. The powder injector (Figure 16.6) is the most important component of the system.

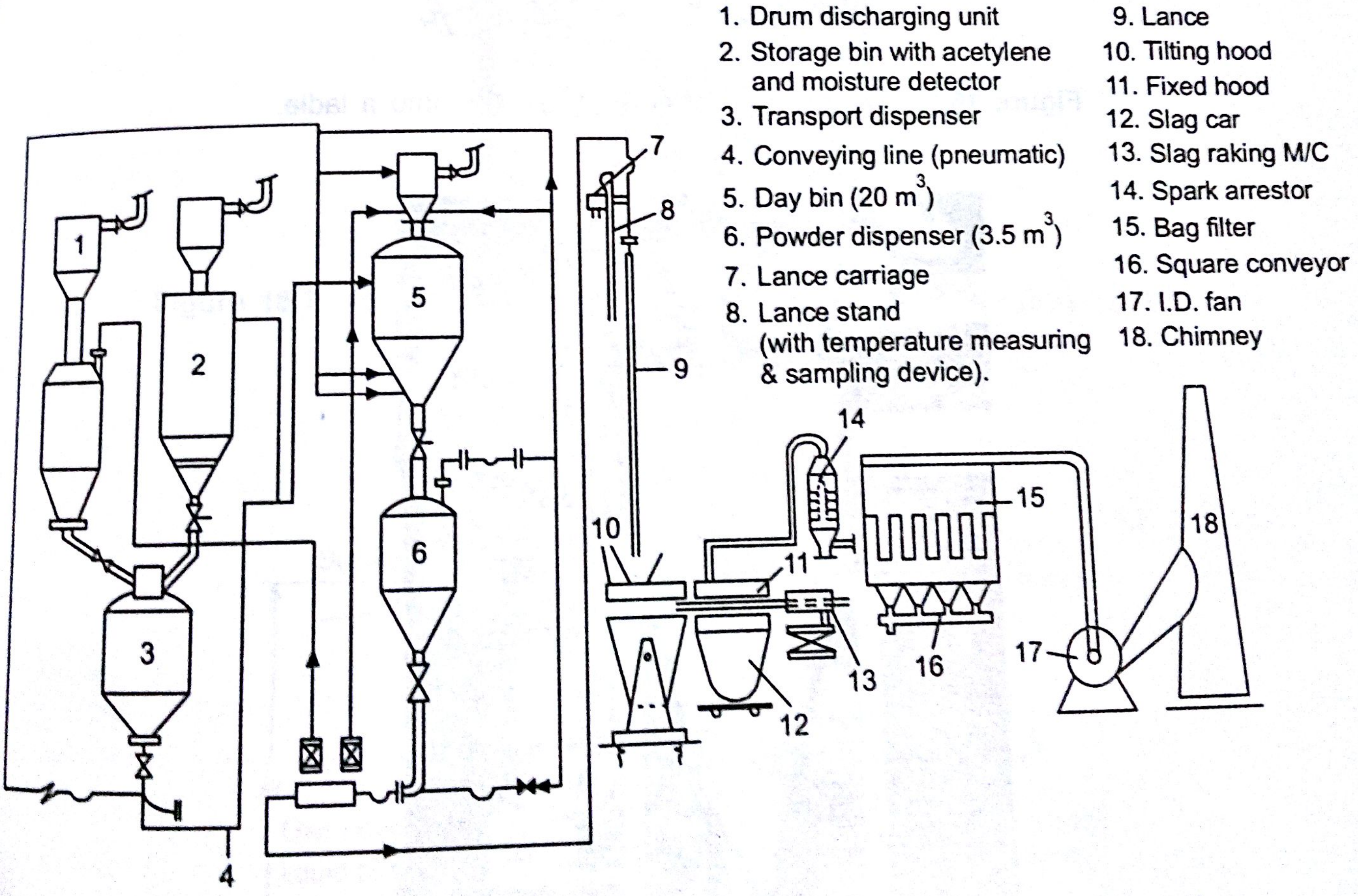


Figure 16.4 Schematic representation of the entire powder injection system.

