

STEEL MAKING

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Composition of pig iron:

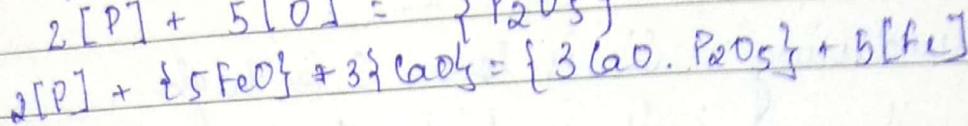
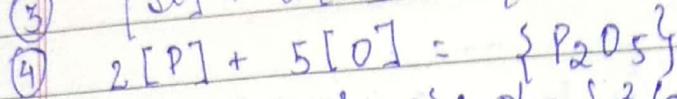
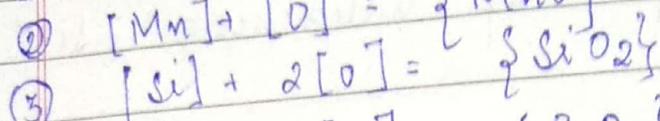
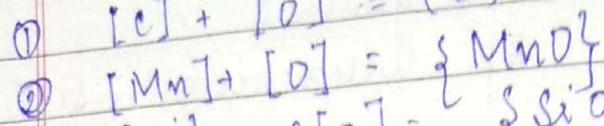
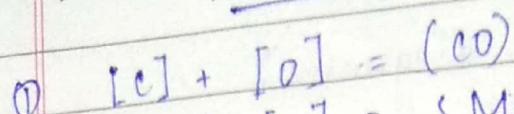
- C ~ 4.1% (from Fe-TesC diagram)
- Depending upon type of smelting, Si & S content will vary
- Acid smelting: Si is low, S is high.
Basic " " : Si is high, S is low.
- Mn: will depend upon smelting composition.
- P content: entire P content in the smelting joins pig iron. (max 0.45%)
- S content: S content should be ideally below 0.05% (except for free cutting steel, to increase machinability)

Steel making process:

It is controlled oxidation of impurities present in pig iron till desired composition is achieved.

- * If acid smelting is done, then S is removed before it is converted into steel by a process k.a. external desulphurisation.
- * In case of basic smelting, as then Si is high & : external desilicification has to be done.

Principles of Steel Making :-



$$A + B = C + D$$

$$\Delta G = \Delta G^\circ + RT \ln \frac{a_C a_D}{a_A a_B}$$

To ensure that ΔG is -ve, activity of the reactant side should be more than activity of product side.

There are 2 main species in reactant side.

- $\textcircled{1}$ The activity of C can't be increased bcoz composition of pig iron supplied is fixed.

Pure oxygen $a_O = 1$

$a_O(\text{air}) = 0.21$

$$a_{\text{slag}}\{\text{FeO}\} = 10^{-6} - 10^{-7}$$

Process that used air as oxidizing medium are k.a. pneumatic process or Bessemer process after Henry Bessemer.

- * FeO, MnO - weak basic oxide
- SiO_2 - strong acid oxide

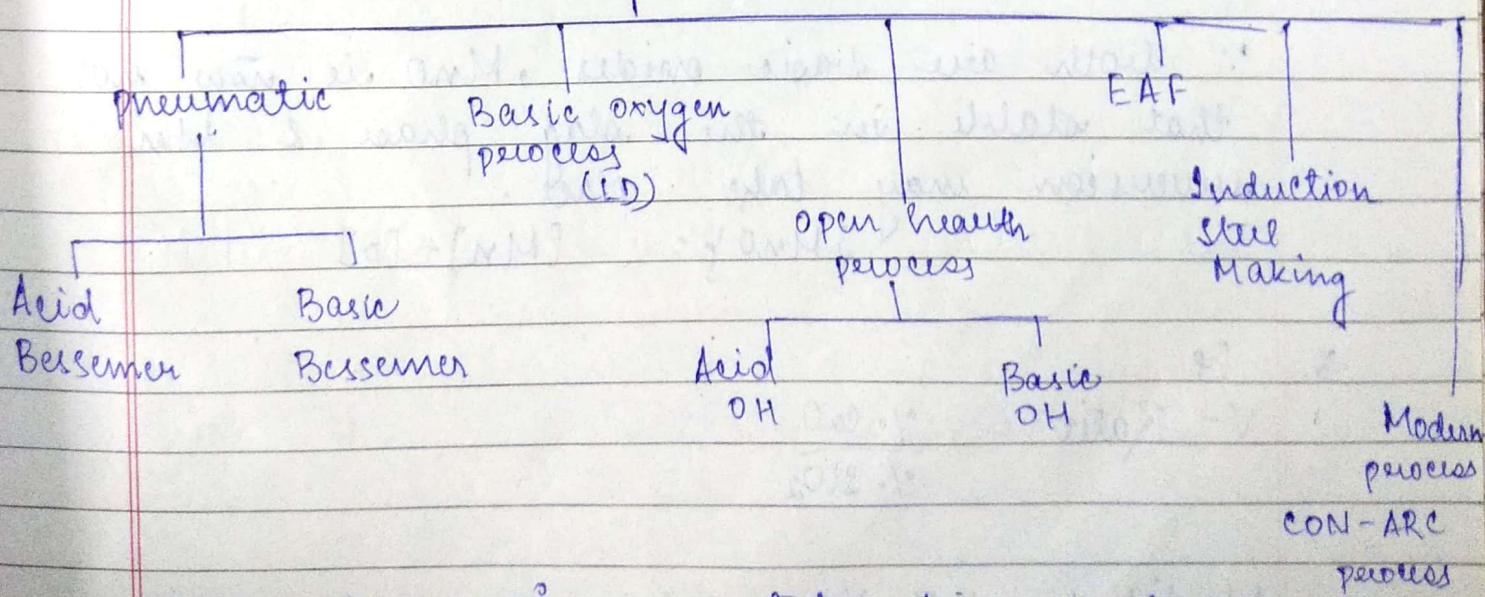
FeO & MnO combined with SiO_2 to form stable compounds $\{\text{MnO.SiO}_2\}$ & $\{\text{FeO.SiO}_2\}$

$\because \text{SiO}_2$ is dominant, \therefore slag produced is K.A. acid slag. Since acidic slag is formed, \therefore acid refractory lining is necessary. Thus, this process is K.A. acid steel making.

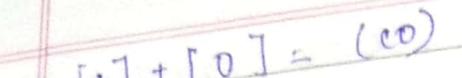
- * P_2O_5 is a weak acid oxide. ~~∴ MnO & FeO~~
 - ∴ to stabilise P_2O_5 in slag phase, a strong basic oxide is needed. FeO & MnO are weak basic oxides \therefore these oxides can't stabilize P_2O_5 . Hence, an external flux like CaO (calcined limestone) or calcined dolomite is used to stabilize P_2O_5 .

$\therefore \text{CaO}$ is added as an external flux, nature of slag is now basic. This \therefore the refractory lining should also be of basic nature. The steel making process which produce basic slag are called basic steel making processes.

Classification of Steel Making Process



These are primary steel making process.



$$K = \frac{P_{CO}}{h[C] h[O]}$$

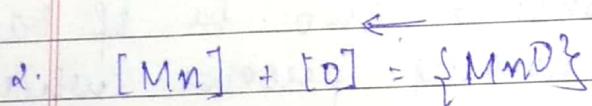
$$\Rightarrow h \log h[O] = 1/K$$

$$\Rightarrow f_c [wt\% C] f_O [wt\% O] = 1/K$$

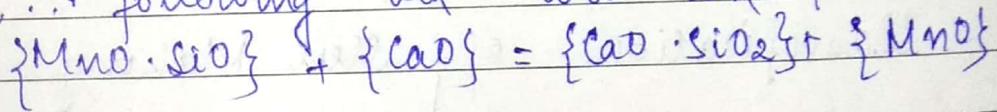
$$\Rightarrow [wt\% C] [wt\% O] = 1/K \cdot f_c \cdot f_O = \text{const}$$

Based on above wt% of O & C, steel is classified.

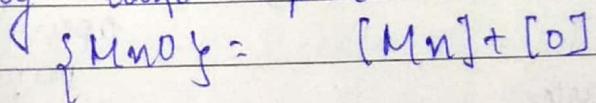
- Rimming Steel : Boiling action below gases are going out. This takes place if %C < 0.15%.
- Killed Steel : no boiling action seen.



MnO is a weak basic oxide. In the case of basic slag, strong basic oxide like CaO is present, ∴ following rxn will take place



∴ both are basic oxides, MnO is now not that stable in the slag phase & Mn reversion may take place.



3. Ef

$$V\text{-Ratio} = \frac{\% CaO}{\% SiO_2}$$

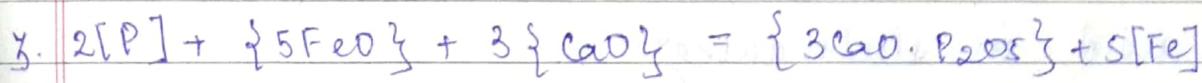
$$\text{Modified V-Ratio} = \frac{\% CaO}{\% SiO_2 + \% P_2O_5 + \% Al_2O_3}$$

Vigorous stirring is caused in Bessemer Process by bottom blowing, in OH & EAF by carbon coil ; in Kaldo process by rotation of vessel & in DATED & Rotating PAGE:

$$\text{Basicity, } B = \frac{\sum (\text{l. basic oxide})}{\sum (\text{l. acid oxide})}$$

$$\text{Common Basicity, } B = \frac{\sum (\text{l. CaO} + \text{l. MgO})}{\sum (\text{l. SiO}_2 + \text{l. P}_2\text{O}_5 + \text{l. Al}_2\text{O}_3)}$$

$$\text{Specific Basicity, } B = \frac{\sum (\text{l. (RO - 4P}_2\text{O}_5))}{\text{l. SiO}_2}$$

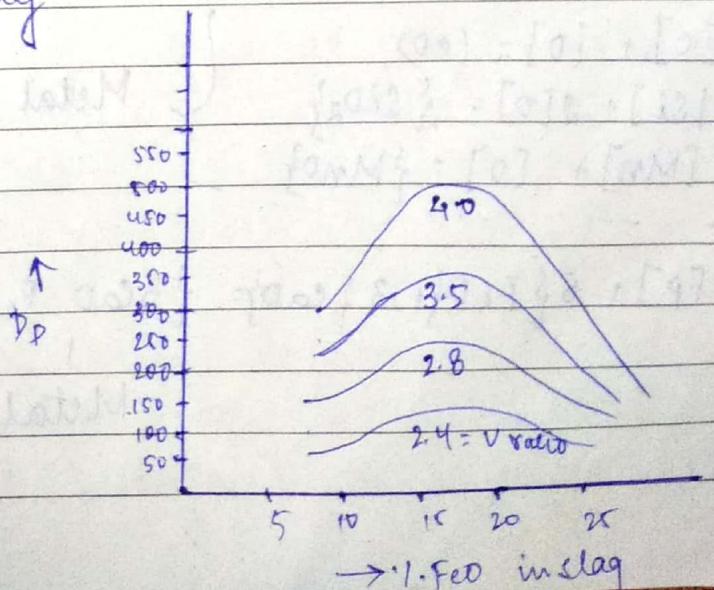


$$K = \frac{a^3 \{3CaO \cdot P_2O_5\}}{a^2 [P] \cdot a^5 \{FeO\} \cdot a^3 \{CaO\}}$$

$$D_p = \frac{a^3 \{3CaO \cdot P_2O_5\}}{a^2 [P]} = K \cdot a^8 \{FeO\} \cdot a^3 \{CaO\}$$

D_p = dephosphorization index

- To see D_p to be large
- higher 'K' : lower temp.
- large l. FeO (oxidising slag) $FeO \approx 15\%$.
- high basicity



15.1. FeO is an optimum value for max D_p . As % of FeO is increased, D_p starts decreasing. This happens bcoz, as % FeO increases, % CaO decreases in the slag, which affects V-ratio.

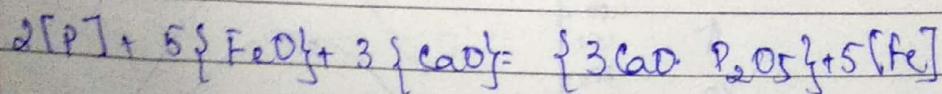
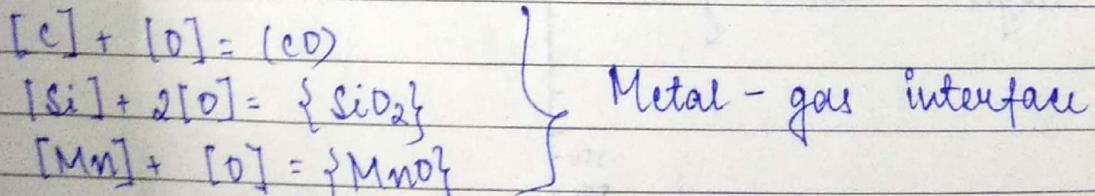
∴ A very high basicity slag is viscous which will not take part in refining. Caustic soda (NaOH) is 100 times more effective than CaO. But is highly corrosive, ∴ can't be used in steelmaking.

Hot mixer:

- storage reservoir
 - maintain temp
 - homogeneous composition
- } Inactive mixer

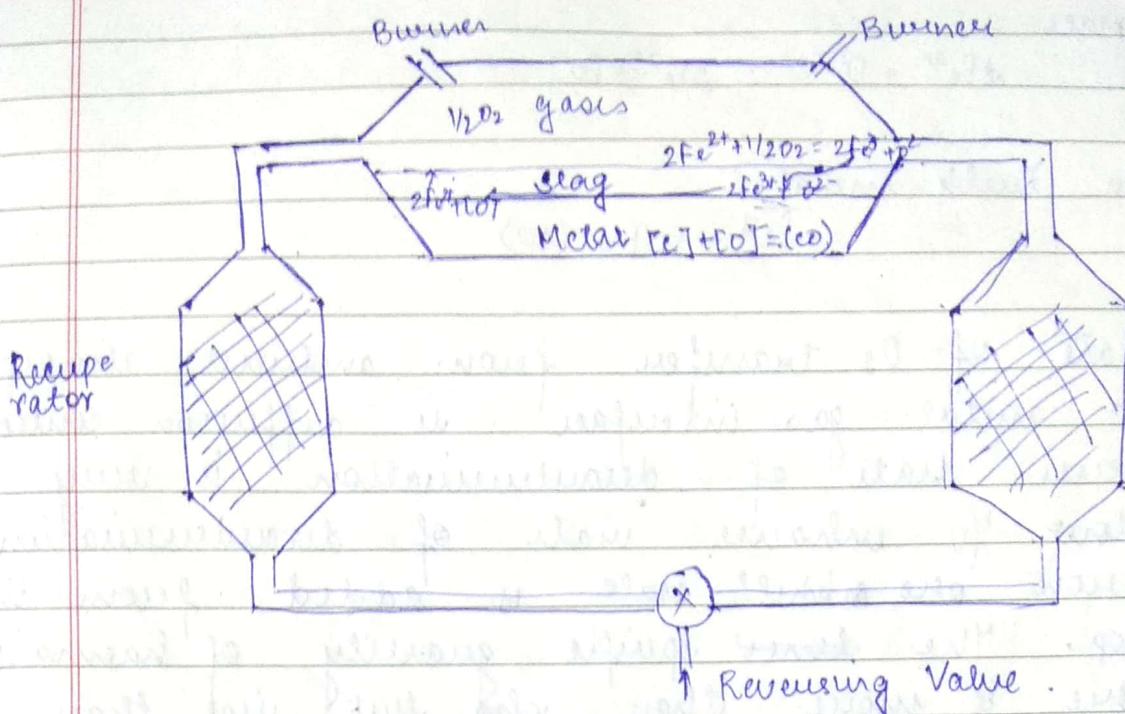
If using synthetic slag, if removal is done then it is called active mixer.

Mechanism of oxygen transfer in OPEN HEARTH PROCESS:



Metal-slag interface



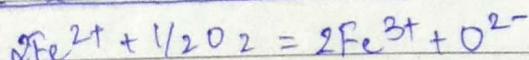
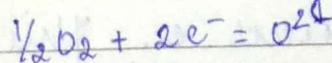


Direction reverses after every cycle.

Reaction take place at metal & gas interface.

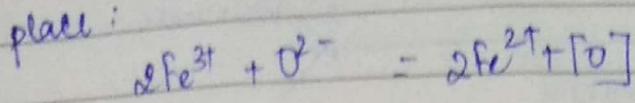
- * In pneumatic processes, there is no problem of contact with metal & gas at the metal-gas interface. (O_2 is blown from below)
- * Similarly in LD process, due to high oxygen pressure contact at metal gas interface is not a problem. (O_2 is blown from top)

Reaction taking place at slag gas interface:

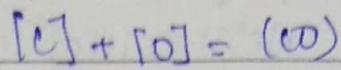


Due to convection & diffusion Fe^{3+} & O^{2-} are transported to metal slag interface.
At metal slag interface, the reverse rxn takes

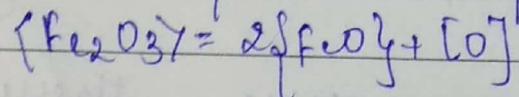
plate:



In bulk metal:



Rate of O₂ transfer from ambient atmosphere to metal gas interface is diffusion controlled. Hence rate of deaeration is very slow. To enhance rate of deaeration, iron ore or mill scale is added from the top. The ~~decreas~~ specific gravity of haematite ore is more than slag but less than metal. ∴ iron ore rests at metal slag interface & decomposes as per this rxn:



This technique is called oxiding practice.

At melt out composition C should be 0.5-0.6% higher. When CO bubbles go up it causes turbulence in the bath. This helps in increasing rate of diffusion & also continuously replenishes the metal slag layer. ∴ at melt out stage there must be sufficient C. This phenomena of turbulence is called CARBON BOIL

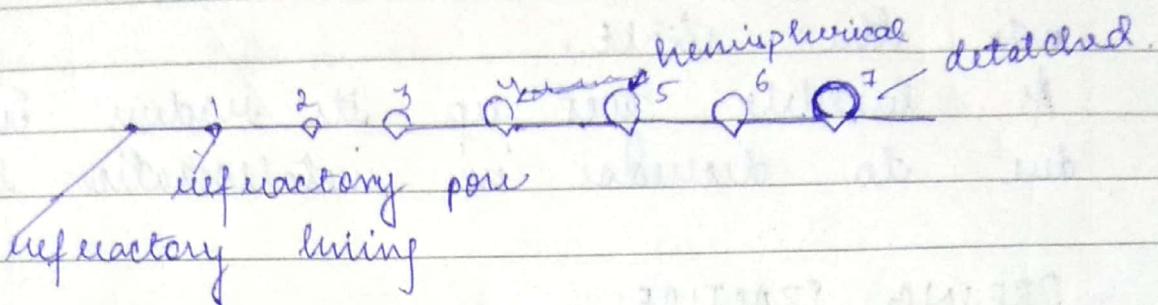
$$P_b = P_0 + \frac{\gamma}{Y}$$

P_b = press inside CO bubble

$$P_b = P_{\text{metal}} + P_{\text{slag}} + P_{\text{ambient}}$$



τ = surface tension of bath, viscist diameter
 r_e = bubble radius of bubble



As the radius of the bubble increases, $\frac{\sigma}{r_e}$ decreases. P_b also decreases as the bubble moves up. It has been found that for a bubble radius of 5.8 Å, P_b should be in the range $10^4 - 10^5$ atm.

$$[\text{wt. C}] [\text{wt. O}] = \frac{P_{CO}}{K_f c f_0}$$

But such a high P_{CO} is can't be achieved by above eq. reaction. This means nucleation of CO bubbles is not by homogeneous nucleation but heterogeneous nucleation.

Refractory lining consist of small pores. Surface tension of molten metal bath prevents its entry into the pores. These refractory pores act as preferred nucleation sites for CO bubbles.

The necessary condition for detachment of CO bubble from refractory pores is that the bubble must acquire a hemispherical shape before bubble press is

O₂: black cylinder
N₂: red
Ar: blue
He: light green

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equal to eq Peo. If eq. Peo is achieved before acquiring hemispherical shape, the bubble will collapse & dissolve back into the melt.

As bubble goes up its radius increases due to decrease in metallostatic head

REFINING PRACTICE:

Iron ore

feed ore

charge ore

It is addition of iron ore for refining purpose

Feed ore: It is called feed ore when it is used specifically for refining purposes only.

Charge ore: Iron ore added to refine at a correct melt-out composition is called charge ore.

Deoxidation of steel

$$[\text{O}]_{1600^\circ\text{C}} = 0.28\%$$

$$[\text{O}]_{1800^\circ\text{C}} = 0.43\%$$

$$[\text{O}]_{\text{room temp}} = 0.003\%$$

This means a lot of O₂ gas evolves during solidification of casting. This may have bad effect on soundness of casting

$c \rightarrow co$

- for faster removal of co
- inert gas flushing
- vacuum treatment

Si Mn Al Ti B Zr Nb \xrightarrow{c} costly

Elemental Si is not used bcoz an oxide layer of Silica is present which doesn't dissolve easily in the melt \therefore ferro-silicon & ferro-Mn is used.

First ferro-Mn is introduced bcoz MnO is lsg at $1600^{\circ}C$. Then Fe-Si is added \therefore SiO_2 dissolves in MnO to form $Mn_2Fe_2SiO_5$ which is lsg & lighter therefore it rises up.

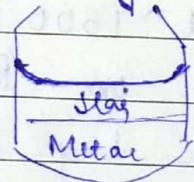
Al is added in elemental form because ferro-alloy of Al is not made.

Properties of Slag

'A good slag maker is a good steelmaker'

'Take care of slag, it will take care of steel'.

- It should act as a sink for impurities
- Viscosity - low
- Thermal conductivity - should be high (particularly for OH process heat). ambient heat must be transferred to the metal via slag
- Surface tension - should be on lower side - may result in slag refractory etc" if it is high.



Structure of Slag

Slag - atleast any 2 oxide of opposite nature.

Basic Oxides: CaO, MgO, MnO, FeO, Na₂O, K₂O ...