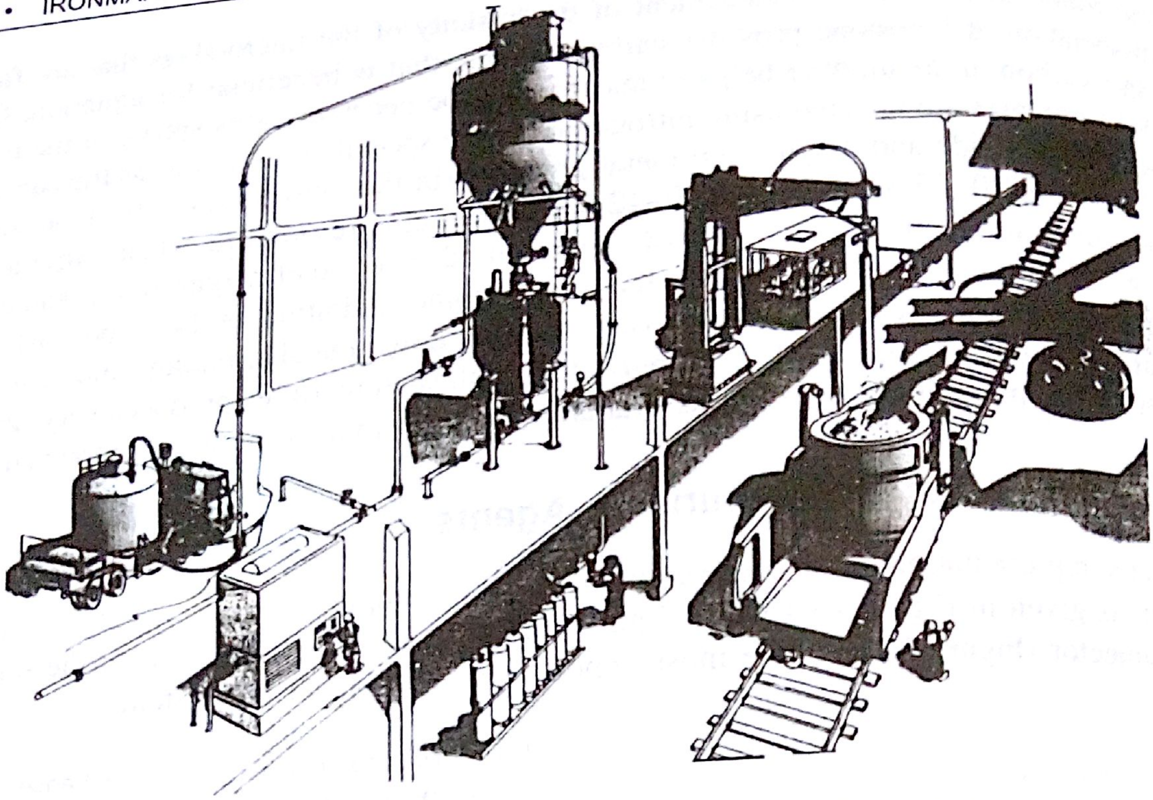


Figure 16.5 Pictorial view of powder injection into a ladle.

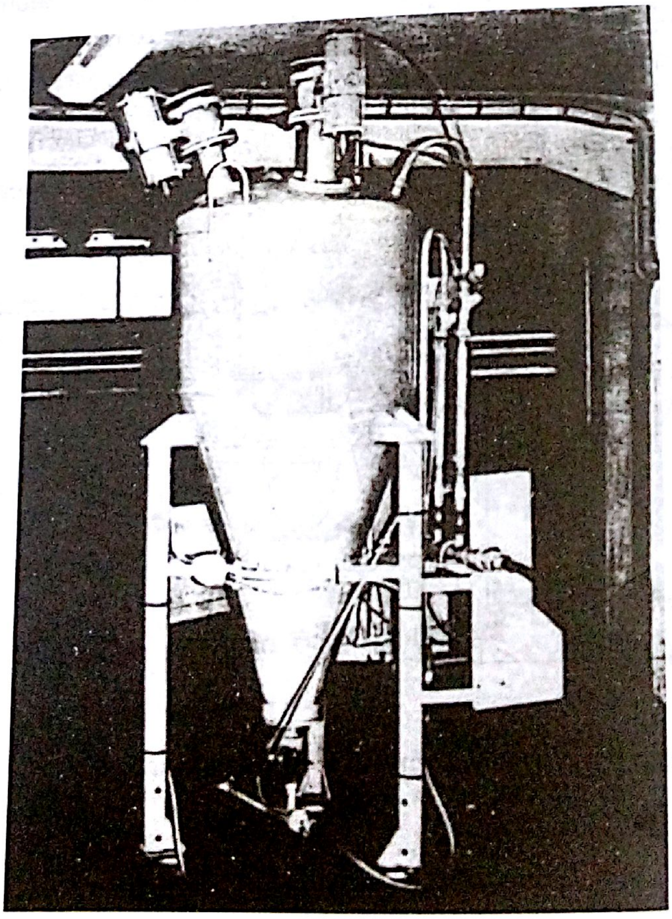


Figure 16.6 Close-up of a typical powder dispenser.

When a powder like calcium carbide is injected, using a carrier gas (nitrogen/argon), the gas and calcium particles penetrate into the liquid hot metal as a gas particle jet until their momentum is dissipated, which has been confirmed by water model studies. At the bottom of the jet, a *plume* (photograph taken in room temperature model studies shown in Figure 16.7) is created, where the gas forms spherical-cap bubbles, 20 to 100 mm in diameter. The physical and chemical phenomena in the plume are shown schematically in Figure 16.8.

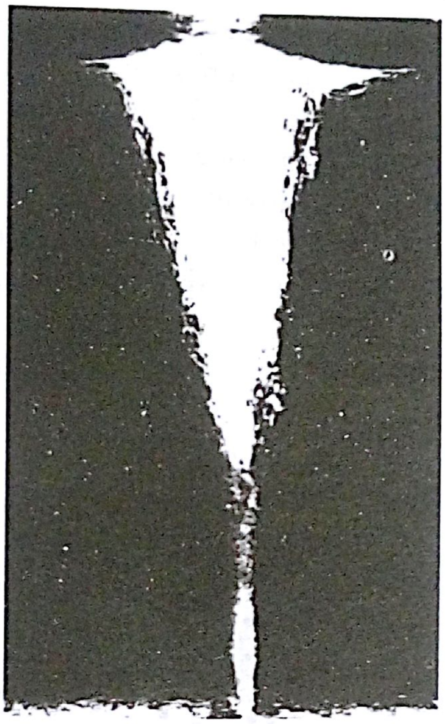


Figure 16.7 Photograph of the plume (air-water room temperature model).

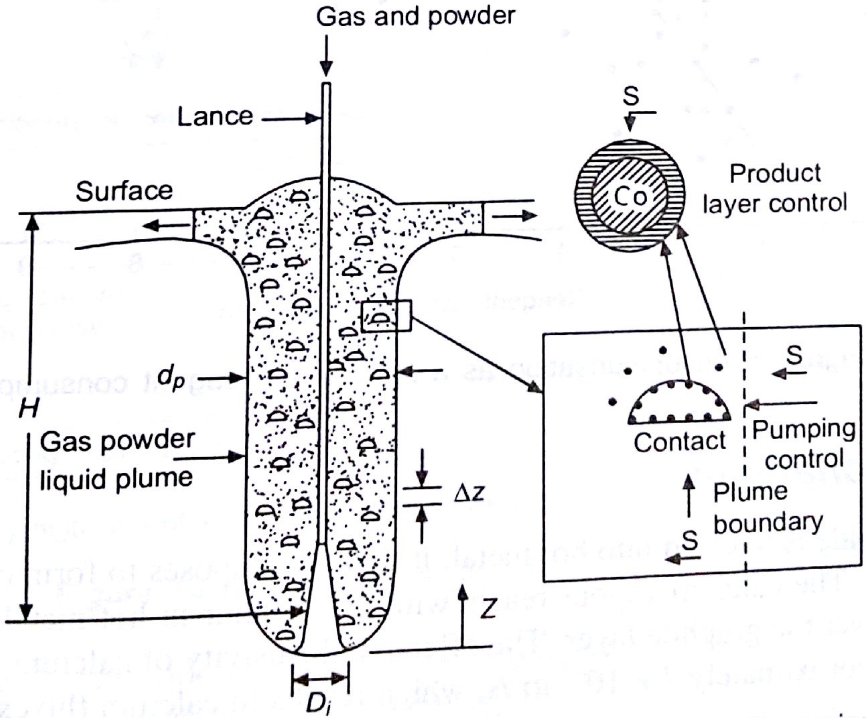


Figure 16.8 Physical representation of bubble formation and powder dispersion following injection.