Acid Oxides: SiO₂, P₂O₅, B₂O₃ ...

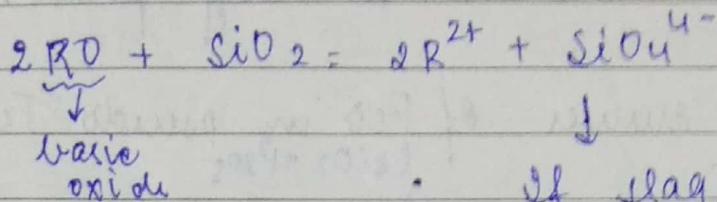
In case of basic oxides, predominantly ionic bonding exists. → May exist in the form of simple cations & anion.

In case of acid oxides, predominantly covalent bonding exist. Hence, they do not dissociate easily & exist in the slag in complex form.

Simple cations: Fe^{2+} , Ca^{2+} , Mg^{2+} , Mn^{2+} , K^+ , Na^+ , etc.

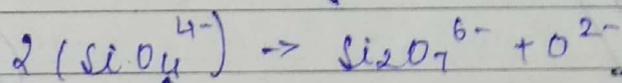
Simple anions: O^{2-} , S^{2-} , F^-

Complex anions: SiO_4^{4-} , PO_4^{3-} , AlO_3^{3-} , FeO_2^{2-} etc.



If slag consists of only (SiO_4^{4-}) , it is called orthosilicate slag - neutral slag

If slag is saturated by SiO_4^{4-} this means there are no free O^{2-} ions. If free O^{2-} ions are present, then nature of slag will be basic. But in reality, a neutral slag doesn't exist.



The orthosilicate ion polymerises & produces free O^{2-} ions. Thus making the slag basic

These compositions depend upon V-Ratio.

Oxidising / Reducing power of slag

Oxidising / Reducing power of slag is equal to P_{O_2} in equilibrium with FeO content of the slag.

Let P_{O_2} be the eq. partial pressure of O_2 in contact with pure FeO .

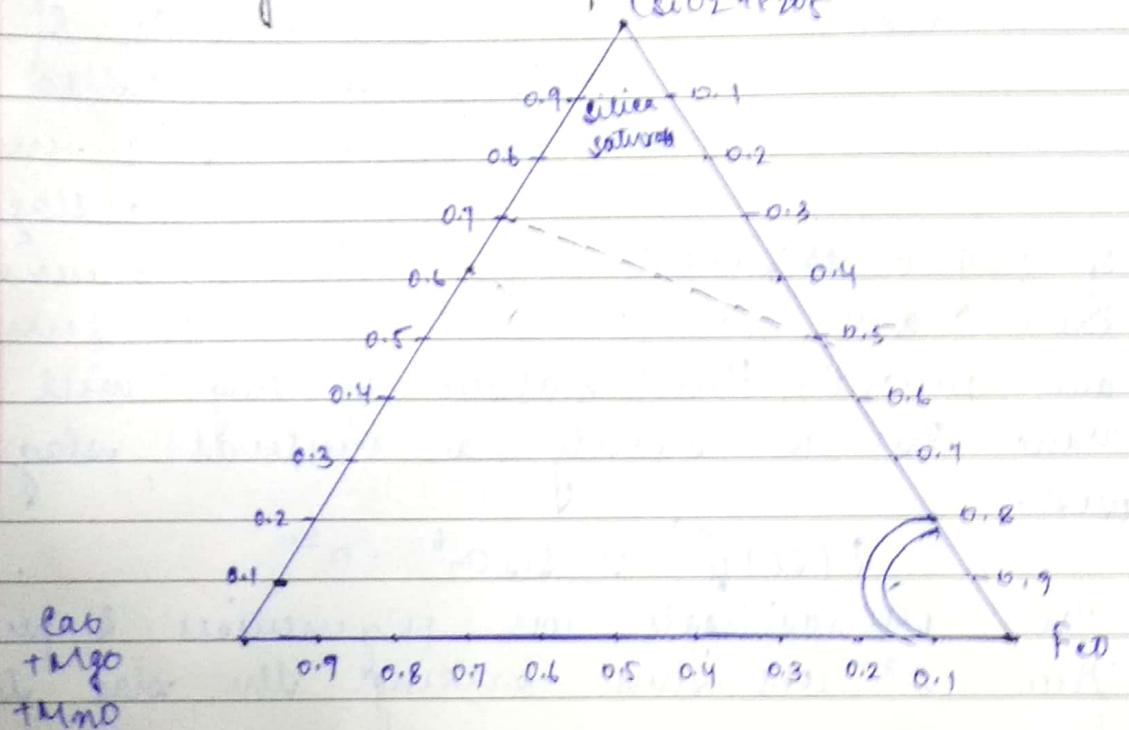
$$\alpha_{\text{FeO}} = \frac{P_{\text{O}_2}}{P_{\text{O}_2}}$$

$$\Rightarrow P_{\text{O}_2} \propto \alpha_{\text{FeO}}$$

This means P_{O_2} is proportional to activity of FeO in slag phase.

\therefore Oxidizing power of slag is directly proportional to FeO content in slag phase.

Isoactivity curves of FeO in pseudo Ternary dia:
 $CaO + SiO_2 + P_2O_5$



Isoactivity curve: activity of FeO along each curve is fixed.

Silica saturated: Acidic slag saturated with silica (SiO_2 may be as high as 65%). The slag saturated with silica is dry & viscous because m.p. of silica $1710^{\circ}C$. & still melting temp is $1600^{\circ}C$. Hence it doesn't take part in refining.

Process	(% FeO (approx))	Type of slag	Approx V-ratio
Acid Bessemer	12-18	FeO · MnO · SiO ₂	- Nil -
Basic Bessemer	12-18	FeO · CaO · P ₂ O ₅	2.5 - 3.0
Acid O.H.	15-25	FeO · MnO · SiO ₂	- Nil -
Basic O.H.	15-30	FeO · CaO · P ₂ O ₅	1.5 - 3.0
Basic EAF (oxidising)	15-25	FeO · CaO · P ₂ O ₅	1.5 - 3.0
Basic EAF (reducing)	0.5 - 2.0	CaO · CaC ₂	3.0 - 5.0
Basic O ₂ process	15-40	FeO · CaO · P ₂ O ₅	2.0 - 3.5

Theory of Slags

These are set of principles which help in calculating stn. eq. const. for metal-slag, slag-refactories, slag-gas systems.

1. Molecular Theory

It was proposed by Schenk & co-workers. It assumes the existence of neutral molecules such as silicates, phosphates, S²⁻, O²⁻, etc. in molten slag.

It also assumes that complex molecules dissociate

into corresponding simple molecules.

$$\{FeO \cdot SiO_2\} = 2\{FeO\} + \{SiO_2\}$$

The free oxide conc can be calculated from dissociation const of such reactions.

$$D = \frac{\{FeO\} \cdot \{SiO_2\}}{\{FeO \cdot SiO_2\}}$$

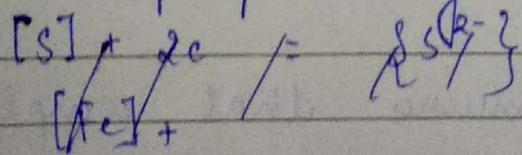
A series of temp dependent values of dissociation const were computed from lab & work data. The eq. const. for partition Rk^n between slag & metal were derived. \because activity of oxides in complex silicate slags don't deviate much, the free oxide conc calculated were not far off from true activity values, which are known today.

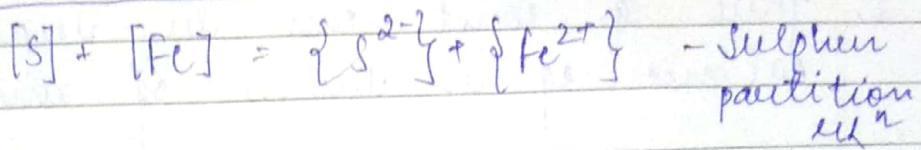
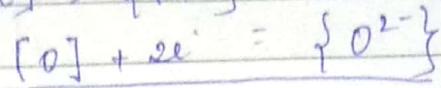
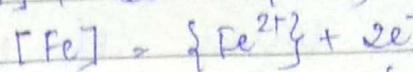
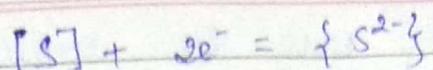
Molecular theory is a simple theory, but original simplicity no longer exists. This theory couldn't explain following phenomena observed in slag:

- electrical conductivity
- electrolysis
- electrocapillarity

2. Ionic Theory

Now it is universally accepted that slags are conc melts. Rk^n are electrochemical in nature. It was proposed by Flood & coworkers





$$\kappa = \frac{a_{S^{2-}} a_{Fe^{2+}}}{a_{[S]} a_{[Fe]}}$$

This theory attempts to compute activities of ions to determine equilibrium const. Flood & coworkers assumed the slag to be a mix of 2 independent regular solutions. 1 regular sol. consist of only cation & the other only anions (Regular soln). $\ln \gamma_A = \kappa x_A^2 \quad \underline{\Delta S_{reg}^M = \Delta S_{id}^M}$

On this basis, the activities are evaluated as

$$a_{Fe^{2+}} = N' Fe^{2+} \cdot N' S^{2-}$$

where N' = electrically equivalent fraction of ion.

Rules:

- ✓ Cations alone det the fraction of any cation
- ✓ Anions " " " " " " " " " " " " anion

If valency of ions is same, then ionic fraction = N' .
But if they differ then N' is calculated as follows:
In a mix. of A^+ , B^{2+} , C^{3+} , D^{4+}

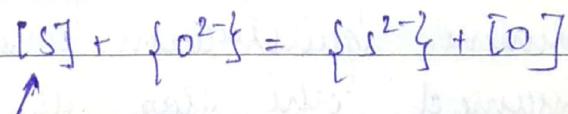
$$N'_{C^{3+}} = \frac{3 n_{C^{3+}}}{n_A^+ + 2 n_{B^{2+}} + 3 n_{C^{3+}} + n_{D^{4+}} \dots}$$

where n = no. of moles

1. True eq. const can be represented for an anionic eq in terms of cation fractions.
2. True eq. const can be represented for cationic eq in terms of anionic fractions.

Because opp. charges only have necessary bond to be retained in slag phase.

's' partition reaction:



Anionic eq

Eq const can be represented as:

$$\log K = N'_{Ca^{2+}} \log K_{Ca^{2+}} + N'_{Fe^{2+}} \log K_{Fe^{2+}}$$

Since, even in simple eq^n , these values are not found without assumptions; true eq. const is generally replaced by eq. quotient

$$\log K' = N'_{Ca^{2+}} \log K'_{Ca^{2+}} + N'_{Fe^{2+}} \log K'_{Fe^{2+}}$$

Flood's additive fun for s-partition eq^n
where $K' = eq$ quotient

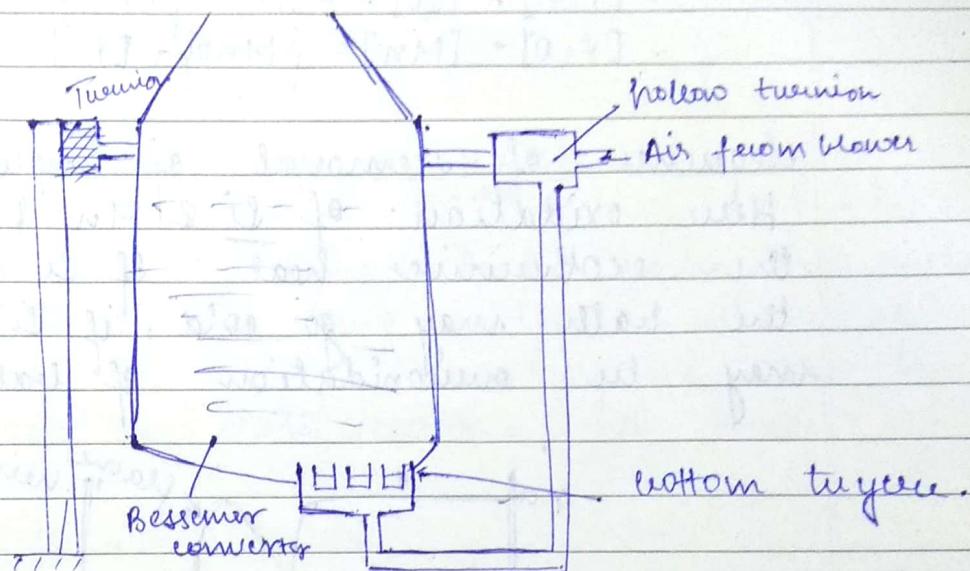
It is more practical to consider anionic eq with cation fractions. \because Acid slag are highly complex, it is very difficult to find activity of anions in complex slag. Fortunately most of steelmaking process have basic slag in which nature of anions can be precisely

predicted.

Hot softness = 5
cold " " 9
soft brittle DATE doesn't affect at Fe
swarf cold swarf scaling

Bessemer process of Steel Making

Acid Bessemer Process



Inner lining is of silica bricks & outer wall is rammed silica.
Wall are made of armoured steel.

Pig Iron composition

P & S $< 0.05\%$.

C $\approx 4\%$.

Si - 2.5% min & 3% max

Mn $\approx 1\%$.

exception - free cutting

steel ($S \approx 0.1\%$)

wheathering steel

(P $\approx 0.1\%$)

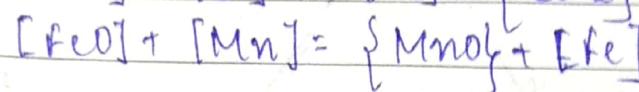
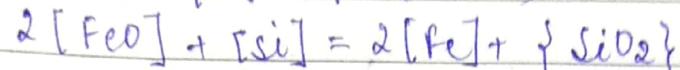
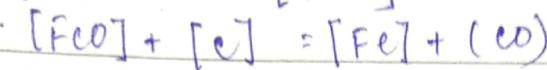
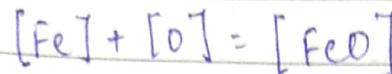
Pig iron with above comp. was available only in Sweden : called Swedish Pig Iron

Excess of N_2 causes work hardening.
∴ not suitable for deep drawing

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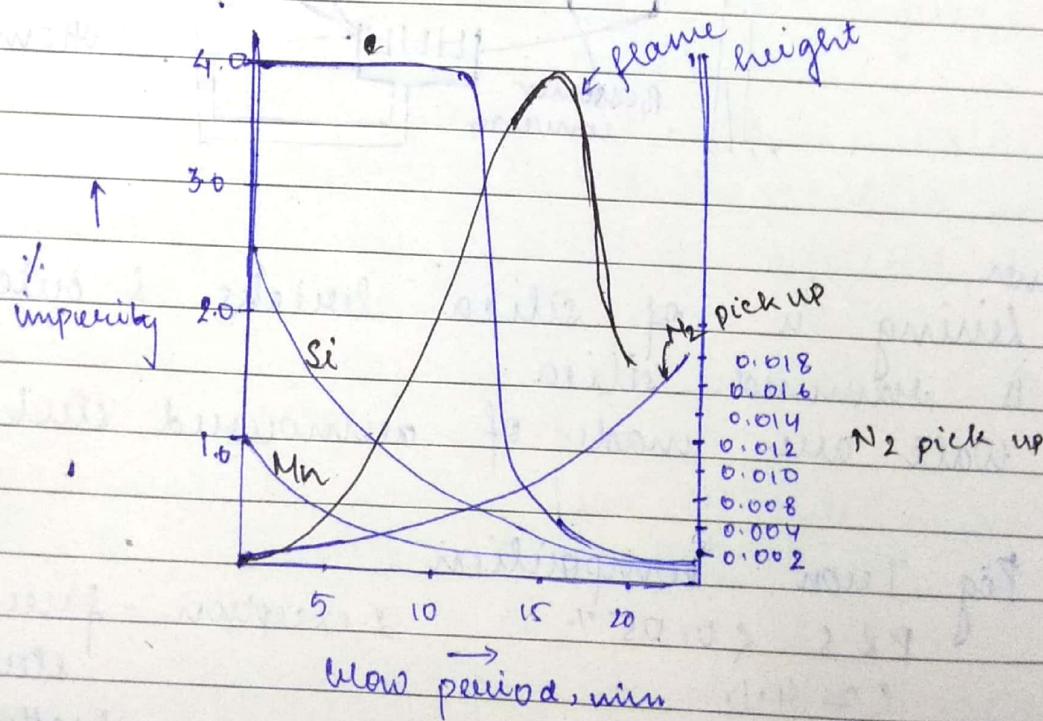
Si is the chief producer of heat.

In half region, tuyeres are present & above it only scrap is charged. Hot metal is charged in the other half.

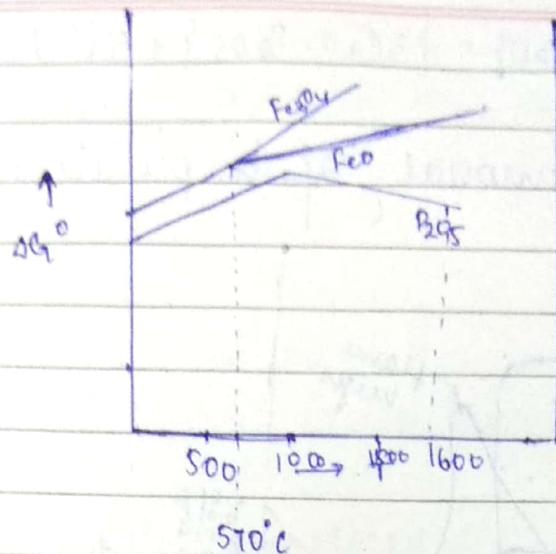


Sequence of removal of impurities:

Here oxidation of Si & Mn & C provides the exothermic heat. If Si is $< 2.5\%$, the bath may go cold, if Si $> 3\%$, there may be overoxidation of bath.



Application: Railway wheels, axles, nuts, bolts



The iron making temp in isothermal region is around 1000°C where the ΔG° of FeO & P_2O_5 is very less & \therefore both Fe & P enter hot metal. Whereas slabmaking temp is 1600°C where ΔG° diff with FeO & P_2O_5 is very large & ~~can't~~ $\therefore \text{P}_2\text{O}_5$ can be stabilised in slag phase.

Basic Bessemer Process

$$\text{C} \approx 4.0\% - 4.0\%$$

$$\text{Si} = 0.5\% - 1.0\%$$

$$\text{Mn} = 1.0\% - 3.0\%$$

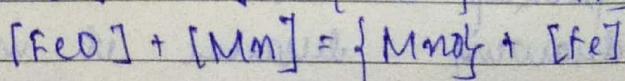
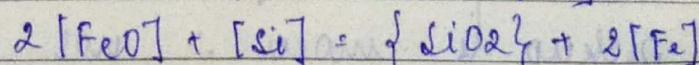
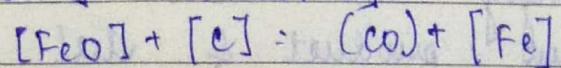
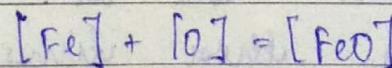
$$\text{P} = 1.5\% - [\text{Mn}]$$

$$\text{S} \leq 0.05\%$$

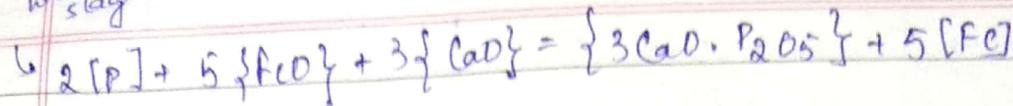
Thomas grade of Pig Iron

British grade of Pig Iron

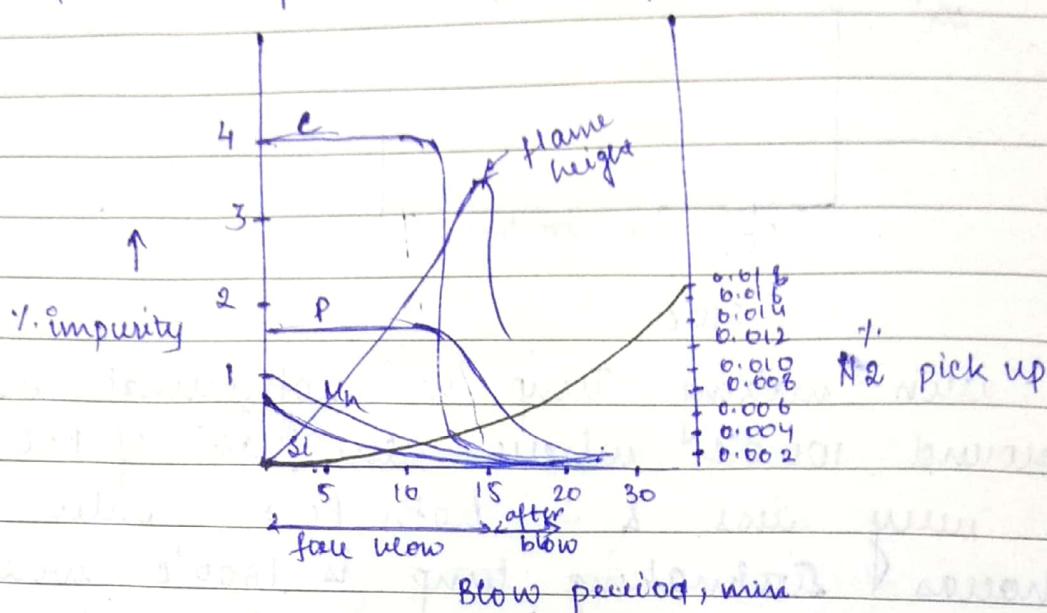
Si should preferably $\{ 1.0\%$ & P should be 1.5% . min. In this process P acts as heat carrier. Oxidation of P provides the exothermic heat.



Fe^n with slag



Sequence of removal of impurities



MnO is a basic oxide & slag is also basic, that's why removal of Mn is a problem. From the flame height, duration of after blow is judged. C starts oxidising only after Si & Mn is lowered.

Removal of P requires highly oxidising ($15\% FeO$ or more) slag. \therefore P removal starts only after this (at this) time of FeO is available in slag.