Owing to buoyancy the gas rapidly accelerates and the drag force between the gas and the liquid causes the liquid to be accelerated as well. The carbide particles which are also buoyant then start to rise—a fraction of the particles rise on the bubble interfaces, while the remainder rises, dispersed in the melt. The particles and gas are heated as they rise, and the particles react, resulting in the removal of sulphur. The rate of mass transfer is governed by the rate at which sulphur-rich liquid is pumped into the plume by entrainment (normally termed *pumping control*) as well as the rate at which sulphur diffuses through the boundary layers to the particles (normally called *contact control*). The rate of desulphurisation with respect to time follows first order reaction kinetics, and the rate of desulphurisation in the plume is determined by the reduction of the sulphur content and the flow rate of liquid at the top of the plume.

Some typical results obtained in an operating unit are presented in Figure 16.9 (Pandey et al. 1996). It is clear that following calcium carbide injection, the kinetics of desulphurisation can be described as first order, with respect to the sulphur content in the hot metal. The first order rate constant is approximately proportional to the square root of the gas flow rate, and the cube of the slag weight. Therefore, removal of slag to the maximum possible extent prior to external desulphurisation, is extremely important.

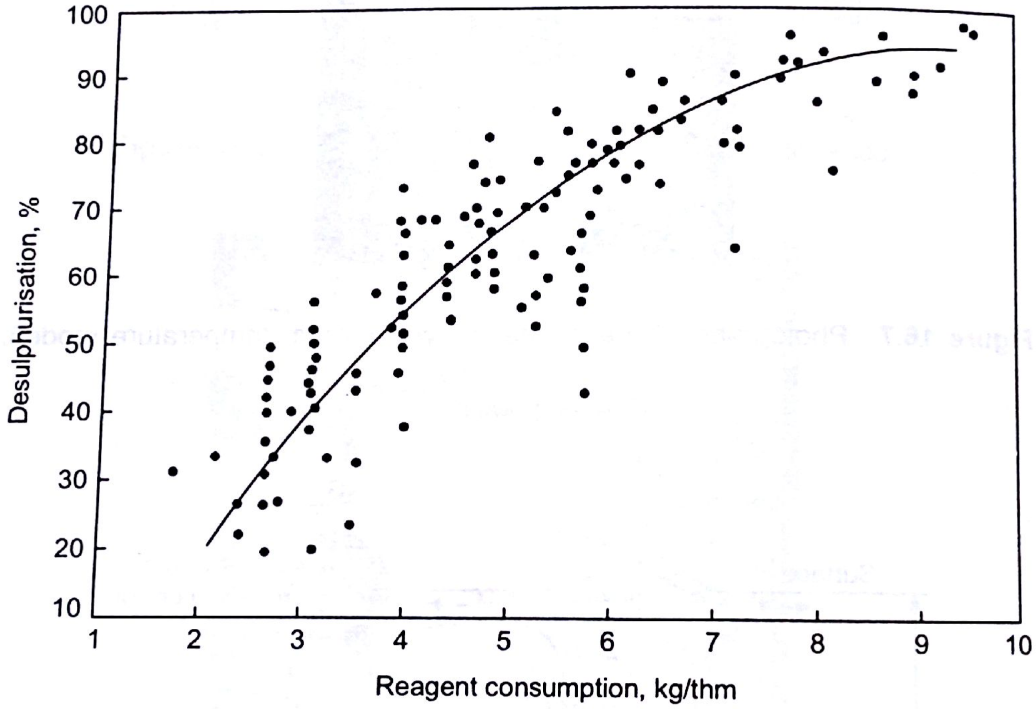


Figure 16.9 Degree of desuplhurisation as a function of reagent consumption (CAD 80).

Reaction mechanism

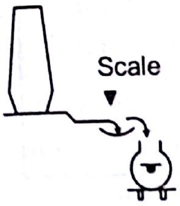
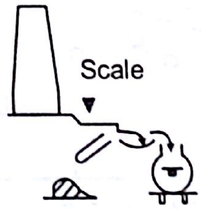
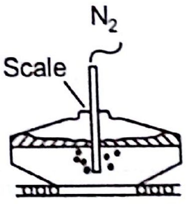
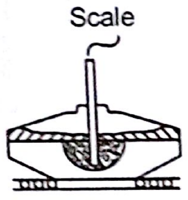
When calcium carbide is injected into hot metal, it first decomposes to form calcium vapour and a layer of graphite. The calcium vapour reacts with the sulphur in hot metal to form a layer of calcium sulphide over the graphite layer. The effective diffusivity of calcium vapour through the product layers is approximately 7×10^{-7} m^2/s, which results in calcium fluxes much greater than fluxes of sulphur through the boundary layers, around each particle. Therefore, the step of calcium diffusion through the product layers does not contribute any significant resistance to the overall rate of desulphurisation. The layers of graphite and calcium sulphide progressively thicken so that the calcium vapour has to diffuse through them. These two layers are formed topo-chemically on the surface of the particles, and the mass transfer resistance offered by the chemical reaction rate is negligible. As a result, the rate of desulphurisation is relatively fast.

16.8 HOT METAL PRE-TREATMENT STATION(S)

16.8.1 Desiliconisation

The blast furnace runner, transfer ladle or torpedo car can be used as the place for desiliconisation as shown in Figure 16.10. The desiliconisation agent is added using one of the following methods:

- Top charging with nitrogen bubbling
- Blasting
- Injection.

Method	In blast furnace runner		In torpedo car and ladle	
	Top addition (1)	Top addition (2)	Top addition	Injection
Schematic diagram		(Slag separation by skimmer) 		
Merits	• Additional process not required	• Easy separation of desiliconisation slag	• Selective treatment possible	• High desiliconisation efficiency ([Si] 0.10% attainable)
Demerits	• Slag foaming in torpedo car	• Low desiliconisation efficiency • Restriction due to cast house layout	• Low desiliconisation efficiency	• Complicated equipment
Remarks	• Blasting method is tested		• O_2 blowing practice can be used jointly	

*Both blasting (very high rate of addition) or normal feeding can be applied

Figure 16.10 Desiliconisation processes used industrially.

In Japan, desiliconisation of hot metal is carried out in the blast furnace runner because of advantages, such as adequate mixing of the reagents owing to the energy of the flowing molten iron stream, saving in time, and increased ladle availability compared with separate desiliconisation in a ladle. Figure 16.11 shows a typical set-up that is often used for runner desiliconisation, along with the results obtained (Gupta and Chatterjee, 1995). It needs to be stressed that hot metal from blast furnace has to be separated from slag using a slag skimmer in the main runner before desiliconising agents such as mill scale and calcined lime are added continuously. Only in this way can the reagent efficiency be increased. Normally, about 20 kg mill scale per tonne of metal is needed to reduce the silicon level from 0.5% to less than 0.2%. On the other hand, for reducing silicon from 1.5% to 0.6%, 35–40 kg/thm is required. The heat balance for runner desiliconisation, given in Table 16.3, indicates that there is no temperature drop during this treatment even though it is carried out in an open runner (Gupta and Chatterjee, 1995). This is because of the heat generated by the oxidation of silicon to silica.