In the beginning since the slag was very much in $3CaO \cdot Fe_2O_3$ ($Ca_3(PO_4)_2$ calcium phosphate), it was used as a fertiliser. Surprisingly in those times the slag was main product & still was by product. N_2 pickup is more: not suitable for deep drawing because it makes the steel

strain hardens.

- ∴ Basic open hearth process was its competitor
- following modifications were made:

 1. O₂ enrichment
 2. inert gas flushing
 3. steam flushing
 4. side blown converter (so that N₂ pickup lower)

Tata Steel practised a combination of basic Bessemer + Basic open hearth process to reduce tap to tap time of open hearth process. The process is K.A. duplex process. This was in practice till Tata switched to LD process (1982).

8/8/86

Acid open hearth ~~furnace~~: process:

It was silica brick lining on side walls as originally well as bottom hearth. Again in bottom silica meant brick ramming with sea silica & over that to acid slag wash is given.

melt
steel
scrap.

Charge: scrap. As supply of ~~scrap~~ became deficient then scrap + cold pig iron was added 65 35

If cold pig iron is more, refining period ↑.
Comp. of pig iron:

$$C \approx 4.0\%$$

$$Si \approx 1-2.5\%$$

$$Mn \approx 0.75-1.5\%$$

$$P \& S < 0.05\%$$

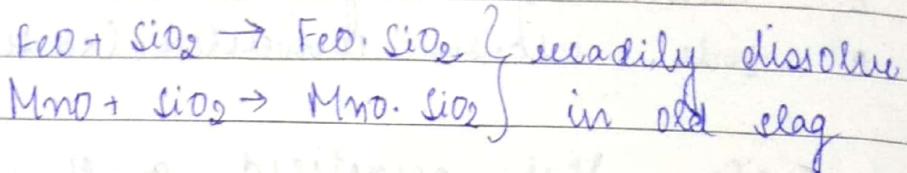
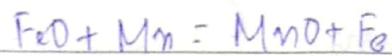
- Hot Fetting / Hot Repairs
Repairs done during hot condition

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- ## → Changing Sequence

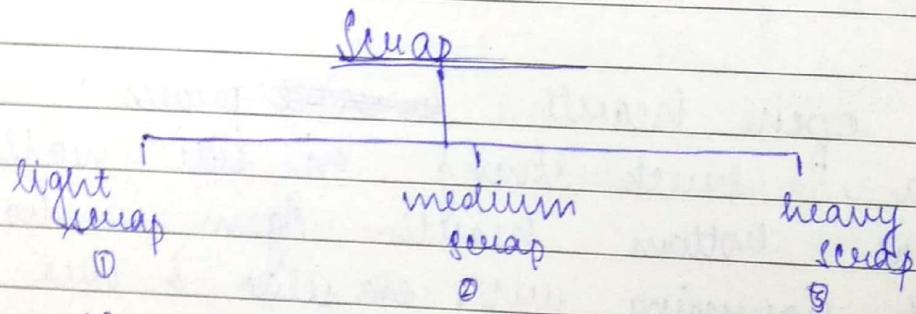
Propane gas is used as a fuel which has low S content.

- i. wild pig is charged first



around 10% slag is left behind which is called 'Hed'.

If snap is charged 1st then FeO formed will attack the acidic lining.



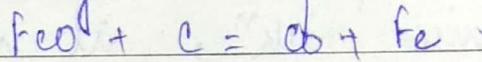
be a light snap is changed first, then medium snap is heavy snap at top, so that it is exposed to highest temp.

- ## Meltout Stage

Snap is added when cold pig is in sweating stage. Snap is added as flame is operated at very high combustion rate.

If furnace is operated at slower combustion rate there will be over oxidation of bath. Once the bath is completely molten, the first sample is taken out for carbon analysis. The % of C should be $0.3 - 0.6\%$. more than the end composition. For correct estimation of C level, the bath should be 'quiescent' bath.

'Quiescent' bath no chem rxn should take place. Particularly the following:



To make the bath quiescent Fe-Mn & Feo-Si added.

If the C level at meltout stage is more than desired level, charge ore is added to bring down C level. If the C level at meltout stage is less than desired level then unburnt coke breeze, broken electrode pieces are added to makeup the C level.

→ Refining:-

Although some refining takes place during meltout stage itself, actual refining takes place during this period. Before addition of feed ore is made to start the refining at a vigorous space. Evolution of CO from the bath causes violent agitation in the bath which is k.a. carbon boil.

For an effective refining, there must be sufficient C level. % of C at melting stage should be sufficiently high.

Removal of Si & Mn starts at the melting stage itself. Removal of C takes place during refining period.

During end of refining period, addition of feed ore should be in a limited amt. since decomposition of iron ore is an endothermic rxnⁿ, it may bring down the temp of the bath which may create problem in tapping.

→ Blocking of heat

It is temp. stoppage of refining. This is done to estimate correct end composition of carbon. Ferro-Mn & Ferro-Si are added to deoxidise the bath. Sample is taken out for C estimation, if C level is OK, then the refining is stopped permanently. If C level is still higher, refining is resumed.

→ Deoxidation of bath.

Once correct C level is achieved, the bath is fully deoxidised. In case of acid process the bath can be fully

deoxidised in the furnace itself hence there is no danger of removal of P.

→ Addition of alloying elements:

Alloying elements can be added in the furnace itself.

→ Tapping of steel

Temp. of bath at the time of tapping must be in range $1550 - 1580^{\circ}\text{C}$.

9/8/18

Basic Open hearth process - cold practice
scrap & pig is cold

→ Hot fettling

- Charging it involves hot repair of refractory lining.

→ Charging Sequence

Charge consist of 65% scrap & 35% of cold pig. There is no restriction regarding comp of pig iron; highly versatile. Surplus molten pig iron is cast into pigs in Pig Casting Machine. Flux: limestone, dolomite in raw form.

Deoxidisers: ferro-Si, ferro-Mn. If needed stronger deoxidiser like Al shots are used.

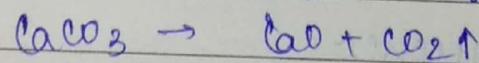
In this case, cold pigs are charged first. FeO formed doesn't react with basic lining. Cold pigs if charged first then SiO₂ may react with basic lining.

Flux is charged after scrap in order to form an early slag.

→ Meltout Stage:

Scrap is charged in the seq: light → medium → heavy. Light scrap which is charged 1st provides a cushioning effect which prevents damage.

Flux is charged when scrap starts sweating. After that cold pigs are charged. The O-H furnace is now operated at max combust rate. Once it is completely molten, the bath is made quiescent. Addition of raw limestone causes 'lime boil'



An experienced meltter judges the evolution period of CO₂ during lime boil. Once this is over, the bath is made quiescent by the addition of ferro-Mn & ferro-Si. 1st sample is taken out for estimation.

→ Refining

Although refining engine during meltout stage itself, actual refining is carried

out by profuse addition of iron ore. It is removed in no time while removal of Mn takes place at a slower pace because MnO is a basic oxide.

Removal of P starts once enough FeO is available in oxidising slag ($> 15\%$).

During end of refining limit addition of iron ore should be made.

→ Blocking of heat

The refining process is temp. stopped by addition of deoxidisers for correct C level estimation.

Rimming tals are not blocked.

→ Alloying addition

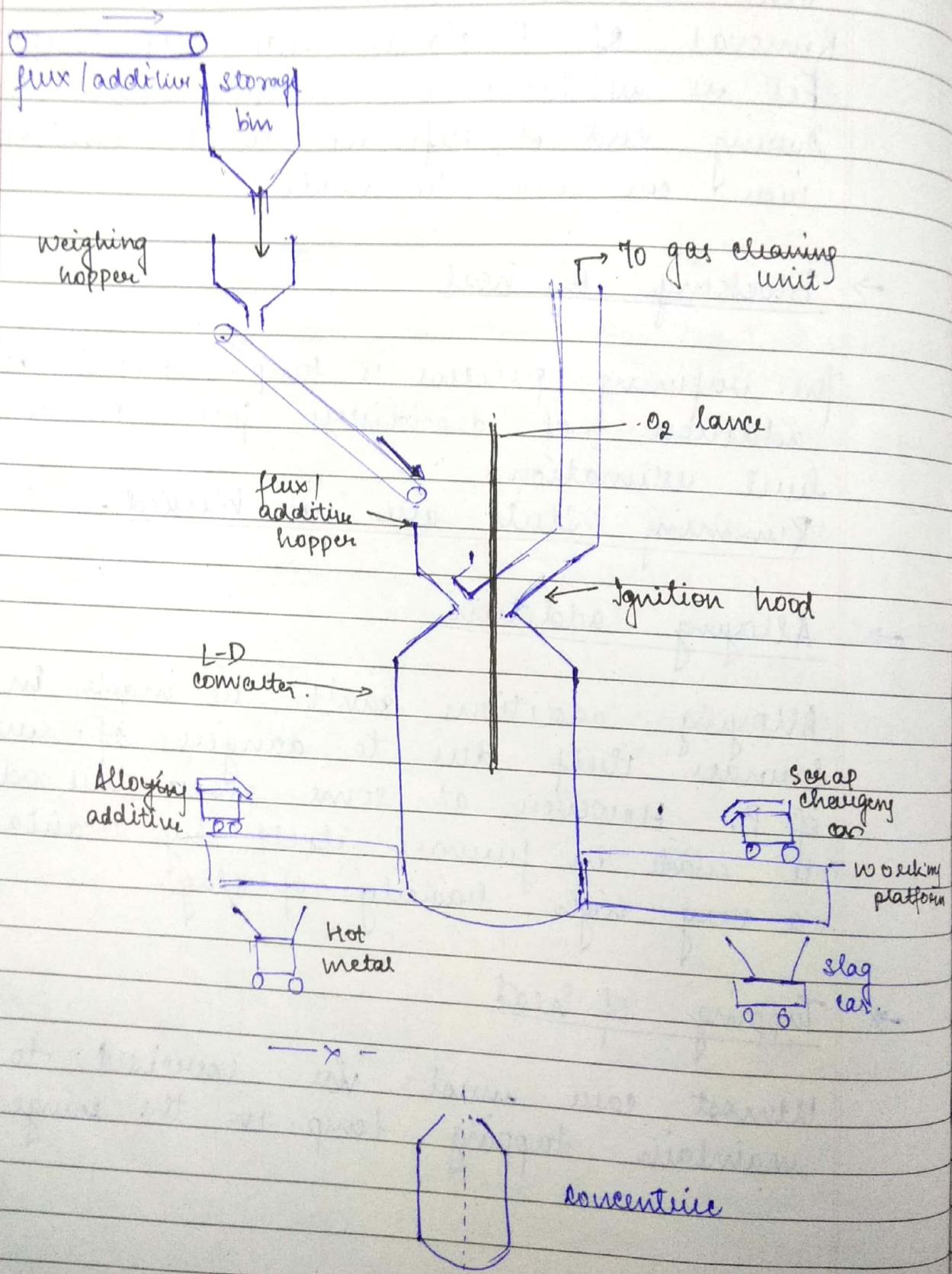
Alloying additions can't be made in the furnace itself due to danger of evaporation of P. However at some places this addition is made in furnace itself by maintaining a very high basicity of slag.

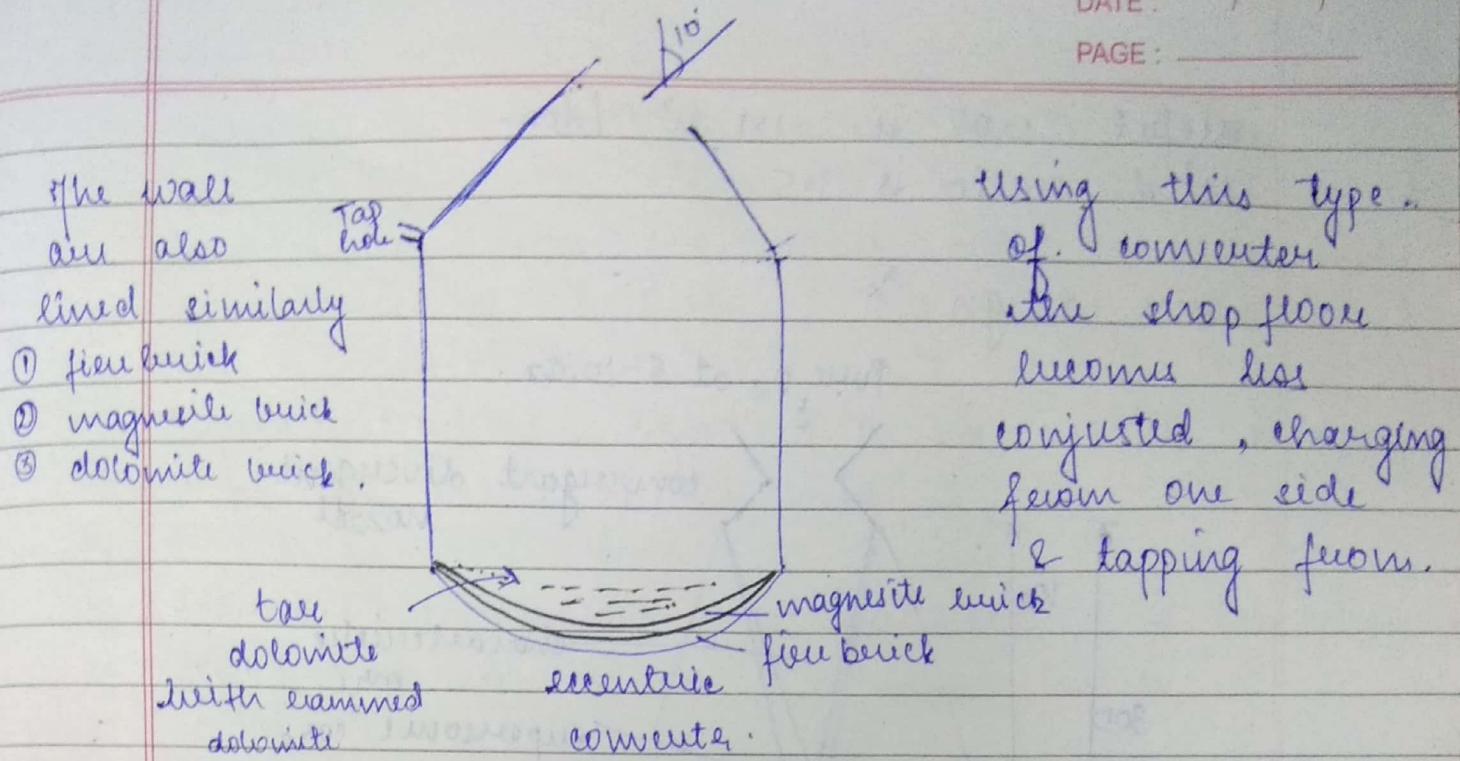
→ Tapping of heat

Utmost care must be exercised to maintain tapping temp. in the range $1550-1580^\circ\text{C}$.

L-D PROCESS

Linz & Sonowitz, Austria
India - 1956/60 Rourkela





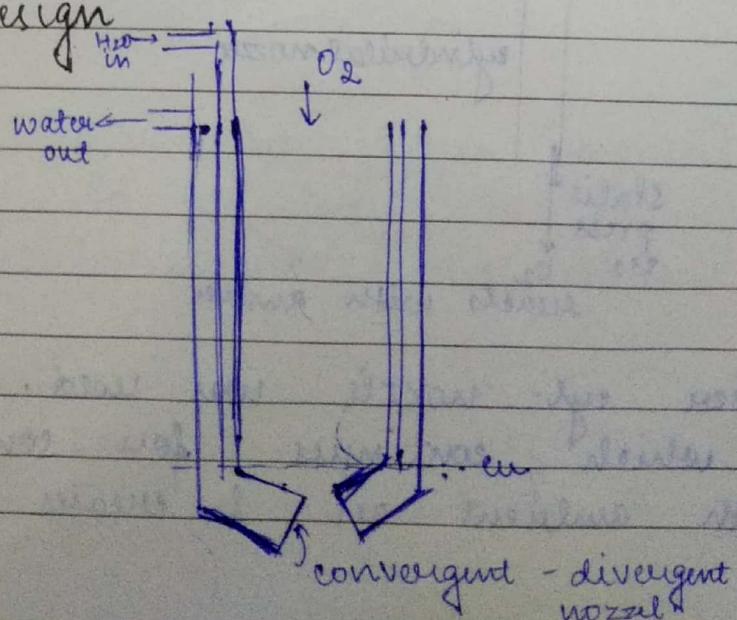
Slopping / ejections: phenomena of splashing of hot metal when O_2 is injected.

In concentric converter, ejection occurs on both sides.

In eccentric converter, ejection occurs more on only one side.

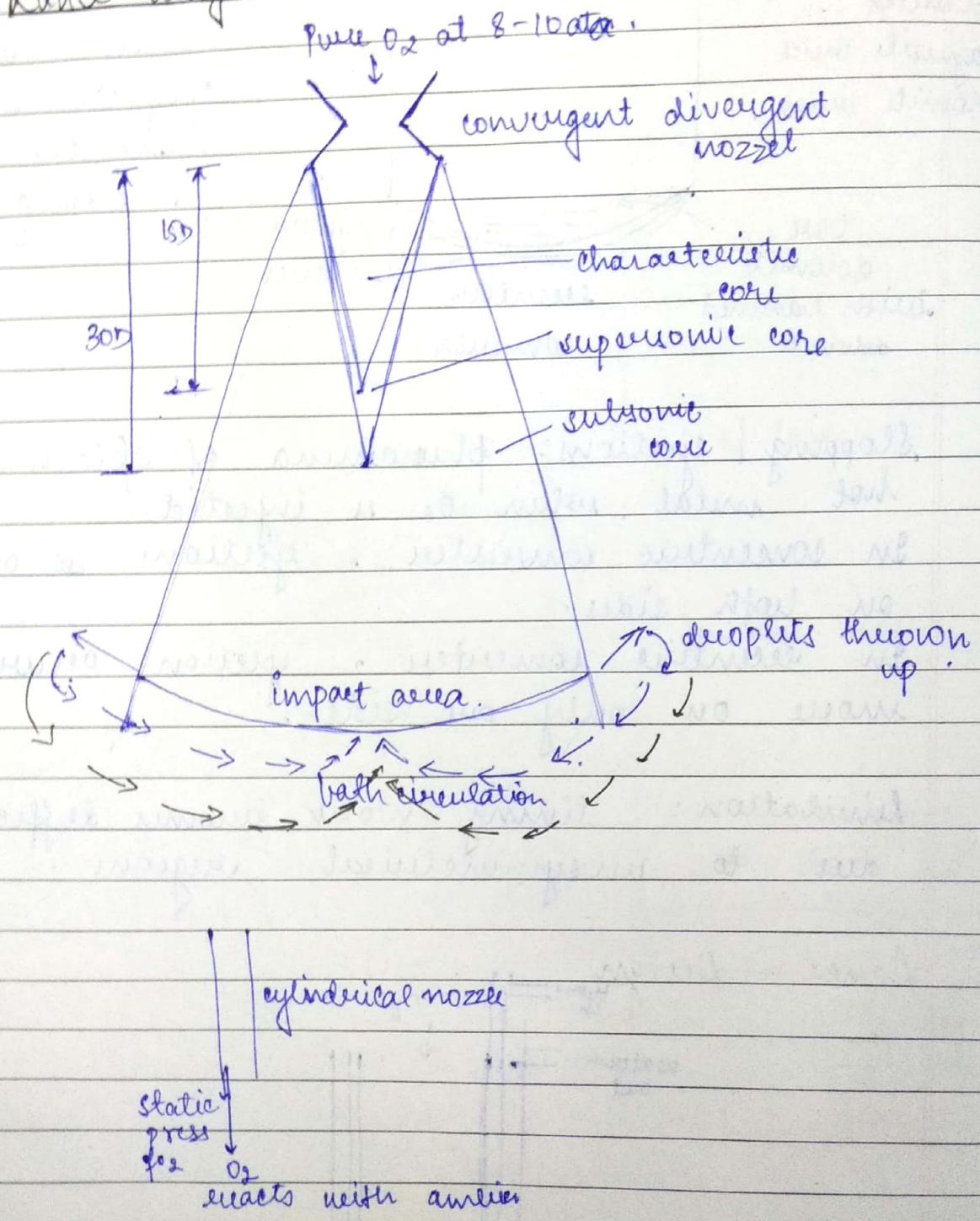
Limitation: lining work becomes difficult due to unsymmetrical regions.

Lance Design



useful vol is $1 \text{ m}^3 / \text{ton}$
 H_2/O_2 ratio is 10.5

Lance design



Earlier cyl. nozzle was used.. Static press of O_2 which continues for some dist. reacts with ambient air & creates shock waves &

results in damp fluctuation.

Now a convergent divergent nozzle is used with
a press of $\sqrt{8-10}$ ata.

Supersonic core: Velo of O_2 is in the range
 $1.5 - 2.5$ mach (velo of sound)

Subsonic core: velo is reduced & is less than
that of sound.

Impact area: area where O_2 impinges the
area.

Static press of O_2 continues for a very small
length, hence its interaction with ambient
air is negligible.

JFN - Jet Force Number = $\frac{O_2 \text{ press} \times \text{nozzle dia}}{\text{Height of lance}}$

height of lance = dist of nozzle from bath
surface.

In L-D process the main impurities removed
are C & P. So we have to look mainly
into decarburiization & dephosphorisation.

Decarburiization

For decarburiization, metal-gas interface
is critical. \therefore penetration of O_2 into the

metal phase is important. Hence in the beginning JFN should be higher.

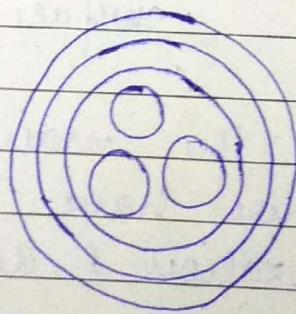
Dephosphorization

In case of dephosphorization metal-slag interface is critical. O₂ jet must create turbulence in the metal-slag interface. As a result metal-slag interface is continuously broken & new interface is generated. ∴ a lower JFN is req. for the purpose.

Thus, slopping is observed in the beginning itself because JFN is high. As JFN is reduced during dephosphorization, slopping is completely stopped.

Multi nozzle design

As the capacity of the converter increased, one nozzle was not sufficient enough to cause circulation in the entire bath. ∴ multi nozzle design came into picture.



The nozzles are inclined at an angle of 10° from the vertical axis of the ladle so that the jets do not interfere with each other.

other.

For the converters of 400 ton capacity, 8 nozzle design is used these days.

Advantage:

1. there is complete & vigorous agitation in the bath.
2. faster removal of impurities
3. lower jet power can be used.
4. total consumption of gas per tonne of steel produced is lowered.
5. there will be less heating of lining above slag surface, hence lining life is increased.
6. No bottom burning, hence bottom life is extended.
7. better thermal balance
8. Better pollution control

LD Process of Steel Making

Charge

- iy Hot Metal
- * $S < 0.02\%$.

\Downarrow

suitable for continuous casting
if $S > 0.02\% \Rightarrow$ transverse cracks

- * External desulphurisation must be carried out either in hot mixer or transfer ladle.
A mixture of (calcium carbide + (Mg + coke)) \rightarrow
Mg + coke
- * P removal is not a problem during steelmaking.
90% of P can be removed during steelmaking.

* Si

Ideally Si should be in range ~~to~~ 0.5 - 0.75%.
It can be tolerated upto 1.4%. Higher Si content requires larger amt. of flux & hence slag will be more. Higher Si (SiO_2) may attack basic lining if an early id is not dissolved early in the slag.

* Mn

Ideally it should be 0.5 - 1.1% to avoid Mn evaporation. But LD process can take 1-3%. A surplus amt. of Mn in hot metal reduces req. of Fe-Mn during deoxidation of the bath.

iv) Scrap

It is around 10-25%.

Cold pig can be used 2-5%.

Iron ore is used as a coolant.
(Fe_2O_3)

But cold pig doesn't melt readily, being heavier lies at the bottom. If it doesn't melt readily, refining process will be delayed.

v) Flux

flux is normally not used in raw form but in calcined form. The dissociation of limestone is an endothermic reaction. Hence, bath may get cold. In lump form, it will not dissolve in the slag easily. In powder form, it dissolves in the slag easily but it may be lost. That is why it is used in granulated form.

As a flux calcined lime is only used.

vi) Dolomite is not used.

vii) Oxygen

Purity of O_2 should be around 99.5%. This purity level insures a N_2 pickup level of less than 0.002.

**

External desiliconisation

It can be carried out in transfer ladle by blowing pure O_2 thru' consumable mild steel pipe lance. This is usually done, 5-10 min.

The practice was adopted at Durgapur Steel Plant. (DSP & ASP - alloy steel plant) before charging it into OH furnace.

Operational steps (LD Process)

1. Inspection of lining
2. Pitting (hot repairs)

3. Charging

Scrap is charged first in 1 lot \Rightarrow the converter is made horizontal. Then it is charged with help of shovel type of charging machine. Once the charging is complete the converter is made vertical once again. The vessel is then rocked 2-3 times in order to bring down all the scrap to the bottom.

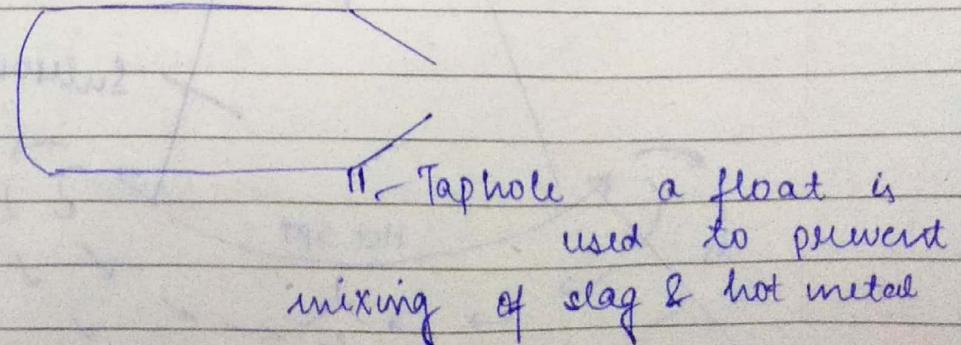
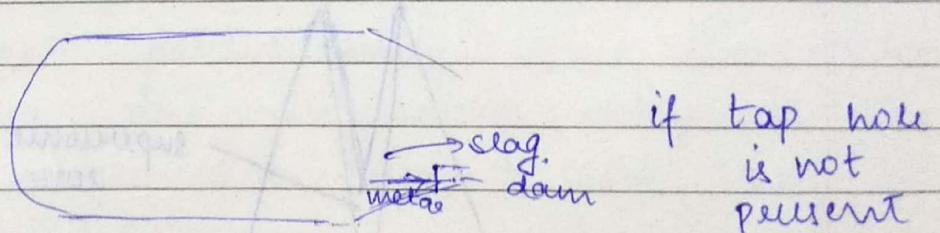
ii) Now the converter is inclined once again to receive hot metal from overhead man. Once the pouring of hot metal is complete, the converter is made vertical again.

iii) Addition of flux (calcined granulated lime) & other additives like quartz (^{to form early slag}), spar (to make slag thin).

Scrap & flux addition practice may vary from plant to plant. At many shops, scrap is may be added in batches. Scrap is added at a later stage as a coolant. But this will increase tap to tap time.

Same practice is done for flux & additive additions.

- iv) Now lance is lowered to the blowing position. In the beginning the lance is kept towards the lower side to prevent slopping. Once all the scrap melts due to exothermic heat generated by the oxidation of Si, Mn & C.
- v) Further addn of flux is made since removal of Phosphorous requires very high basicity.
- vi) Now, converter is tilted to take out hot metal & slag sample. If desired comp has not reached, the blow is continued for 1-2 min.
- vii) Samples are taken out once again & heat is ready for tapping.



Specific gravity of slag is 2.5 & that of molten steel is 7.5. So sp. gravity of float is kept around 5. If steel is heavier than float, the tap hole opens to give way to molten steel. Once molten steel is tapped out the exit of molten slag is prevented by the float.

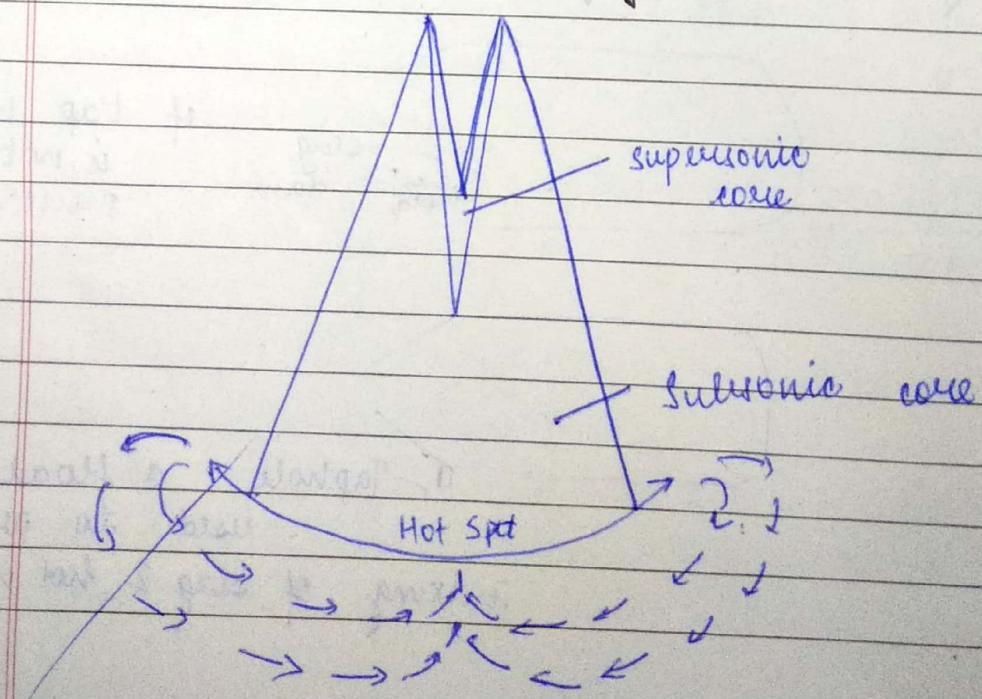
4.

viii) The bath is deoxidised in the ladle itself & then alloying additions are made.

ix)

The heat is ready for tapping once required pouring temp is established. Platinum-Rhodium Thermocouple (1 wire Pt, 1 wire Pt-10% Rh) upto 1600°C upto 250°C - Cromel-Alumel thermocouple for integrated iron & steel plant - radiation pyrometer.

Mechanism of Refining (LD Process)



1. Formation of hot spot
2. Entrainment of ambient gases
3. Dissolution of scrap
4. Dissolution of flux.

1. Formation of hot spot

When the jet of O₂ strikes the bath a deep crater is formed. As a result, molten metal & molten slag is thrown up which may result in scabbing. Since, first contact of O₂ is made at the crater, oxidation of Si & Mn starts. As a result higher temp is developed in the crater which is k.a. hot spot.

2. Entrainment of ambient gas in the jet:

Some entrainment of ambient gases may take place particularly in the initial zone. In the beginning only 60% O₂ is present near the crater rest may be CO, CO₂ & N₂.

3. Dissolution of scrap:

As the temp. of the bath is raised, dissolution of scrap is hastened particularly of larger pieces! Rate of dissolution depends upon: size of scrap, temp of hot metal,

O₂ pressure, etc.

4. Dissolution of flux:

Since the flux is in granular form, its dissolution takes some time. Therefore, in the beginning, the slag is a little viscous. But this is advantageous since the emulsion is more stable in case of more viscous slag.

The actual refining takes place by 2 modes

- i) Bulk Phase Refining
- ii) Emulsion Phase

iii) g.

Bulk Phase Refining

In the beginning, refining takes place by bulk phase refining mode. During this period Si & Mn are oxidized.

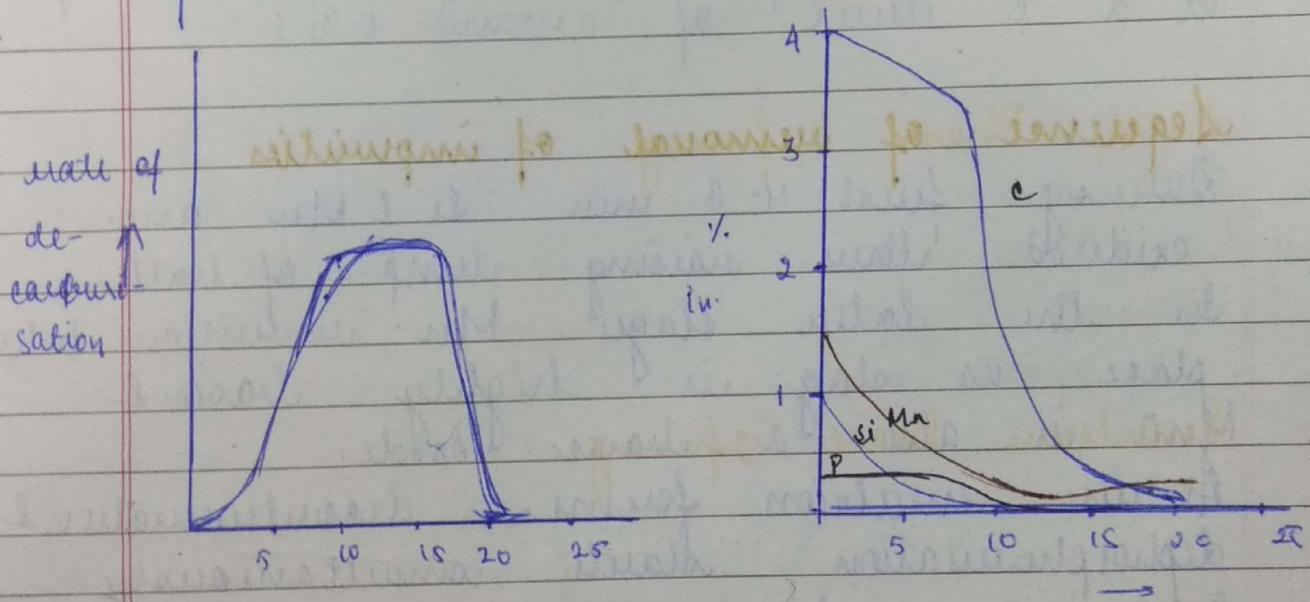
Emulsion Phase Refining

Oxidation of impurities by dissolved O₂ or thru' FeO

Solubility of O₂ is around 0.25 wt % at steel making temp. The consumption of O₂ is 2-3% per ton of steel produced. The oxidation of impurities is over in 15-20 min only. This obviously means dissolved O₂ is not responsible for oxidation of impurity but metallic Fe, as it is in bulk oxidized first in FeO & then impurities are oxidized by FeO.

Formation of emulsion phase:

When tiny liq. droplets are thrown up, they fall down immediately into the bath. But as soon as formation of CO starts, it forms a suspension of metal-slag-gas over the bath surface. The CO bubbles are coated with metal & slag. The residence time of the bubbles in emulsion phase may be in range of 2-3 min. Residence time will depend upon: viscosity of slag, rate of formation of CO.



Desulphurization & deposphorilation, both are very fast in emulsion phase. This happens due to very large interface available in emulsion phase. SA. in the bath could be $10 - 15 \text{ m}^3$ then it becomes 1500 m^3 in emulsion phase. $\therefore \text{reactions}$ are very fast in emulsion phase. Formation of emulsion phase begins only after 4-6 min.

It is max in range 10-15 min, then it starts falling down due to sufficient CO₂ not available for longer residence time. As temp goes on increasing the slag is now less viscous. True ~~less~~ residence time of emulsion phase ↓. Most of the P must be removed during emulsion phase refining itself. If it doesn't happen, then depassivation may proceed by bulk phase refining which may prolong the blow. Most of the P is removed when C is in the range 0.7-1.0. Emulsion collapses at a C level of around 0.3%.

Sequence of removal of impurities

During first 4-8 min Si & Mn are oxidized thus raising temp of bath. In the later stages Mn oxidation takes place as slag is highly basic & MnO is also a basic oxide. At the emulsion forms, decarburization & depassivation starts simultaneously. P removal at higher temp. may be prevented by maintaining a highly basic slag.

~~28/8/18~~

DATE: / /
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Modification of LD Process:

Main problem of LD process:

1. Stratification of lower half of bath
Jet is unable to penetrate upto the bottom of the bath. There is not enough stirring & ∴ composition & temp. differences occur.

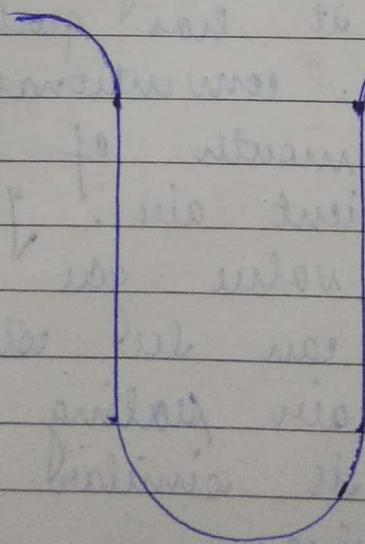
i) Shallower bath

$$h/D = 1.5$$

ii) Use of multi-nozzle lance

3-7 nozzles are used.

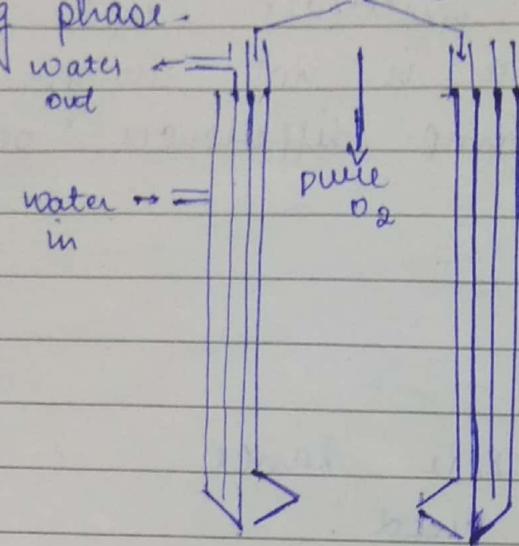
iii) If $P > 0.45$, to bring down P level large amt. of flux will be needed. So the slag vol will be increased. To accommodate larger slag vol, the vessel shape is changed from peashaped to tulip flower shape.



Tulip shaped vessel

iv) of PY 1.5%.

Dissolution of calcined lime will be in the form of powder. For effective removal, the lime should dissolve quickly into the slag phase.



LD-AC Process

↓ Active Calcined

In France it is called DLP - Oxygen Lime Process

v) LD-OG Process

OG Process is for converter gas recovery system. The converter gas 75% CO is combustible which means it has quite a high calorific value. In the conventional LD, converter gas burns at mouth of converter by utilising ambient air. Thus, such a high calorific value gas is not utilised. Converter gas can be stored like in ^{case of} BF top gas by air sealing the hood. Rest of the process is similar to BF top gas cleaning & storing.

circulation

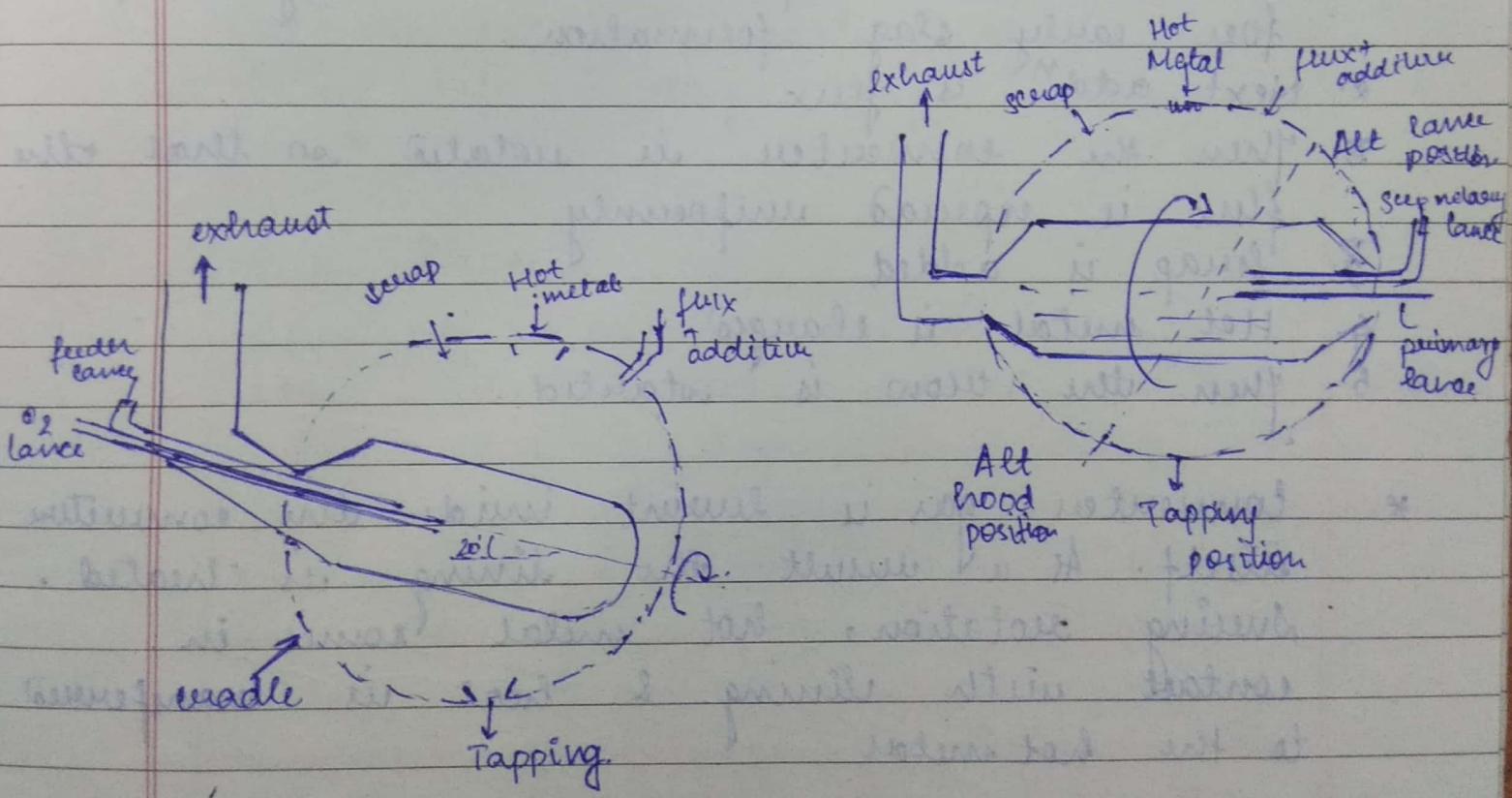
vi) LD-CL Process

In this process the lance is anchored & it is made to circle the bath. As a result, hot spots are generated in the entire bath & rate of refining is much faster.

galfan

Kaldo Process

Rotore Process



Kaldo Process

Domnarfvet Works, Sweden

Prof Kallig

The fig shown is blowing position. The nozzle is inclined at 20° . It can have a max upm of 30. Tundish lance is for the purpose of addition during the process. It is water cooled.

1. First small amt. of initial old slag is left. for early slag formation.
 2. Next addⁿ is flux
 3. Then the converter is rotated so that the flux is spread uniformly
 4. Scrap is added
 5. Hot metal is charged
 6. Then the blow is started.
- * Converter gas is burnt inside the converter itself. As a result the lining is heated. During rotation, hot metal comes in contact with lining & heat is transferred to the hot metal.
- * The lance keeps on oscillating at an angle of $20^\circ - 37^\circ$ & freq of oscillation is 15-20 times per min.

During dephosphorisation period angle of inclination of lance is decreased, oscillation angle & oscillation freq is ↓ & O₂ jet power is

also ↓.