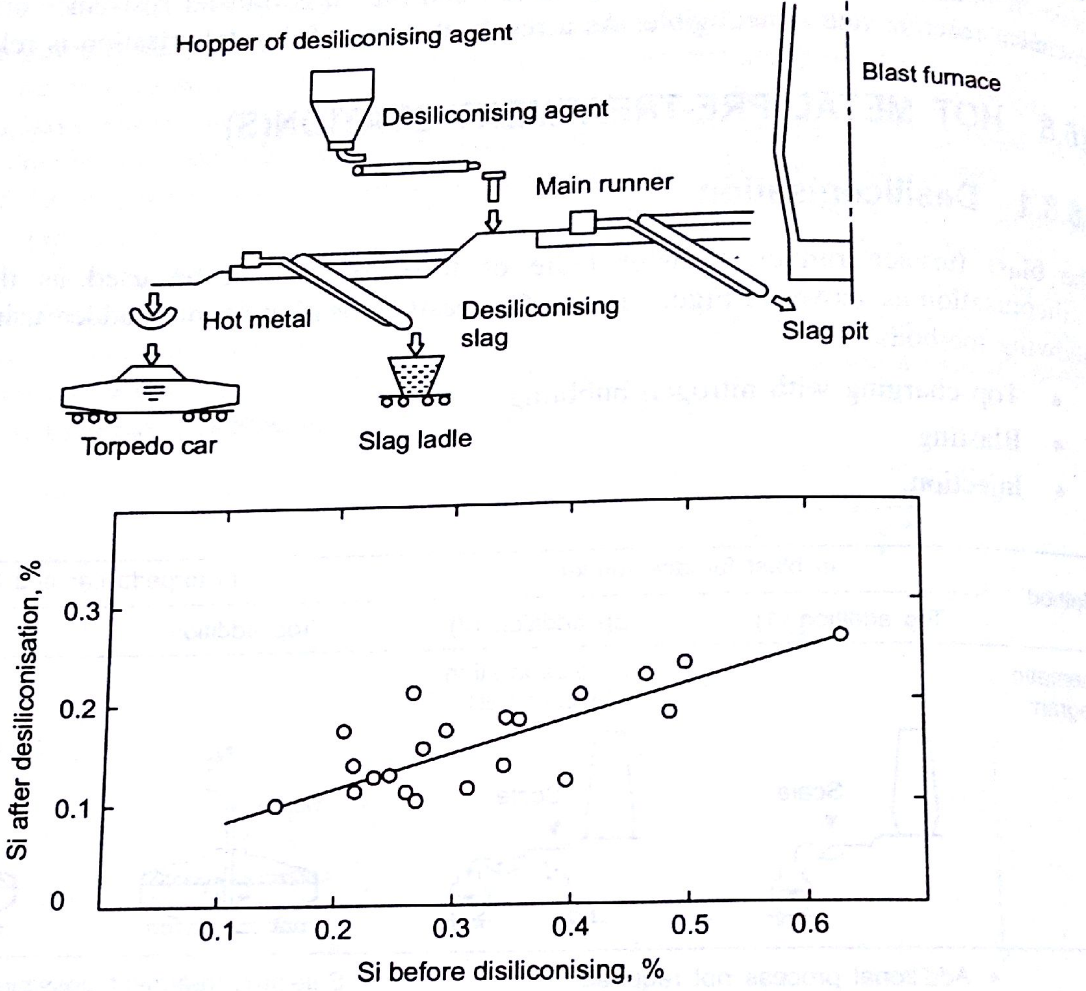


Figure 16.11 Schematic diagram of desiliconisation treatment in a blast furnace runner.

16.8.2 Desulphurisation

Previously, desulphurisation used to be carried out by injecting the desulphurising agent in powder form into blast furnace ladles, en route from blast furnaces to steelmelting shops.

Table 16.3 Typical heat balance for runner desiliconisation treatment

Heat source		Desiliconising with mill scale (mixed with 20% lime) kcal/t	Quantity
Input heat	(1) $Si + O_2 \rightarrow SiO_2$ + 7460 kcal/kg-Si	14920	Si = 0.20%
	(2) Mn + (1/2)O_2, >MnO + 1680 kcal/kg-Mn	840	Mn = 0.05%
	(3) $Ti + O_2 \rightarrow TiO_2$ + 2830 kcal/kg-Ti	570	Ti = 0.02%
	(4) C + (1/2)$O_2 \rightarrow$ CO + 2200 kcal/kg-C	220	C = 0.01%
	(5) Average slagmaking heat 140 kcal/kg-slag	1260	Amount of slag: 9 kg/t
Total Input		17810	
Output heat	(1) FeO → Fe + (1/2)O_2 – 900 kcal/kg-FeO	9040	FeO in mill scale: 77%
	(2) $Fe_2O_3 \rightarrow 2Fe + (3/2)O_2$ – 1230 kcal/kg-Fe_2O_3	2570	Fe_2O_3 in mill scale: 16%
	(3) Sensible heat of slag formed 0.217 kcal/kg-slag. °C	2940	Amount of slag: 9 kg/t
	(4) Sensible heat of iron reduced 0.170 kcal/kg Fe °C	2300	Amount of iron reduced: 9 kg/t
Total output		16850	
Sum total		960	
Net increase in hot metal temperature		+5.6°C	

Nowadays desulphurisation stations normally form a part of the BOF shop. In a typical case of reducing the initial sulphur content of hot metal from 0.070% to a level of 0.020%, i.e. a desulphurisation efficiency of 70–75%, the operating parameters would be:

- Reagent consumption: 5 kg/thm
- Reagent rate: 45 kg/minute
- Hot metal temperature: 1300°C and more.