Advantages:

- i) Rapid Mixing
- ii) More effective heat transfer

Limitation

- i) capacity of converter has to be less if it is mounted on cradle.
- ii) Due to excessive heating of the lining, lining life is very poor.

Rotary Process

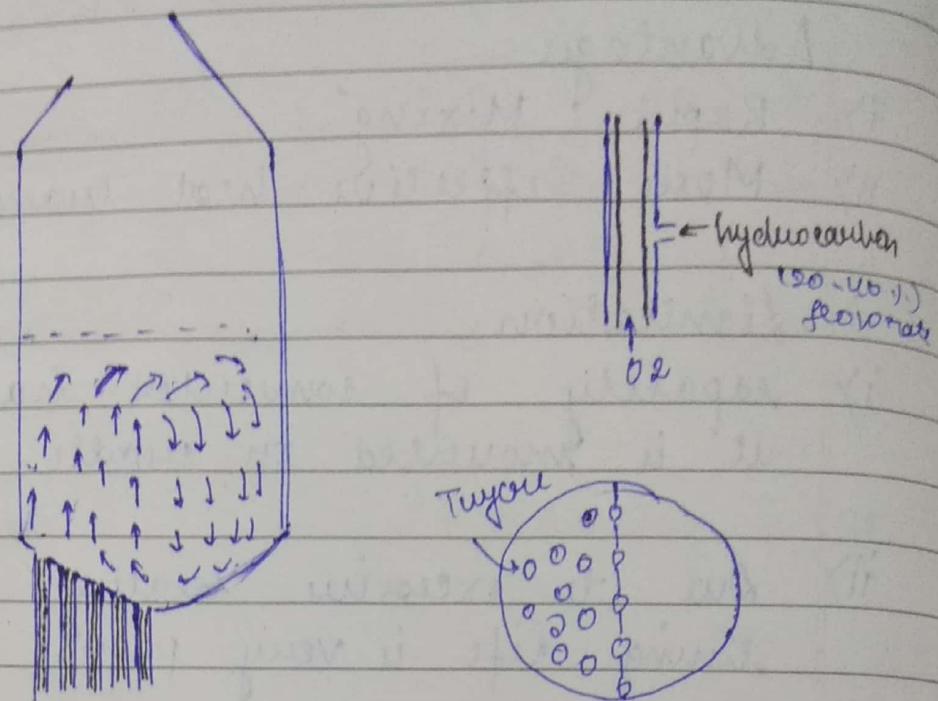
Shape of converter is similar to OH process. This is also mounted on a cradle. All the sequence are same since it is basic process. Primary lance is for main refining, it is inclined at an angle of 20° from the bath. When slag forms the primary lance is submerged in slag phase. This makes a change in sound of O₂ jet which is an indication to the 'mettler' that slag has formed. During dephosphorilation period, primary lance angle is decreased. Secondary lance is for burning converter gas. Speed of rotation is in range 0.4 - 4 rpm.

Advantages:

- i) Rapid Mixing
- ii)

8/18/00

OBM Process



Max millan iron & steel co. 1969 , Germany.

OBM Process - Oxygen Bottom Blowing process

France - LWS process

USA : Q-BOP : Quick Bottom Oxygen Blowing Process
 Temp at Tip of the tuyeres ↑ thus decreasing tuyeres life.
 hydrocarbon when it reaches tip of tuyeres, it is cracked into C & H₂. ∵ the cracking is endothermic, it provides a cooling effect to the tip of the tuyeres thus tuyeres life is increased. The heat released by cracking is another source of heat thus combustion 50% of H combined with O₂ to form H₂O which is exothermic etc.

Scrap is charged when half of converter where tuyeres are not located. Thus preventing damage of tuyeres. Now the tuyeres can be used as a burner to preheat the scrap. Entire bath is agitated & air is blown from the bottom & circulation of bath takes place as indicated in fig.

Operation.

- The first blow is for a period of 15-16 min during this blow highly phosphatic slag is taken out. This process is more suitable for Thomas grade of pig iron. ($P \geq 1.5$) The P level is around 0.08.
- Now new slag is made by fresh addition of lime & blow is continued for around 3 min. Once again sample analysis is done & P level is around 0.025.
- Now N_2 is bubbled thru' the bottom & is called Nitrogen Rinsing. This brings down level of H_2 but N_2 level is ↑. Later on rinsing was carried out by Ar gas. But using costly, it increases cost of product.

Advantage:

1. Complete mixing of bath
2. No stopping
3. Shop height is reduced
4. Preheating of scrap takes place, hence proportion of scrap can be increased.

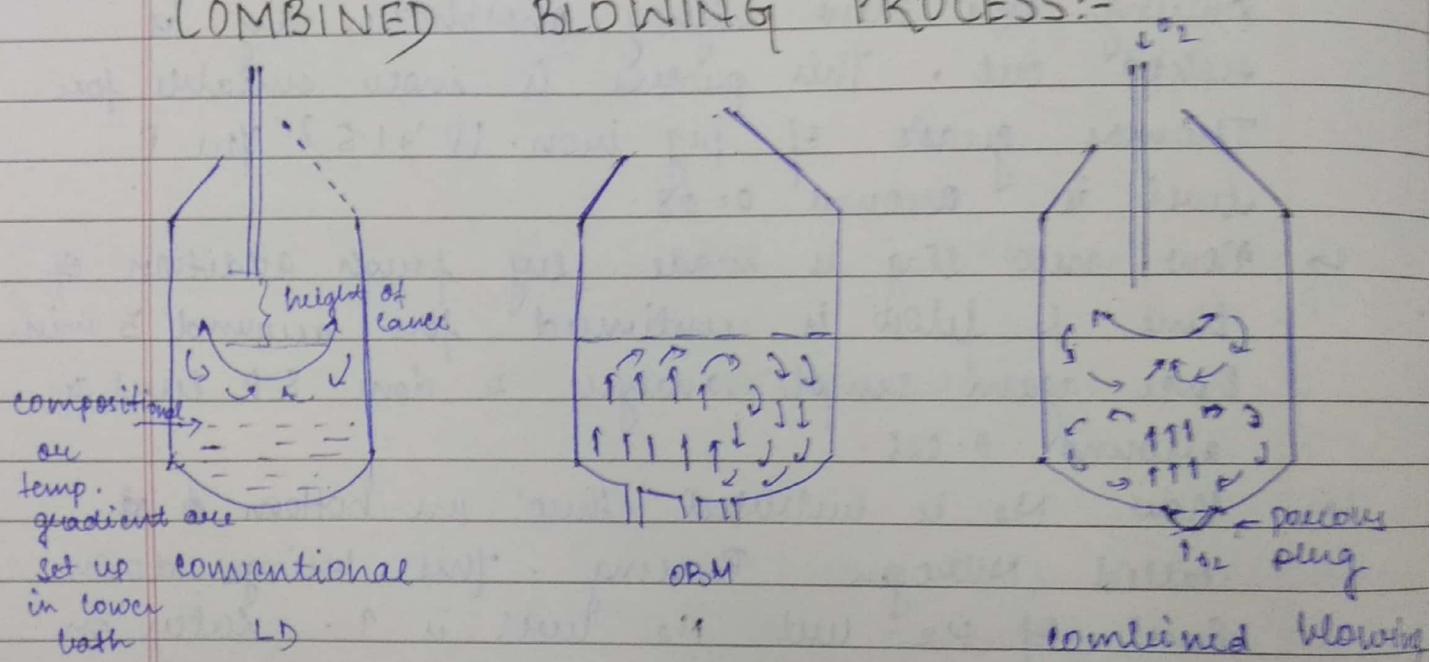
limitation :

1. higher N_2 & H_2 pickup
2. tuyere life is still not long enough.

scope in India:

With the advent of combined blowing & bottom agitated process. adv is claimed by OBM process became well.

COMBINED BLOWING PROCESS:-



In case of conventional LD:

If jet peers 1 & lance height is lowered to solve the problem of stratification. But this results in excessive ejection.

OBM:

Excellent mixing as entire bath is agitated. But high N_2 & H_2 pickup & tuyere life \downarrow .

Combined Blowing

If O_2 is blown from top as well as bottom then it is called Combined Blowing.

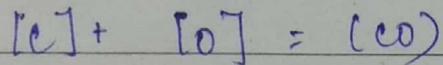
Hybrid Blowing.

If O_2 is blown from top & some other gas (Air, N_2) from bottom. This is also called bath Agitated process.

A porous plug is a refractory plug with very high porosity. Porous plug in place of tuyeres are sufficient enough because rate of flow of gas from bottom is very less. It is in range $0.2 - 0.3 \text{ Nm}^3 \text{ per ton of steel produced!}$

Life of porous plug is almost equal to lining life of converter.

1. LBE Process (Lance Bubble Equilibrium)



This process says that formation of CO bubble take place under equilibrium condn.

$O_2 \downarrow$

\uparrow

$Air - 5 \text{ Nm}^3/\text{min}$

Porous plug life is equal to lining life of converter.

2. LD - KG Process

$O_2 \downarrow$

Kawasaki of Japan

$Air \uparrow$

$0.02 \text{ Nm}^3/\text{min}$

3. LD-AB Process

Developed by Nippon Steel of Japan

$$Ar - 0.013 \text{ Nm}^3/\text{min}$$

4. LD-OB

$$O_2$$

$$\uparrow O_2 \quad 0.3 - 0.8 \text{ Nm}^3/\text{min}$$

5. STB ← Bottom

→ Sumitomo Steel

$$\uparrow \text{co}_2 \text{Ar} \quad 0.1 - 0.2 \text{ Nm}^3/\text{min}$$

flow rate of Neutral gas should be optimum
because:

- it has chilling effect on bath
- bath needs to be stirred well.

6. LD-HC

→ Hainautsamme & CRM Steel

Use CO_2 or natural gas $2-6 \text{ Nm}^3/\text{min}$

7. K-BOP → Basic O₂ Process

↳ Kawasaki

$$\uparrow O_2 1.5 \text{ Nm}^3/\text{min}$$

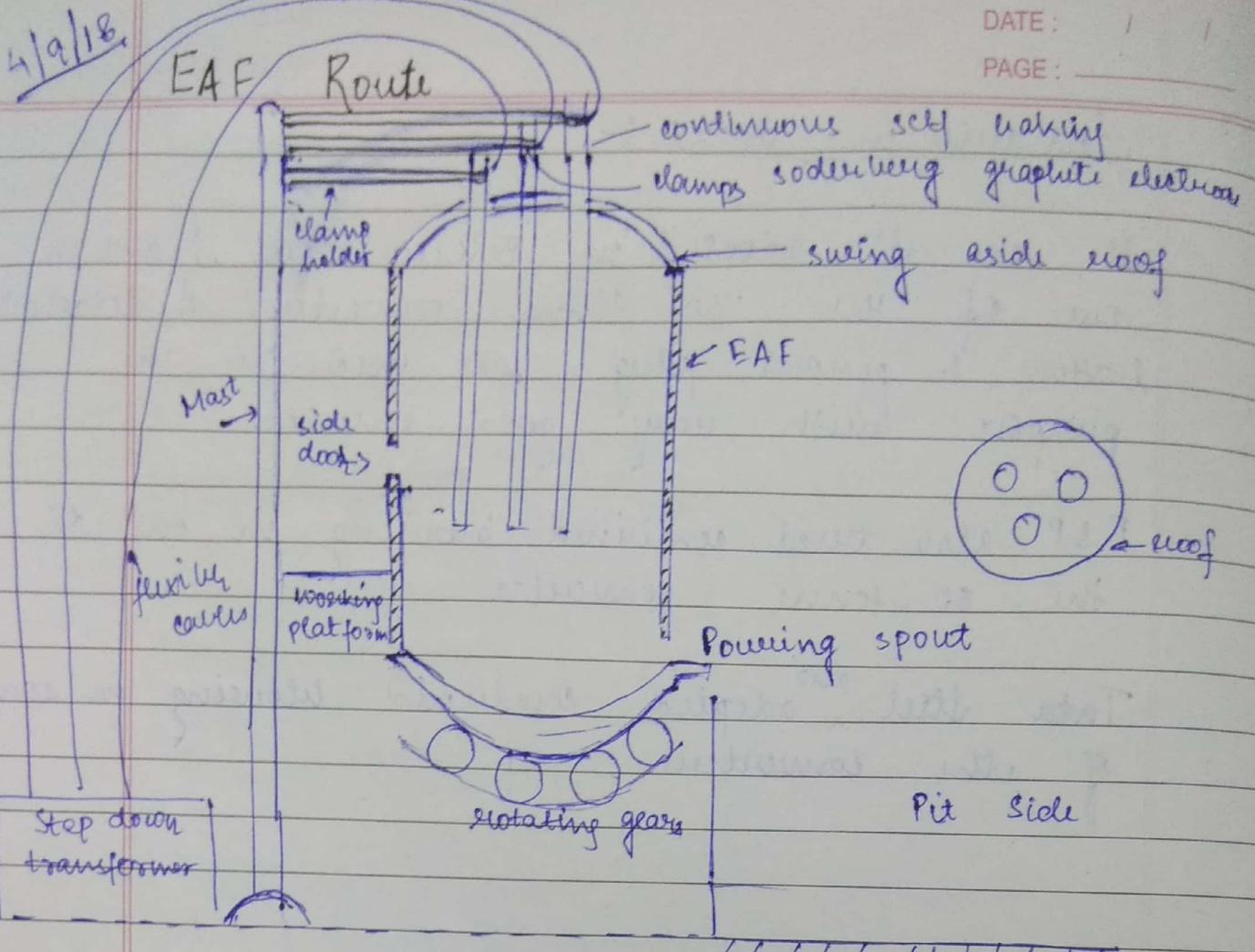
\uparrow time (so that dissolution of lime is easier)

Scenario in India :-

It was first adopted in Bokaro Steel Plant in one of the 130 tonne converter. A detachable bottom & porous plug was used for the purpose with very good result.

RSP also tried combined blowing in one of the 60 tonne converter.

Tata Steel ^{also} adopted combined blowing in some of the converters.



3C ← manually joint electrodes

Transformer Rating

100 - 200 kVA/ton

200 - 400 kVA/ton

400 - 700 kVA/ton

> 700 kVA/ton

Powers

low power / Regular

Medium

High power (HP)

Ultra high (UHP)

Construction & Working

Outer shell of EAF is made of armored plate & is surrounded by water circulating pipe

Bottom:

1st layer is of fire brick

Then magnesite bricks

Then above that scanned magnesite.

Both side walls are exposed to immense heat ∵ they are made of Chrome Magnesite Brick.

Side door is used for addition of additives during the heat. The same door is used for taking sample & for making purpose.

Pouring spout is to facilitate accurate pouring into ladle.

At the roof the lining is of silica bricks since it is not exposed to very high heat.

Rotating gears are present for working purpose & for tilting so that hot metal is poured.

WP is the 1st floor.

Electrodes are self baking & ∵ meg size is available all the time.

The 3 electrodes are connected independently with the help of flexible cable to step down transformer.

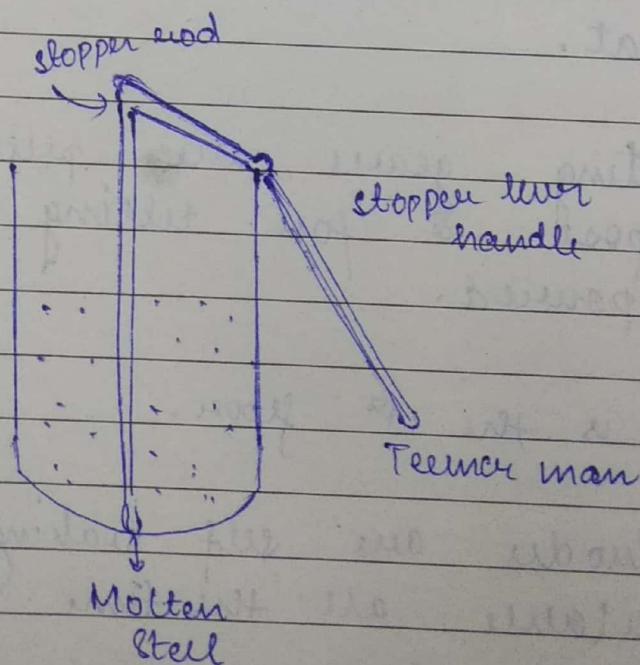
The mast holds the electrode with help

of clamp & holders. The clamp is made of Cu & the power is supplied to this clamp only.

Three electrodes can move up & down independent of each other.

Electrodes are lowered & made to touch top surface & then lifted up slightly as a result arc is produced. Arc gap is very critical here. If arc gap \uparrow , arc will extinguish \therefore a certain arc has to be maintained. This is done by having a control based on impedance (resistance) in arc gap.

Teming Ladle



It was made for melting of scrap. Bcz of gap is demand & supply of scrap, its cost is increasing. Also comp of slag is undetermined. Scrap etc may also be present.

5/9/18

Production of a typical mild steel heat in an EAF (by double slag practice)

Scrap is the main raw material.

Scrap contains tramp elements which can be categorised as:

i) Volatile - Zn, Cd, Pb, etc (escape at sm temp.)

ii) Non oxidisable - Cu, Ni, Sn, Mo, As, etc. (^{oxide not} _{stable})

iii) Partially oxidisable - P, Cr, Mn, etc.

iv) Completely oxidisable : Al, Si, Ti, V, Zr, etc.

- Stability of oxide
- Oxide which occupy pos. at middle of Ellingham diagram
- Oxides lying in lower portion of Ellingham diagram.

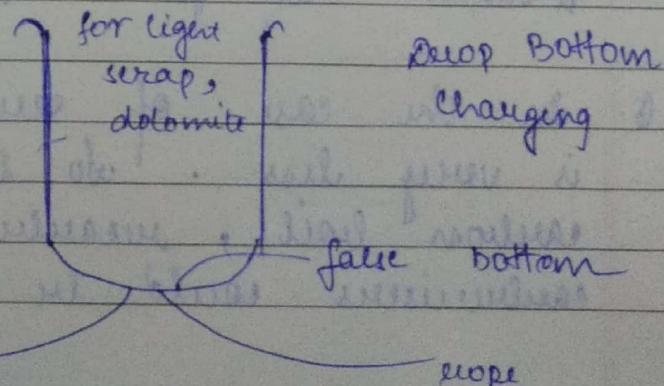
log shed

Time	Operation	Remarks
when heating	up to	comp & aust

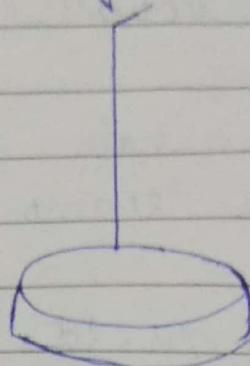
Operational Steps

1. Hot fettling: repair

2. Flux is charged first. Flux is ~~charged~~ now dolomite.



Scrap is also charged by magnetic crane.



electric magnet
for heavy scrap

Light scrap is compacted.

The furnace is packed to spread dolomite at bottom.

3. Scrap is charged in order:

light - medium - heavy.

Temp at arc tip = 3000°C . & at a dist of 1 m it is 2000°C . \therefore Avg temp of arc is 2000°C .

4. Roof is brought to its position & electrodes are lowered. The arc is started when electrode tip touches the charge surface & is then lifted slightly to maintain the arc.

5. Once it is completely molten 1st sample is taken out for chemical analysis.

6. In the case of scrap as major charge, C is very less. So to carry out effective carbon boil, manganese are added. Carbureisers could be coke breeze, broken

electrode pieces.

Refining is carried out by addn of iron ore or commercial O_2 thro' O_2 gas cylinder.

7. Slag is analysed for basicity. Beoz for removal of phosphorous higher basicity is needed. Depending upon this next lot of dolomite is charged. Now,

8. Now, operation is stopped, electrodes are removed & roof is swung aside. The furnace is tilted & 1st slag is tapped out. \hookrightarrow oxidising slag.

9. Now, fresh dolomite addition is made to achieve a very high basicity which is necessary for removal of S. This slag is a reducing slag.

10. Once again operation is stopped, roof is swung aside & 2nd slag is also tapped out.

11. 2nd sample is taken out.

12. Addition of deoxidiser

— — — Mild Steel is prepared.

13. Alloying additions are done in case of Alloy Steel.

Scrap

- Poor control over comp. due to presence of scrap element
- Variety of scrap e.g.: MC scrap, cold pipe, foundry return, mill scale, etc.
- Due to increasing gap between demand & supply, cost of scrap is ↑ day by day

Sponge Iron

- Poor thermal & electrical conductivity
- All gangue remains in sponge iron.
- highly reactive since it is porous.
- Gas based DRI is more reactive than coal based DRI.
- Carbon content of sponge iron is very low 0.1 - 0.2%. The % of C can be increased in gas based processes by cracking natural gas in hot sponge. But this ↑ cost of product
- Residual O₂ is in the range 0.6 - 1.2%. In gas based DRI % metallization achieved is upto 92%. In coal based DRI it is in range 86 - 88%.
- That is why higher % of C is needed so that it can neutralise residual O₂.
- Sponge Iron must always be kept under shade.

Merkal: DRI is very cheap & no tramp elements

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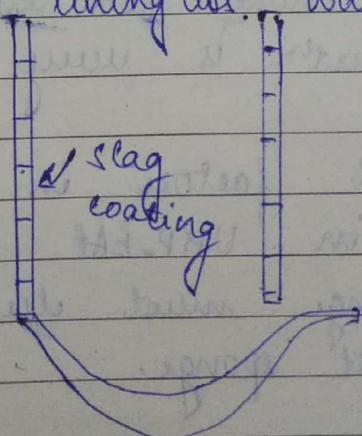
If 100% DRI is used then production cost of steel is 30-40% less than conventional route. Regular power EAF can takes not more than 25% of DRI. This is due to the fact that thermal & electrical conductivity of sponge iron is poor. It is not easy to melt sponge iron.

- Problem of ice lining formation: Since thermal & electrical conductivity of sponge iron is poor. Many solid lumps of sponge iron keep on floating over molten iron giving the appearance of an iceberg.
- Since all the gangue remains with sponge iron large amt of flux is needed to stabilise them. Hence this results in large increase in slag vol.