It is possible to complete the treatment in around 15–20 minutes in most cases by adjusting the reagent addition rate. For this purpose, sometimes even two lances are used as shown in Figure 16.12 (Frithjof et al. 1980).

16.9 SIMULTANEOUS REMOVAL OF SULPHUR AND PHOSPHORUS

Based on Japanese research, the optimum conditions for simultaneous removal of sulphur and phosphorus have been identified as follows:

- Slag basicity, CaO/SiO_2 > 2
- Hot metal temperature < 1400°C
- Hot metal silicon < 0.25%

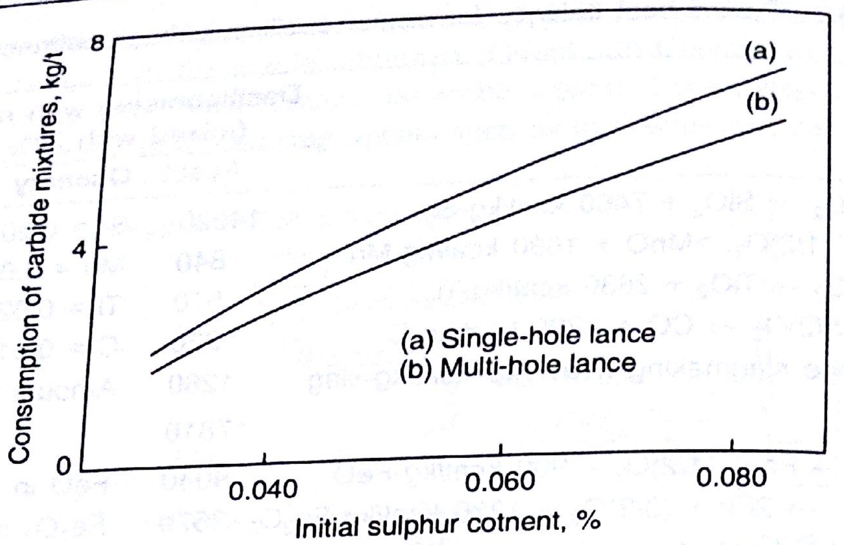


Figure 16.12 Consumption of calcium carbide as a function of the initial sulphur content in hot metal using single-hole and multi-hole injection lances (final sulphur 0.015 %).

The pre-treatment procedure is carried out in two-stages—first, desiliconisation, and second, simultaneous removal of sulphur and phosphorus using either lime-based or soda-based reagents. Since the silicon content of Indian hot metal is far higher than that in Japan, the first-step becomes even more important.

In any case, it is not advisable to attempt the reduction of silicon, sulphur and phosphorus simultaneously because of the following reasons:

- High reagent consumption coupled with abnormal drop in temperature, which would pose problems in steelmaking
- Severe slag handling problems
- Unfavourable techno-economics.

16.10 GENERAL COMMENTS ON PRE-TREATMENT

In recent years, injection metallurgy has been developed to such an extent that it is now widely used to pre-treat hot metal before charging into BOF vessels, thereby virtually restricting steelmaking to decarburisation alone. Desulphurisation has now become an integral part of most integrated steel plants. Reagents like soda ash were directly added into open ladles earlier, but owing to ecological considerations (aggressive fumes, ground water contamination by the post-treatment slag, etc.), injection of calcium carbide based reagents is now widely employed. Efficient removal of the slag after pre-treatment, utilisation of the optimum lance(s) design and geometry as well as the development of suitable refractories for the ladle in which pre-treatment is carried out, are areas in which work is still continuing.

Nonetheless, it can be concluded that with ever-increasing demand for lower levels of impurities in steel (particularly sulphur and phosphorus), pre-treatment of hot metal will be adopted even more widely in the years to come.