UHP EAF

Transformer rating 700 kVA

Outer wall is made in segments & is water cooled. ∴ it is called lining less walls.



Roof is also water cooled.

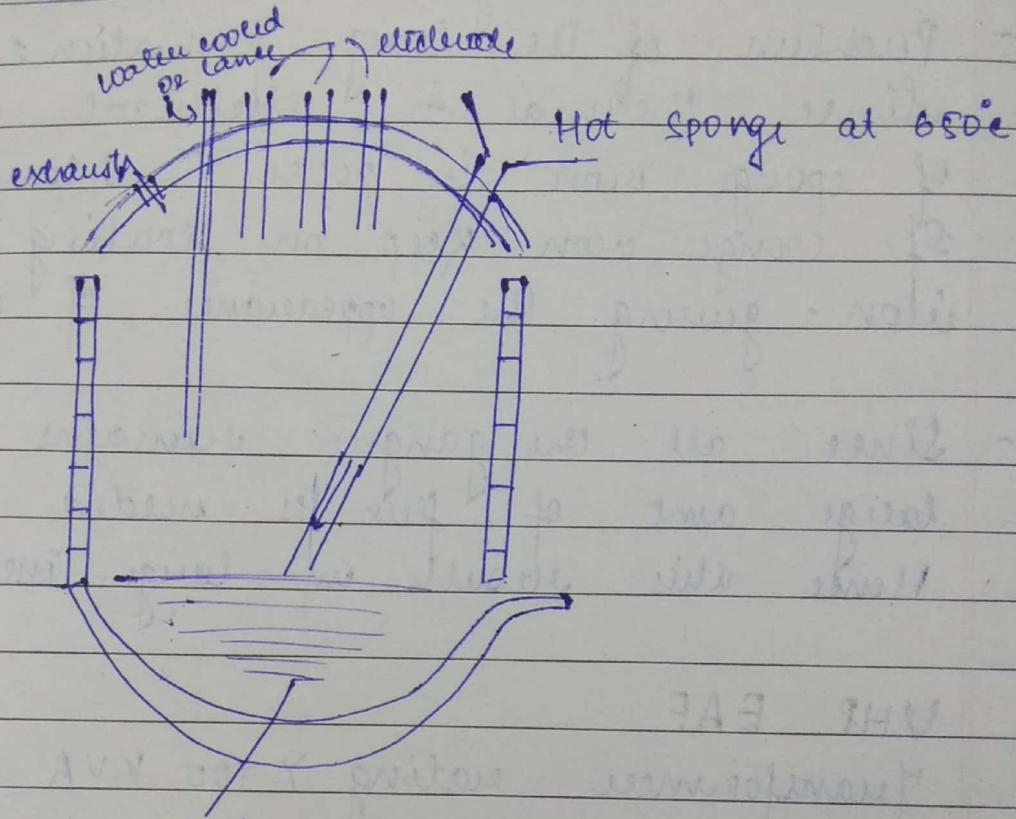
- Electrode

10% loss due
to breaking, etc

clamp is also water cooled.
coating of refractory
40% loss due to Fe^{+2} of current
 \rightarrow 50% loss by oxidation of tip

flexible cables are also water cooled.

- Roof



Hot heat 25% of hot metal is retained.

Hot DRI is choke fed thru' hopper tube hence its cross-section is very critical.

Most critical factor in production of such thru' DRI in UHP-EAF is that feed rate of hot sponge must be equal to melting rate of hot sponge.

4/9/18

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DRI - EAF

vs

BF - BOF

EAF \Rightarrow to melt scrap $\xrightarrow[\text{add}]^{\text{alloying}}$ Alloy
steel
 \Downarrow
substitute

Sponge / DRI - merit / limitations

DRI - scrap - hot metal \leftarrow Integrated I&S Plant.

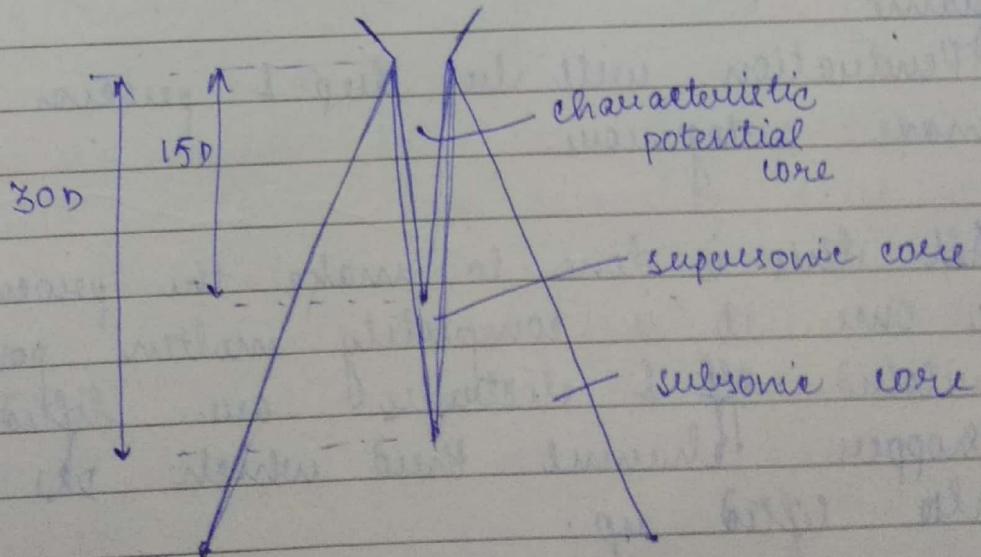


for smaller plant

DRI - EAF

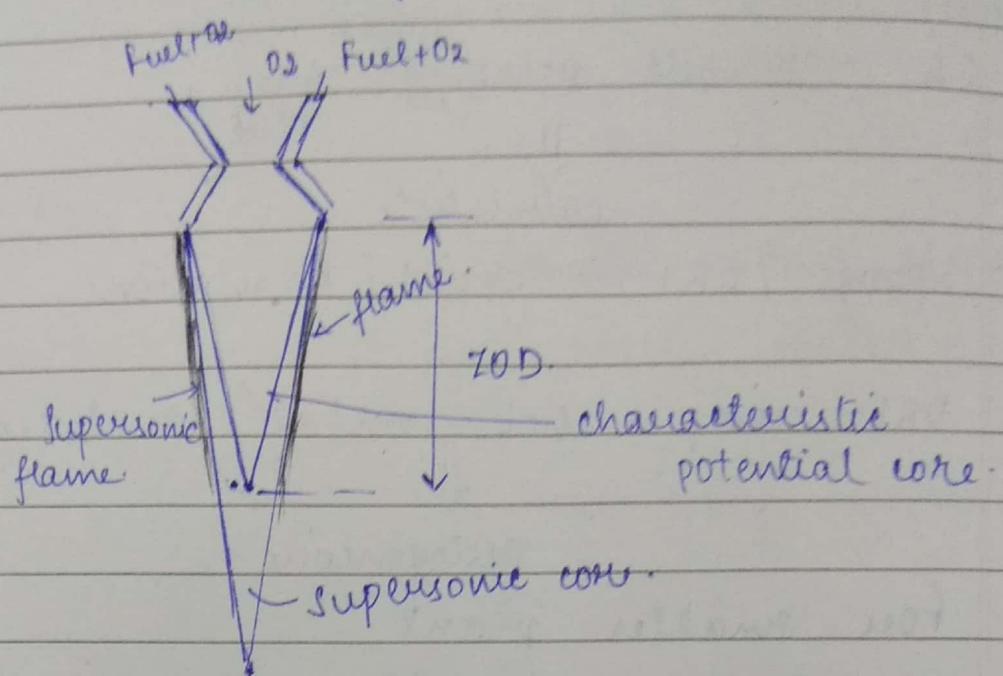
VHP is used & power consumption is very high.
* would produce thru' EAF - 50%.

VHP - melting 1.5 MW/tonne
Regular Power - Refining 350 kW/tonne



Coherent Jet Technology

Cohesive Jet Technology



I adj convergent - divergent nozzle.
 length of char potential core is ZOD & supersonic cone also increases proportionately.
 It is called cohesive jet tech bcoz supersonic flame & supersonic cone are merged together
 Length of cone ↑ due to presence of supersonic flame.

Penetration will be deep & process can be made autogenous.

All this is done to make the process autogenous
 ∵ once it is completely molten power is switched off & electrodes are lifted up. The hopper channel through which SRI is fed is also lifted up.

Foamy Slag

A foamy slag is preferred in the beginning of melt down stage. To have a foamy slag, slag must be viscous. In the beginning slag is viscous because the temp is low. In the beginning metal gas Fe^{+2} takes place in which oxidation of Si, Mn, C takes place in this order. When during desuperheating Co bubbles go up, it lifts the viscous slag & thus a foamy slag is formed.

* Need of Foamy Slag:

Foamy slag covers the arc near the electrode tip. As a result more & more arc heat is transferred towards hot metal. Moreover, it also prevents overheating of refractory lining thus increasing lining life.

Now a modern EAF can be used in production of : deep drawing steel (DD), extra DD steel, special DD steel, special wires, IF (interstitial free) steel. & all kind of stainless steel other than regular products like : flat products, angles, channels, bars, etc.

S.S - contains very less % of C

C: $\left\{ \begin{array}{l} * \text{Austenitic S.S.} = 18:8 \Rightarrow \text{cutaway steel} \Rightarrow C = 0.03 - 0.05 \\ * \text{Ferritic S.S. - no. Ni} \Rightarrow \text{cheaper} \Rightarrow \text{for high temp app} \\ \qquad \qquad \qquad \Rightarrow \text{steam turbine blades.} \end{array} \right.$

intergranular corrosion - ~~but~~ Chromium Carbide

- * Martensitic S.S. : cutting tools
- * Dual Phase S.S.
- * Complex Phase Steel

Stainless Steel Making by Rustless Process:-

It was difficult to melt S.S. scrap, either electrode will break or dissolution of C takes place ∴ low C content maintenance is difficult.

→ Raw Material:

1. S.S. scrap
2. High carbon Ferrochrome (low C ferrochrome is costlier)
3. Chromite Ore
4. Iron Ore for refining

One modification in EAF lining operating temp is around 1800°C .

Side walls are made of chrome brick over which chromite ore wash is given.

→ Charging Sequence: from bottom:

1. Chromite ore is evenly spread at the bottom
2. Light → Medium → Heavy scrap
3. Iron ore (15-20% of total charge)
4. High C Ferrochrome

B. On top double light screw.

$$\frac{4}{3} \langle \text{C}_2 \rangle + \langle \text{O}_2 \rangle = \frac{2}{3} \langle \text{CO}_2 \text{O}_3 \rangle$$

$$2 \langle \text{C} \rangle + \langle \text{O}_2 \rangle = 2 \langle \text{CO} \rangle$$

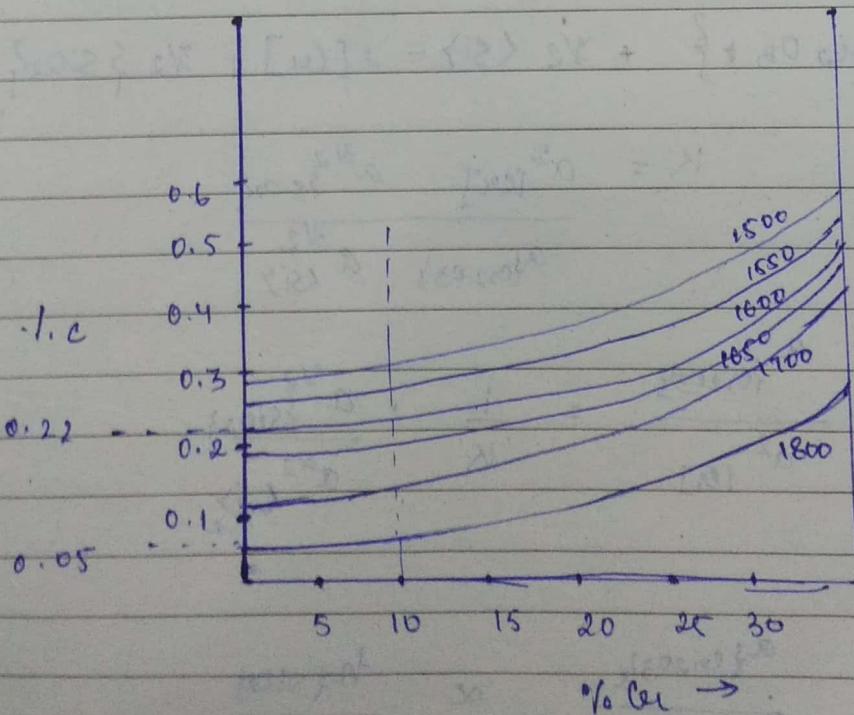
Overall $3 \langle \text{CO} \rangle + 2 \langle \text{C}_2 \rangle = \langle \text{CO}_2 \text{O}_3 \rangle + 3 \langle \text{C} \rangle$

$$K = \frac{\alpha_{\text{CO}_2\text{O}_3} \alpha_3^3}{\alpha_{\text{C}_2\text{O}_3}^2 \cdot P_{\text{CO}}^3}$$

Equilibrium Temp = 1220°C

CO is the only gaseous phase

let us assume CO_2O_3 to be pure solid &
 P_{CO} to be 1 atm pressure.



equilibrium plot of Y.C vs % C₂O in bath.
 Main obj is to have low C. C should be in
 Range 0.03 - 0.05

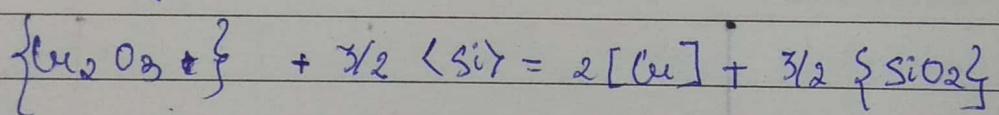
When we oxidise Cr, Cu will be also oxidised & it will be lost to slag phase.

At 1600°C , for optimum 10% Cr we have 0.22% C. But at 1800°C for 10% Cr we have 0.05% C.

Now at 1800°C we have 0.05% C & reasonable melt of Cr i.e. 10%. Rest of Cr joins slag phase.

→ How to recover Cr which has been lost to slag phase.

\because there is no danger of reversion of Cr (Cr being a gas). Now the nature of the bath can be changed from oxidising to reducing.



$$K = \frac{a^2 [\text{Cr}]^{3/2} \{ \text{SiO}_2 \}}{a_{\{ \text{Cr}_2\text{O}_3 \}}^{3/2} a^3 \langle \text{Si} \rangle}$$

$$\frac{a_{\{ \text{Cr}_2\text{O}_3 \}}}{a^2 [\text{Cr}]} = \frac{1}{K} \cdot \frac{a^{3/2} \{ \text{SiO}_2 \}}{a^{3/2} \langle \text{Si} \rangle}$$

$$\frac{a_{\{ \text{Cr}_2\text{O}_3 \}}}{a^2 [\text{Cr}]} \propto \frac{h \{ \text{SiO}_2 \}}{h \langle \text{Si} \rangle}$$

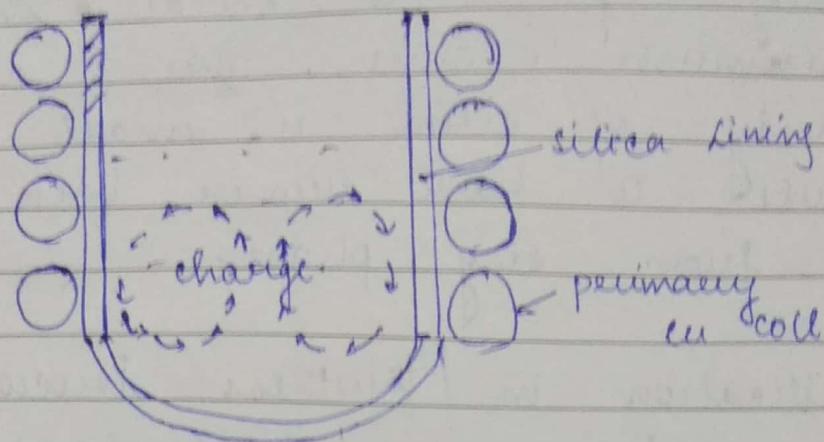
As a deoxidiser Fe-Si is used. ~~Astically~~
Ratio of activity is a_{Fe} in slag phase to
activity of a_{Fe} in metal - should be
minimum. Since, this is a basic process
activity of silica is small. It is
possible to recover back most of the
 Fe from slag phase.

Modification in Rustless Process:

For refining, now-a-days commercial O_2
is used so refining is faster.

1800°C is quite a high temp which is not
desirable. Post treatment in AOD (Argon
Oxygen Decarburization process) or VOD
(Vacuum Oxygen Decarburization Process).

2/9/18 Induction furnace steel making route:



cheapest Steel making route. But its capacity is smaller.

Furnace is made of steel plates welded together & lining is of silica bricks which is cheaper compared to basic lining. Slag is not formed & ∴ PLS is not removed ∴ no need of basic lining. Induction furnace is surrounded by water cooled primary Cu coil. These primary coils are hollow Cu tubes.

→ Principle of heating.

When primary coils carry an A.C. current, a magnetic flux is generated. This magnetic flux induces eddy current in secondary coils. The heating effect is due to this eddy current. Here secondary coil is the charge.

Since, slag is non conducting, it can't be melted in this process. Slag remains dry

& viscous & hence does not take part in any kind of refining. \therefore P & S can't be removed at all.

Since the slag is dry & viscous, the separation of hot metal is clean.

Depth of Penetration of Heat :-

$$S = \sqrt{\frac{I}{\pi \mu f}}$$

ρ = Resistivity of the charge

μ = Magnetic Permeability

f = Frequency of supply.

In case of Induction Hardening, small penetration depth is req. so the freq should be very high (500 KHz - 2 MHz).

For steel melting, medium freq is req. since depth of penetration needed is more (100KHz) upto the centre of the furnace.

The \star

The eddy currents cause good mixing/circulation in the bath which is k.a. fountain effect. This due to this lighter non-metallic inclusions move up & float to the top.

→ Operation:-

* Charge

* Scrap - 20%.

Cast iron - 15-20%.

Rest is sponge iron

CI is added to make up a level for
Cauldron Boil. for refining.

- It is added to have a reasonable level in the beginning, but one has to be careful about P's content in CI.
- Commercial Os cylinders with consumable MS pipes are used for refining.
- Deoxidizers, alloying elements
- Since, sponge iron contains residual oxygen, some of the alloying additions may be lost due to oxidation.
- Petroleum coke has lower S content hence it is used as a reducing agent for residual oxides.

* Charging Sequence:

- A small load from previous heat is left.
- Scrap is charged in sequence light → medium → heavy
- Once it is completely molten CI is charged
- Once it is completely " Sponge iron is charged.

Silica & Alumina are main impurities in Sponge Iron. Nature of both is acidic.
∴ These impurities do not attack the lining.

Moreover the m.p. of Silica & Alumina both are above steelmaking temp., ∴ they will remain dry & viscous.

Some SiO₂ may react with FeO to form a thin slag, but its proportion is less.

After removal of slag, deoxidizers are added.

It is followed by alloying additions

* Tapping at Correct Temperature :-

- Advantages :-

- cheaper, high temp can be generated quickly
- loss of heat & electricity is low.
- continuous & homogeneous stirring due to fountain effect.
- non metallic inclusions float up.
- N₂ pickup is low.
- clean separation of slag & metal.

4/18/18.

CONARC PROCESS

converter arc.

company

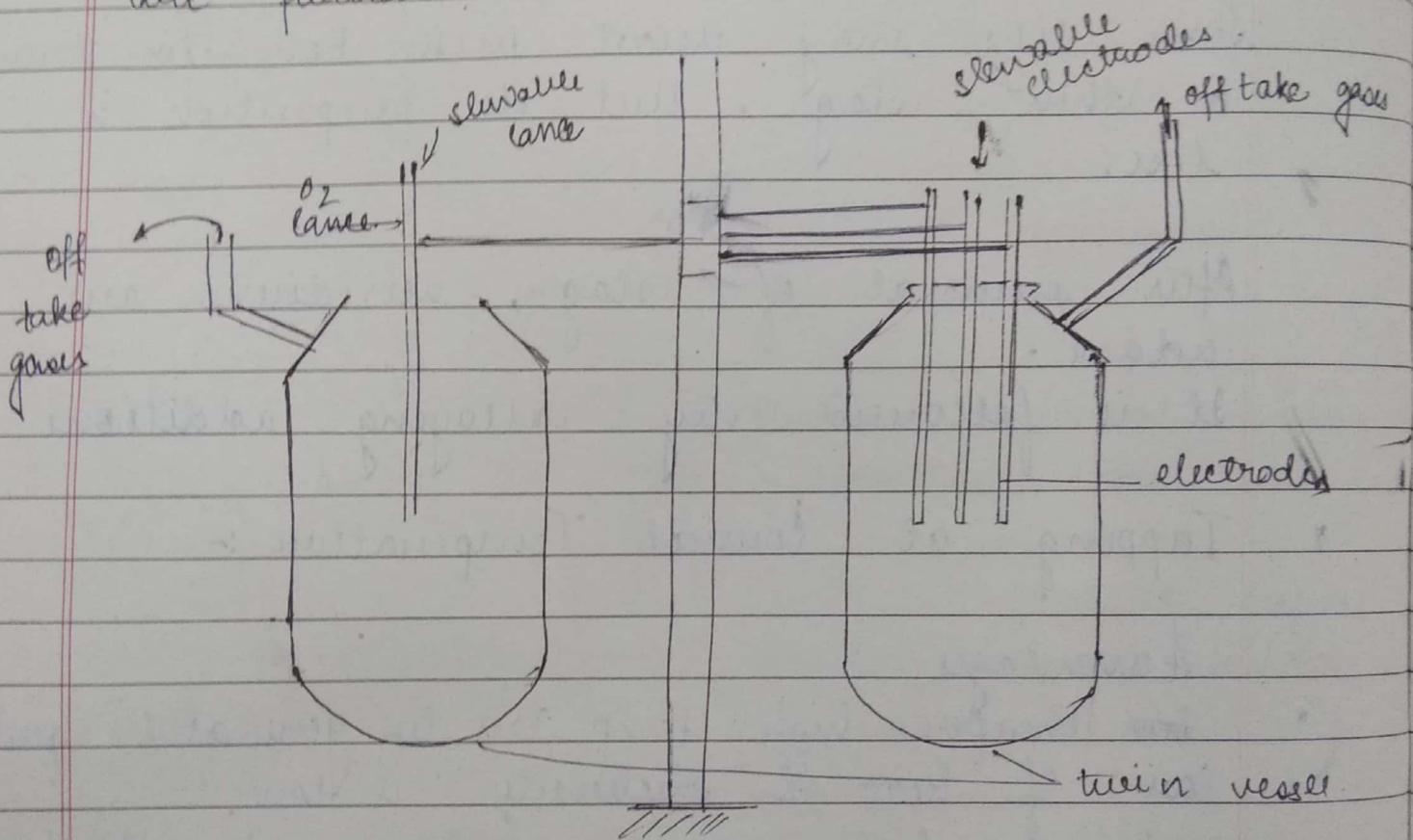
↳ MANNES MAN demag

i) Ispat Industries - Dohar

ii) Bhushan Steel & Steels

Ltd → Jharsuguda - Sambalpur

It is a combination of
LD converter & electric
arc furnace.



The process consists of 2 similar vessels.
The vessel almost looks like a conventional converter.

Essential phases:

- At one time, one of the vessels acts as an electric arc furnace & the other one acts as converter.
- In the next cycle, the first one acts as a converter & second one as EAF

It consist of slave lance on one side & slave electrode on other side.

Two distinct adv:

- The charges used in this process can be 100% scrap, 100% DRI, or any proportion of scrap, DRI & hot metal. Max. flexibility for charging.
This process is utilised in production of:
 - i) Plain Steel
 - ii) Stainless Steel

→ PRODUCTION OF STAINLESS STEEL:-

- for a carbon content of 0.05% 2 step desulphurisation is employed.
- If extra low carbon of the order of 0.02% is desired then 3 stage desulphurisation is employed.
- The chromium which is lost in the slag phase is recovered by addition of Fe-Si.
- Charge material would be mild steel scrap, ss scrap, molten metal, DRI, ferro-chrome, ferro-nickel (austenitic).

→ ENERGY OPTIMISATION:-

- Offtake gases are utilised in preheating of scrap.
- It is also utilised in recuperators.
- It is also utilised in waste heat recovery.

water - for power generation.

SECONDARY

STEEL MAKING

Conventional route:

BF - BOF
EAF
DLF

} Primary steel

In view of increasing demand for:

- Ultra clean steel
- tight grain size
- narrow hardenability range

Hardenability: ability to harden with min cooling.

② - In case of martensite, coarser grain size favours better hardenability because lesser the grain boundary area lesser will be the pearlite formation which is a soft phase.

① - ↑ carbon content ↑ hardenability, but it is limited

$$n = 2^N - 1$$

n = no. of small grain per sq inch $\times 100$

N = ASTM austenite grain size no.

③ - Addition of alloying elements:

There are certain alloying ele like Mo, Mn,

which raise the hardenability * to its
 the only alloying element which ↓
 hardenability *. Other alloying elements
 have no effect on hardenability.

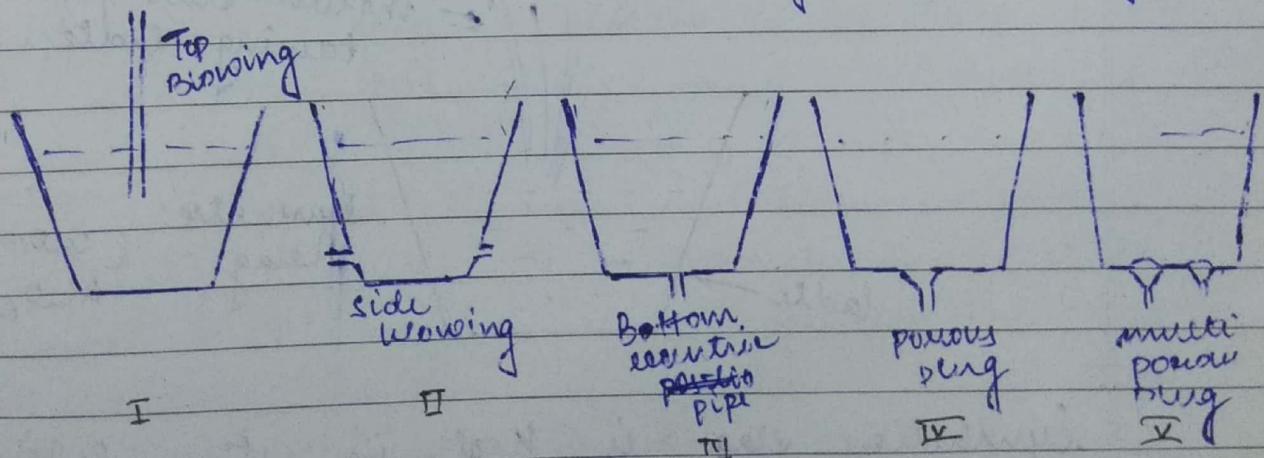
Secondary Steel Making

gross secondary
 steel making route

Fine secondary
 steelmaking route
 (unless dictated by
 customer this
 is not involved)

1. STIRRING PROCESS

Most simplest kind of secondary steel making.



Stirring can be carried out by blowing
 either N_2 or Ar . N_2 is cheaper but
 it has its problems. Ar is costlier

The stirring has a chilling effect. ∴ must be used
 sparingly to achieve max beneficial effect.

Aims of tundish:

1. homogenisation of temp & comp
2. minor alloying for close control of composition
3. cleanliness improvement.

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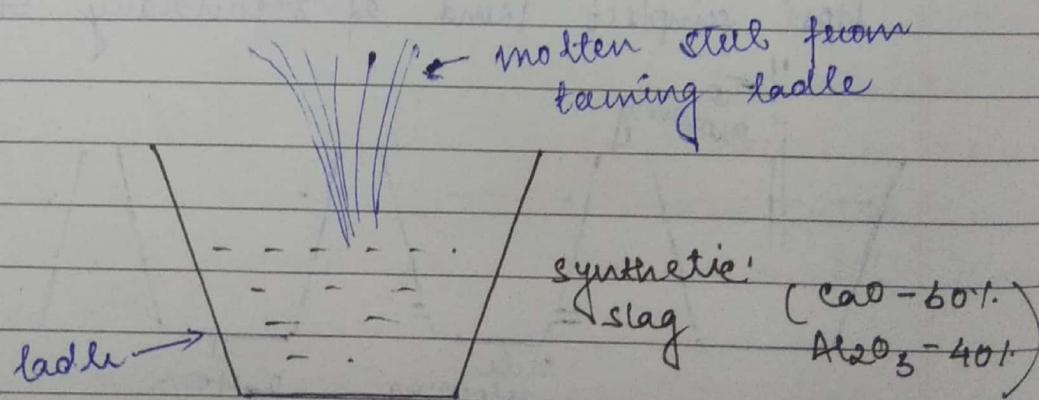
1st 3 are not that good because there is every chance of slag entering the pipe which is left behind after tapping steel.

Porous plug uses 30-35% porosity for Alumina & 20-25% porosity in case of Magnesia.

i) eye space

when Ar bubbling rate reaches a critical value an eye space is formed. Then the inclusions (non-metallic) are carried to this eye space by Ar bubbles. The inclusion then rise to the surface from where it can be separated.

2. SYNTHETIC SLAG REFINING:-



Synthetic slag is kept in the ladle & from the top molten steel is poured. Due to vigorous mixing, it provides large interface for desulphurisation. S is a surface active element so for its removal

Ladle Metallurgy: \therefore all the treatment is carried out in ladle

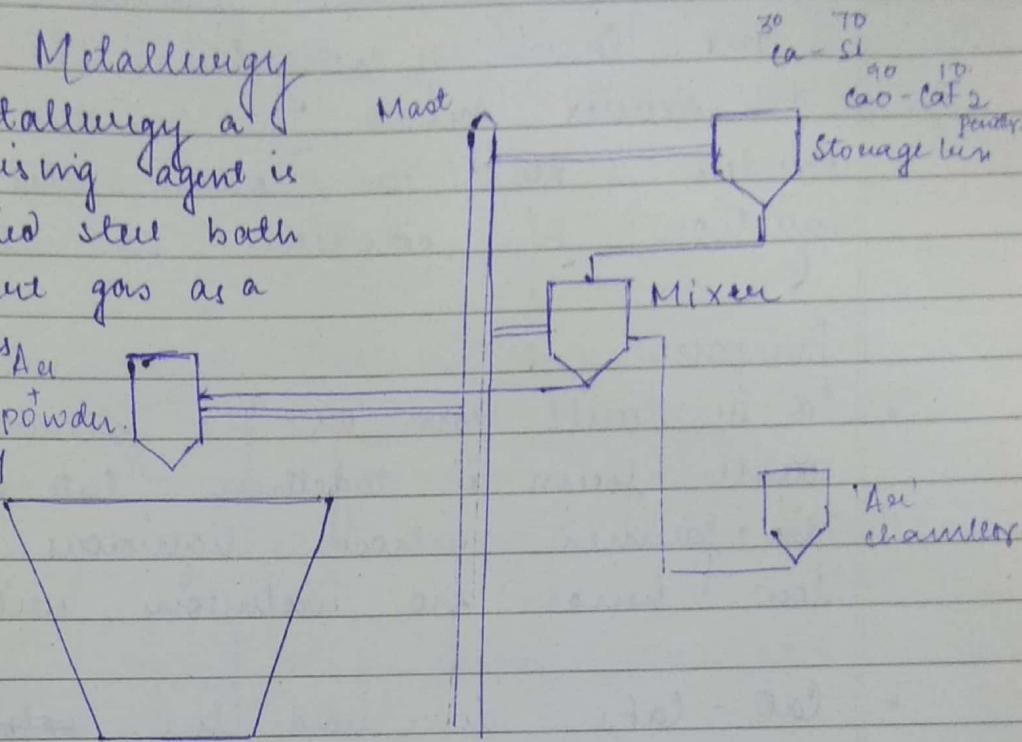
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it requires a large surface area.

3. Injection Metallurgy

In injection metallurgy a strong desulphurising agent is injected in refined steel bath along with an inert gas as a carrier. The enormous interfacial area of contact leads to very efficient interact of reagent with bath. It takes 8-10 min & bath temp comes down by $30-35^{\circ}\text{C}$.



Theisen Neidenheim process (TN) process

Nowadays Al is fed in the form of wire. Al forms Al_2O_3 which is lighter but solid at steelmaking temp. Although it floats to the top, it is dispersed in the form of non-metallic inclusion. During rolling it forms streaks which affects the mechanical properties. If these inclusions remain in globular form then the mech properties are not affected. \therefore thus days either elemental Ca or Ca-Al is fed in the form of wire (CaCO_3 globular calcio silicates are formed which are non-deformable at steelmaking rolling temp thus not affecting the properties).

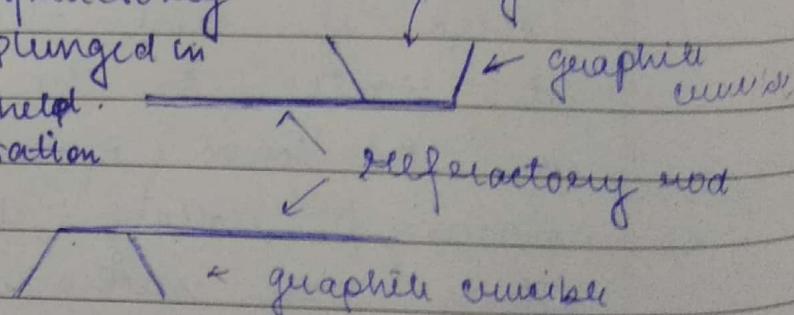
Injection metallurgy involves injection of powder into ladle containing hot metal. These powders are stored in storage bins & are Ca-Si & CaO-CaF₂. Ar is used as a carrier gas. The mixer mixes the powder & Ar. The other bin regulates the injection of powder in the ladle.

Purpose:

- Ca-Si will act as a deoxidizer. CaO & SiO₂ will form & together CaO-SiO₂ slag will be formed whose liquidus temp is very low hence no inclusions will be formed.
- CaO-CaF₂ is used for extra beta lowering of S level & not as a deoxidizer.

4. Plunging Technique

In this a small crucible containing the reagent is attached at the end of refractory protected rod. The crucible is plunged in the bath with upside down & held inside the bath for eq duration during which reagent is expected to interact with the steel.



Mg Coke - MgO + coke breeze

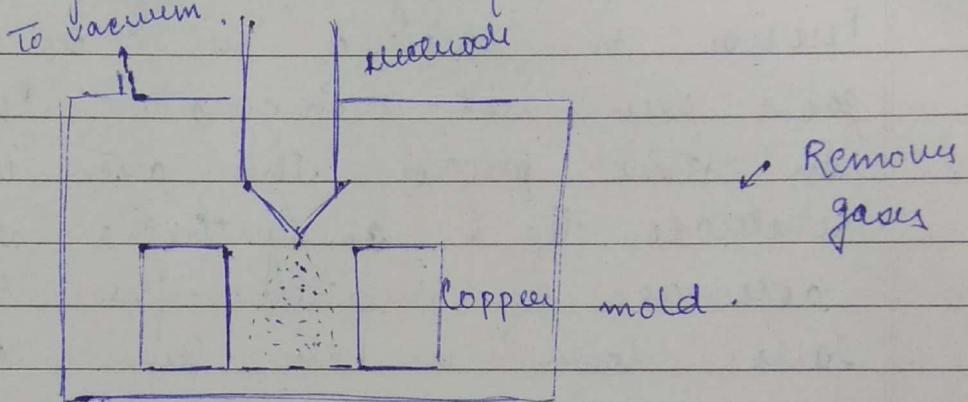
- acts as deoxidizer as well as desulphuriser (high affinity for S)

This technique is adopted when total amt. of reagent to be added is very small DATE _____
PAGE _____ that it can't be injected with a carrier gas.

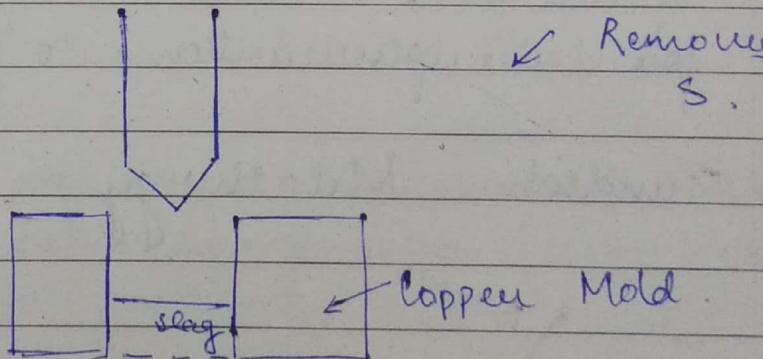
This is very simple & cheap process.

Diffr from "inject" metallurgy & pluming technique is that pluming is carried out at a very small level so the cost involved is very less.

5. Post Solidification Technique



I VAR Process.



II ESR process
electroslag refining

In this process the starting material is primary steel ingot. The ingot is turned (lathe machine) into the shape of an electrode.

Adv of BSR over VAR:

multiple electrode can be melted into single electrode.
cheaper.

surface quality is superior.

ingots of larger size can be produced.

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I VAR (Vacuum Arc Remelting) Process

Here in this process the arc is ignited between the electrode & the mold wall. A water cooled mold is used for the purpose.

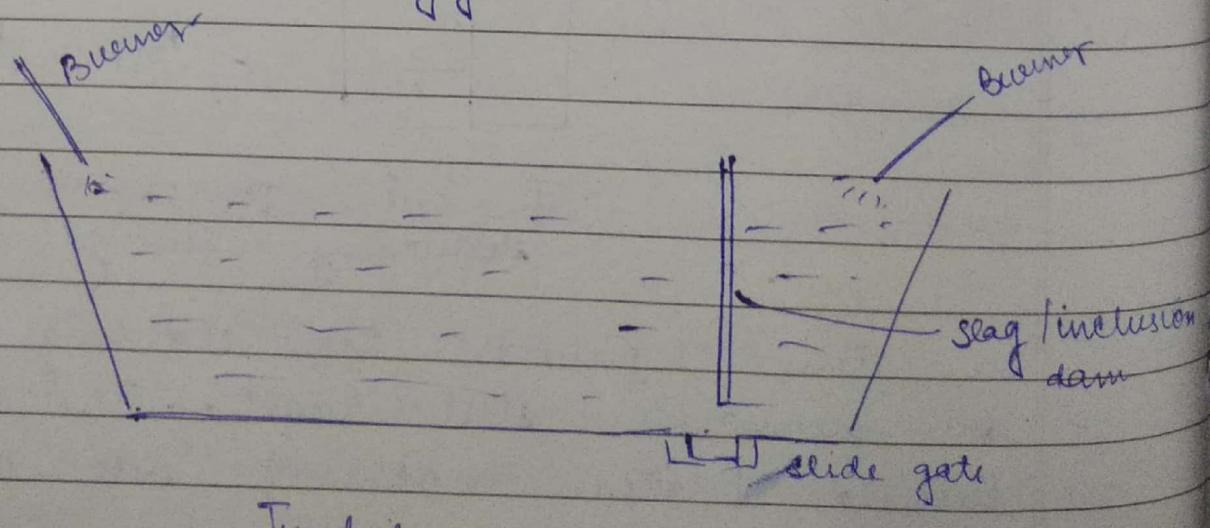
The main purpose of this process is to remove dissolved gases. It is a costly process.
∴ vacuum is established.

II ESR (Electro Slag Refining)

Process is carried out in open air ∵ gases are not removed. Cheap process.

In this process the arc is established between electrode tip & a synthetic solid slag which acts as a resistor. The liquid metal falls down in the form of drops over the resistor surface & thus the slag also melts, since liquid steel is in the form of drops, large surface area is available for desulphurisation to occur.

6 Tundish Metallurgy



Role of Tundish in conventional Casting Techniques:

- It acts as a reservoir
- It maintains a definite metallurgical head.
- Regulates pouring rate
- Fine mesh cones are used to trap inclusions.

Tundish metallurgy: refining is carried out in tundish itself.

Following refining can be carried out in tundish itself:

- Extra desulphurisation by addition of a synthetic slag.
- Extra dephosphorisation by addition of a synthetic slag.
- provision of extra ^{dams} & baffles for diverting & trapping of non metallic inclusions.

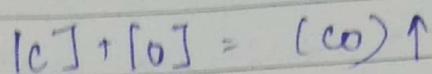
Final desoxidation adjustment, desulphurisation, inclusion modification, temp homogenisation & control, etc are dubbed as tundish metallurgy.

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7. Decarburisation Process:



For a particular heat $[C]$ & $[O]$ are fixed. The other option is to reduce the activity of product.

Activity of product can be reduced by facilitating removal of CO gas from product reaction site.

Slivert's Law :

$$[\text{wt. } \cdot x_2] = k' \sqrt{P_{x_2}}$$

Dissolution of diatomic gas is proportional to the partial pressure of that gas in ambient atm.

The ambient partial pressure can be reduced by following ways:

1. By mixing with another gas preferably inert gas. ($x_2 + Ar$)
2. By applying vacuum

This technique is employed in production of Stainless Steel Making. The operating temp in stainless process is $1800^\circ C$ which drastically reduces the lining life. This causes longer interruption has to be changed more frequently.

For S.S \rightarrow Cr should be min 12%.

For non-magnetic \rightarrow Ni min 8%.

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- It is desired that i) operating temp. should be equal to primary steelmaking process
ii) C should be as low as 0.02%. &
iii) Cu level should be atleast 15-18%.

In normal circumstances if C is low Cu will be also low at equilibrium. If C is preferentially oxidised. as compared to Cu then loss of Cu to slag phase will be less. C can be preferentially oxidised by either mixing oxygen with Ar or oxygen under vacuum.

i) AOD process

Argon Oxygen Decarburization Process

Ar:O₂ = 1:3. Ar + O₂ blown from side tuyeres is in beginning blown in the converter.

3:1 for final part of bath. In the beginning the ratio is 1:3 & towards the end the ratio is reversed. More oxygen is needed for decarbonat^(Ar:O₂ = 3:3) in beginning. At the end of the bath the bath is deoxidised by addition of fluxes - Si. 97%. recovery of Cu. Total duration: 2 hrs.

ii) VOD Process

Vacuum Oxygen Decarburization Process
Blown from bottom O₂ + Ar is helium.
This Ar is only for stirring purpose. In

this process at 1600°C we get 0.02% C & 15-18% Cr can be achieved. The bath is deoxidised by Fe-Si or Al after breaking vacuum.

The same process is K.A.

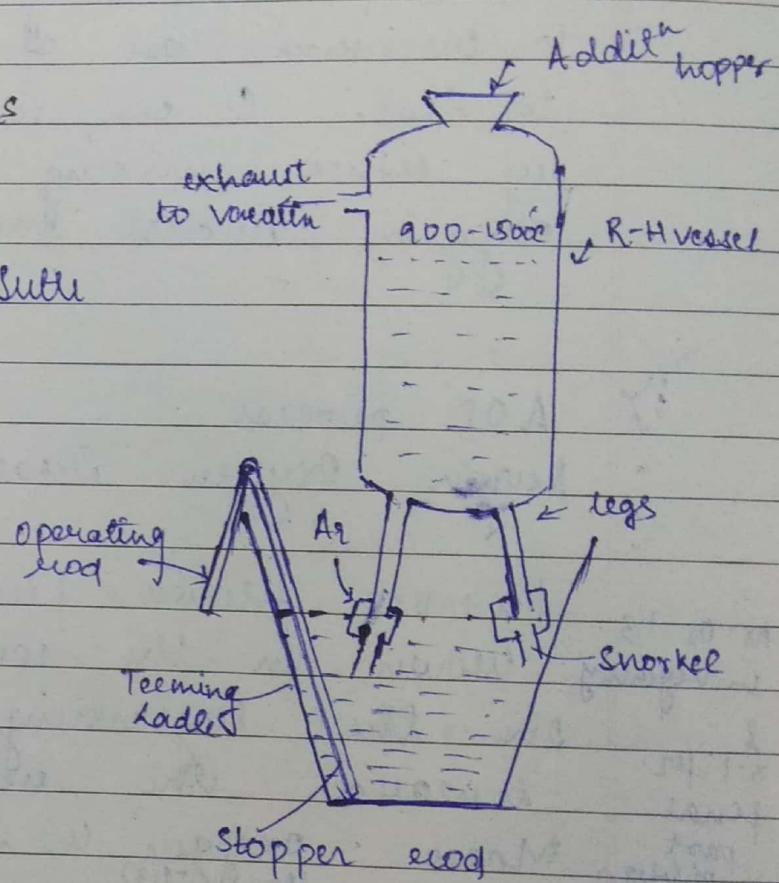
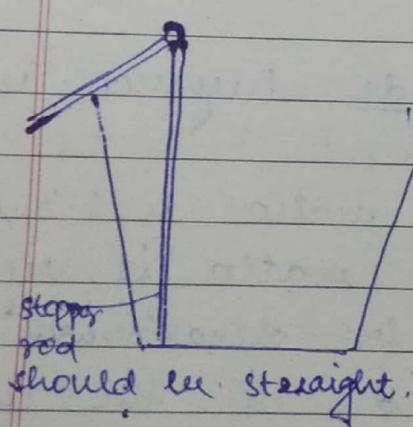
ELV - France/Sweden

MRP (Metal Refining Process) - Germany

Degassing Techniques

① R-H Process

Reinstahl - Heinrich Sutte
(Germany)



The process involves removal of dissolved gases like N₂, O₂, H₂, etc. Principle is based on Henry's law. The R-H vessel stands on 4 legs which is connected to Alumina tubes (snorkel). The vessel is lined with alumina. On top RHS a small opening

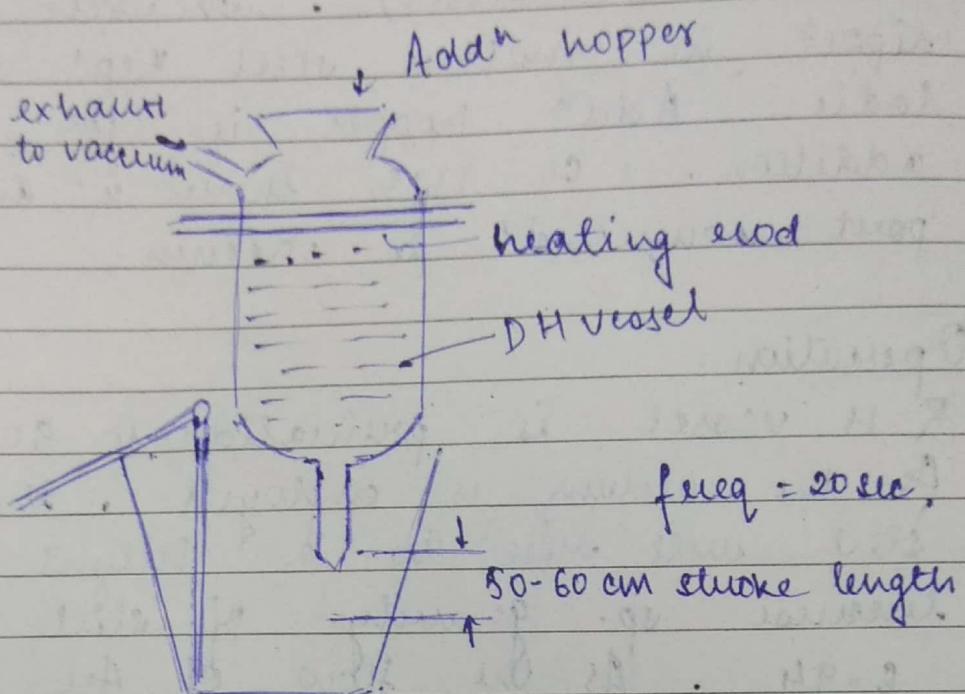
is present above hot metal for Ar gas which acts as a lifting gas (lifts molten steel into R-H vessel). Snorkels are kept dipped in molten steel kept in teming ladle. Addn hopper is for alloying addition. On RHS there is an exhaust port connected to vacuum.

Operation:

- R-H vessel is preheated to 900-1500°C. As the vacuum is employed, the molten steel will rise to a height of 1.45m. because sp. gravity of steel at 1600°C is 6.94. As the flow of Ar gas is started, molten steel is exposed to vacuum where it explodes into tiny particles. Initially the vacuum is kept at a higher press otherwise exploding molten steel may clog exhaust port. Thus molten steel is degassed as large S.A. is exposed to vacuum. The degassed molten steel falls under gravity into the teming ladle through snorkel. Since degassed steel is heavier it settles at the bottom and remaining molten steel being lighter is lifted to the top. The process is continued. The degassing process takes around 20 min & temp comes down by 50°C. Alloying addition may be done accordingly as temp is falling rapidly.

D-H Process

Dortmund Horster - Huntington (Germany)



It has only 1 nozzle which is entirely made of Alumina & length should be atleast 1.45 m. The entry nozzle shape of the nozzle is conical to prevent the entry of slag into the D-H vessel. There is provision for heating. There is a heating rod to maintain temp. of vessel.

Operation

As the vacuum is applied, the molten steel rises up by 1.45 m. Now the emersion of D-H vessel starts. As D-H vessel moves down, molten steel is lifted up & is exposed to vacuum. As D-H vessel goes up, the degassed steel falls down quantity. Now : degassed steel is

heavier it settles at the bottom. In the next stroke lighter molten steel at the top is exposed to vacuum & the process continues.

Classification of Steel

$$[C] + [O] = [CO]$$

$$K = \frac{P_{CO}}{h_{CO} h_{CO}} = \frac{1}{h_{CO}^2}$$

$$\text{or } h_{CO} h_{CO} = 1/K = \text{const.}$$

$$f_c [wt\% C] \text{ for } [wt\% O] = \text{const.}$$

If $[wt\% C]$ is less then $[wt\% O]$ will be more.
If $[wt\% C]$ is high then $[wt\% O]$ will be low.

Based upon dissolved oxygen, steels are classified as:

- i) Rimming Steel.
- ii) Semikilled
- iii) Killed Steel: if no rimming then the bath appears dead & is called killed steel.

Cap Steel - manufacture of flats, bars, wires

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Rimming

$c < 0.06$

$c = 0.06$

$c < 0.15$

rimming will
be very large

if rimming action
is furious liquid metal
will spill out.

To subside rimming
action desoxidizers
are needed. Other
wise rimming
will be violent.

✓ special type of
cap rimming steel
cap steel ≥ 0.15

A cap is put on
top to stop or
reduce rimming

Semi-killed

$0.15 - 0.30$

when deox.
reaction is
controlled

partially

* Manufacture
of structural
shape
like angles,
channels

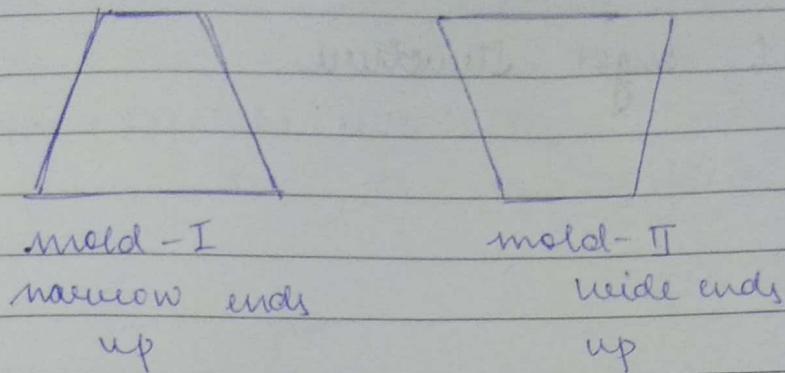
Killed

> 0.30

fully de-
oxidised

* manufacture
* used for
forgings
casting is
defect free

* Manufacture of flats
becoz it gives good
surface finish. Blow
holes are avoided
during hot rolling.



- * molds are tapered for easy removal of casting.
- * In the case of killed steel pipe formation takes place. (\because no gases come out the shrinkage is compensated by pipe form.)
- * For killed steel wide end up mold is used because pipe formation will be shallower because of larger S.A.
- * In other steels narrow end up is used because pipe formation doesn't take place if at all then it is very small.

Very small cast - cast : Billet.

Ingot deformation

Ingot \rightarrow slab \rightarrow bloom \rightarrow HSM \rightarrow CRM
slabbing

before CRM it is ^{multi} unoiled & passed thro' pickling line. In beginning cone is high

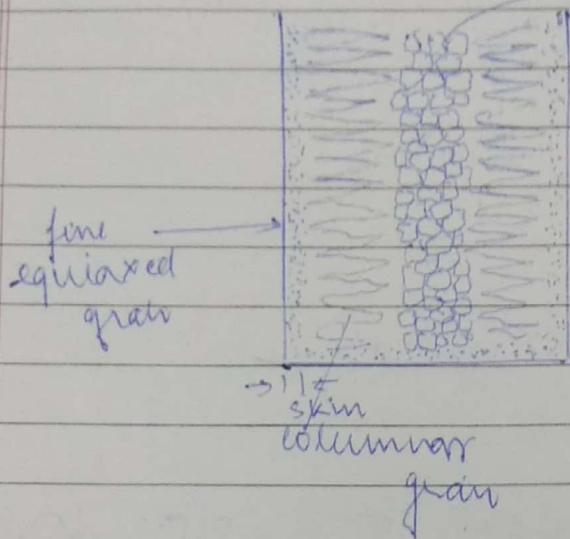
Load will lead to stretcher strains i.e. it is deformed at a load slightly higher than Y.P.,

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CRM → skin pass mill

Killed Steel ingot Structure

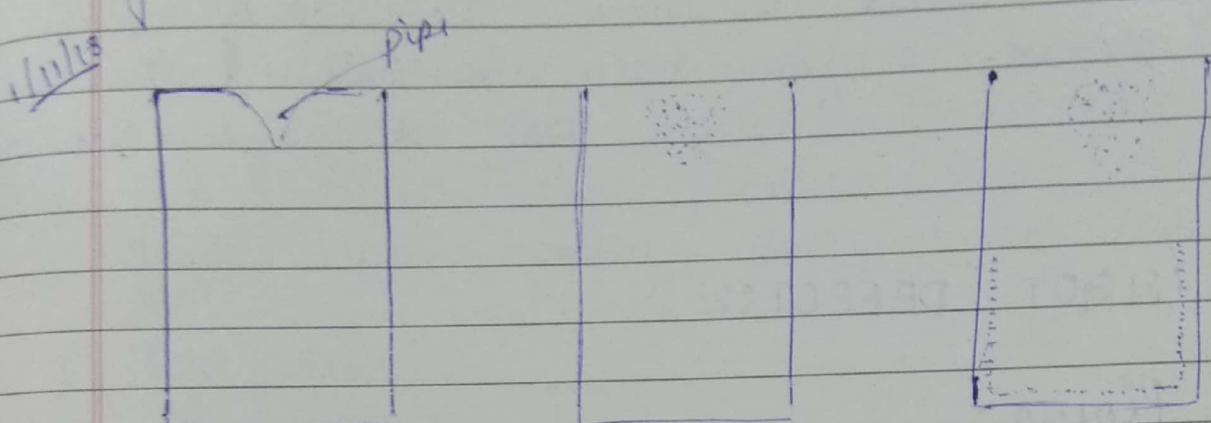
coarse equiaxed grain



When molten steel is poured in mold rate of extraction of heat is fastest at mold walls. Immediately a skin is formed consisting of fine equiaxed grains. Same size, shape, orientation - equiaxed. When all 3 are considered together we call it morphology.

Reason: Since the mold expands on pouring hot metal & skin contracts during solidification an air gap is formed which reduces the rate of cooling. This favours the formation of columnar growth. These columnar grains do not extend till the central part. due to interference from adjacent columnar grains. ∵ the central portion solidifies at the last, rate of cooling is further slow which favours formation

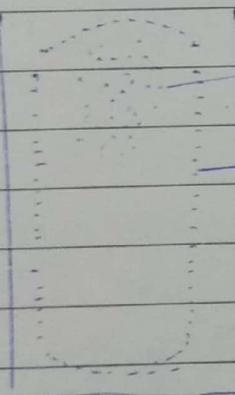
of coarse equiaxed grain. The boundaries of each zone is not distinct but continuous.
 & in the case of semi-killed & running steel this structure (columnar) will not form due to continuous evolution of gases.



I killed steel

semi-killed

capped



Running

secondary Blow holes (spherical)

primary " " (elongated)

I Hardly any gas evolution (the problem of piping occurs).

I Gas evolution takes place = no pipe instead
 2^{nd} blow holes at the top (i.e. it's last portion to solidify).

Si & graphite
2 Si is 2.5

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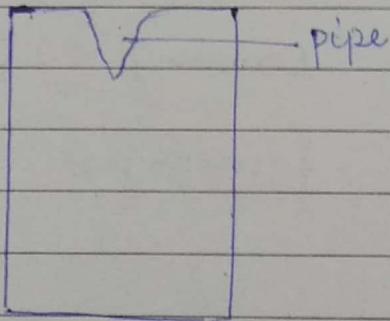
piping of.

- i) Running in primary blow holes slightly elongated in shape.
The gap between primary blow holes & secondary blow holes is called 'rim'.
- ii) : A cap is placed the primary blow holes are formed in lower half only. These primary blow holes couldn't extend to top as running was stopped by capping.

INGOT DEFECTS:-

1. Piping:

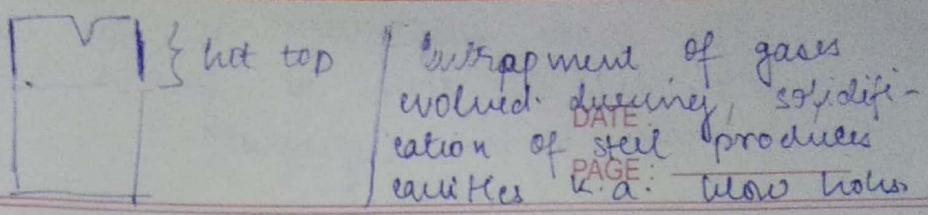
Reason: volume shrinkage.



Problems:

- Since the surfaces in the pipe are open, the surfaces get oxidized during reheating (while hot rolling). During hot rolling these oxidized surfaces do not weld together resulting in ruptures & loss of yield.
- A hot top can be used to compensate for not shrinkage. If at all shrinkage takes place it is limited to hot top region.

only.

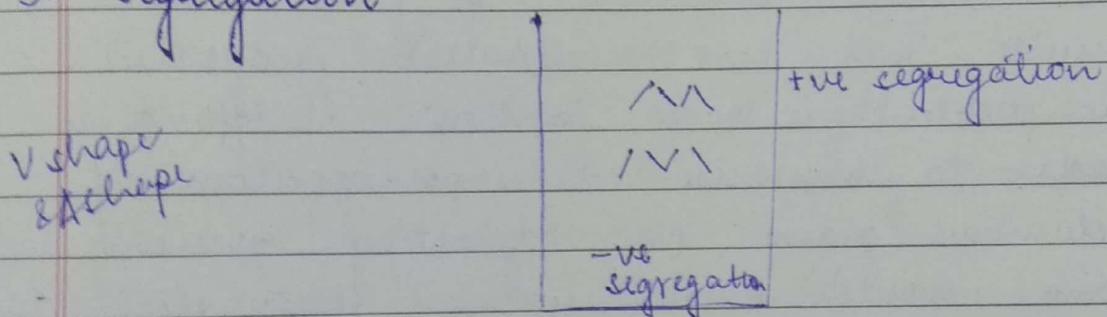


2. Blow Holes

Primary blow holes are normally near the surface. During hot rolling the skin may puncture resulting into very rough surface.

If blow holes (primary or secondary) are away from the surface then they do not create any problem. These blow holes weld together during hot rolling.

3. Segregation



It is preferential accumulation of impurities in a particular region.

-ve segregation: % of impurities is less than avg composition

+ve segregation: % of " " more than avg composition.

* Solubility of impurities is more in liquid state compared to solid state. Since lower part solidifies earlier most of the impurities migrate towards upper part which is still in molten state. ∴ the upper part

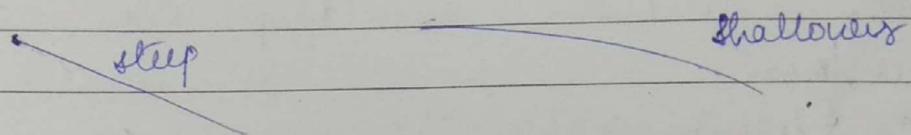
The more shallower is the liquidus i.e. more is the diff. in conc of first & last crystals to solidify, more is the segregatn.

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Solidifies at the end, most of the impurities are segregated in upper portion.

The compositional difference can be reduced by nature of liquidus curve. If the liquidus curve is shallower.



The compositional diff will be more if liquidus curve is shallower

iv) Columnar Structure

A columnar structure is predominant results into poor mechanical properties. The problem is K.a. ingot. ∵ effort is made to minimise the proportion of columnar grains by adjusting pouring temp, mould temp, cooling rate, etc.

v) Inclusions

Inclusions are of 2 types:

- indigenous: these appear during the process like product of deoxidation (Al_2O_3)
- exogenous: these broken refractory parts or any other non metallic inclusions.

vi) Surface cracks

Surface cracks may result due to development of internal stresses during solidification of big metal. or during vibrating of ingot. During solidification enters surface

ools at a faster rate & during reheating outer surface heats at a faster rate. This results in a differential cooling or heating rate ultimately resulting into development of internal stresses.

viii) Internal fissures & hairline cracking

surface blow
hole

A hairline crack appears in the casting if H content is above critical limits.

Fissures arise due to:

- too rapid reheating of an ingot such that the outer layers expand more rapidly than core giving rise to internal expansion.
- Too rapid cooling of an ingot after stripping the mould can cause uneven contraction at the surface & in core resulting in internal fissures.

These can be eliminated by too rapid cooling & reheating of an ingot.

Hairline cracks are formed all thru' the section & are revealed only after deep etching. These are oriented at random.

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CONTINUOUS CASTING OF STEEL

conventional casting

requires:

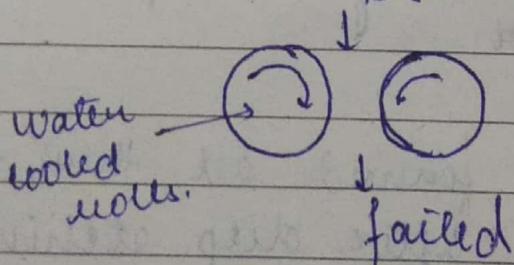
- large pit side area
- moulds
- moulds conditioning
- large cranes
- transport facility
- stripping facility
- reheating furnace
- slabbing mill
- blooming mill
- large man power

80% production is by ccs.

In India it is 60%.

Henry Bessemer

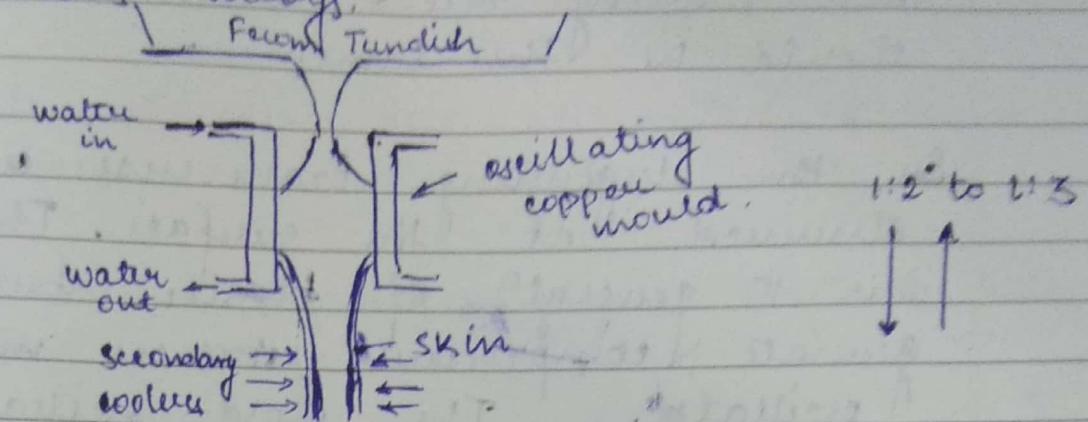
Bessemer steel



Reasons of failure:

- m.p. of steel is very high
- high specific heat
- low thermal conductivity

The same process succeeded in all of non-ferrous alloys.



Tundish maintains the metal head so that the pouring rate is constant.

Modern molds are made tapered in shape as the metal shrinks it gets separated from walls & cooling rates.

These days even curved molds are used to reduce shop height.

At the beginning a dummy bar is placed at the bottom of the mold. As the pouring begins the dummy bar is slowly removed.

Here the thickness of the skin formed is very critical bcz it prevents the leaking of hot metal / molten steel.

Now, pouring rate or withdrawal / casting speed should be co-ordinated.

The principle behind continuous casting is that pouring rate & withdrawal speed should be the same.

In the beginning transverse cracks were observed at the surface. This happened due to generation of tensile stresses. To generate compressive stresses mold was oscillated. The mold oscillates with a ratio 1:2 to 1:3 (downward : upward). This resulted in soln of problem not completely but they were reduced.

Then a technique k.a. negative stripping was applied. In the case of -ve strip the speed of downward movement of the mold (mean mold speed) is kept higher than withdrawal speed.

Negative Strip Time:

It is the duration during which mean mold speed is greater than withdrawal speed.

Negative Strip Ratio:

It is the ratio during which mean mold speed is greater than withdrawal speed:

$$= \frac{\text{time during which mean mold speed is greater than withdrawal speed}}{\text{total downward movement time}}$$

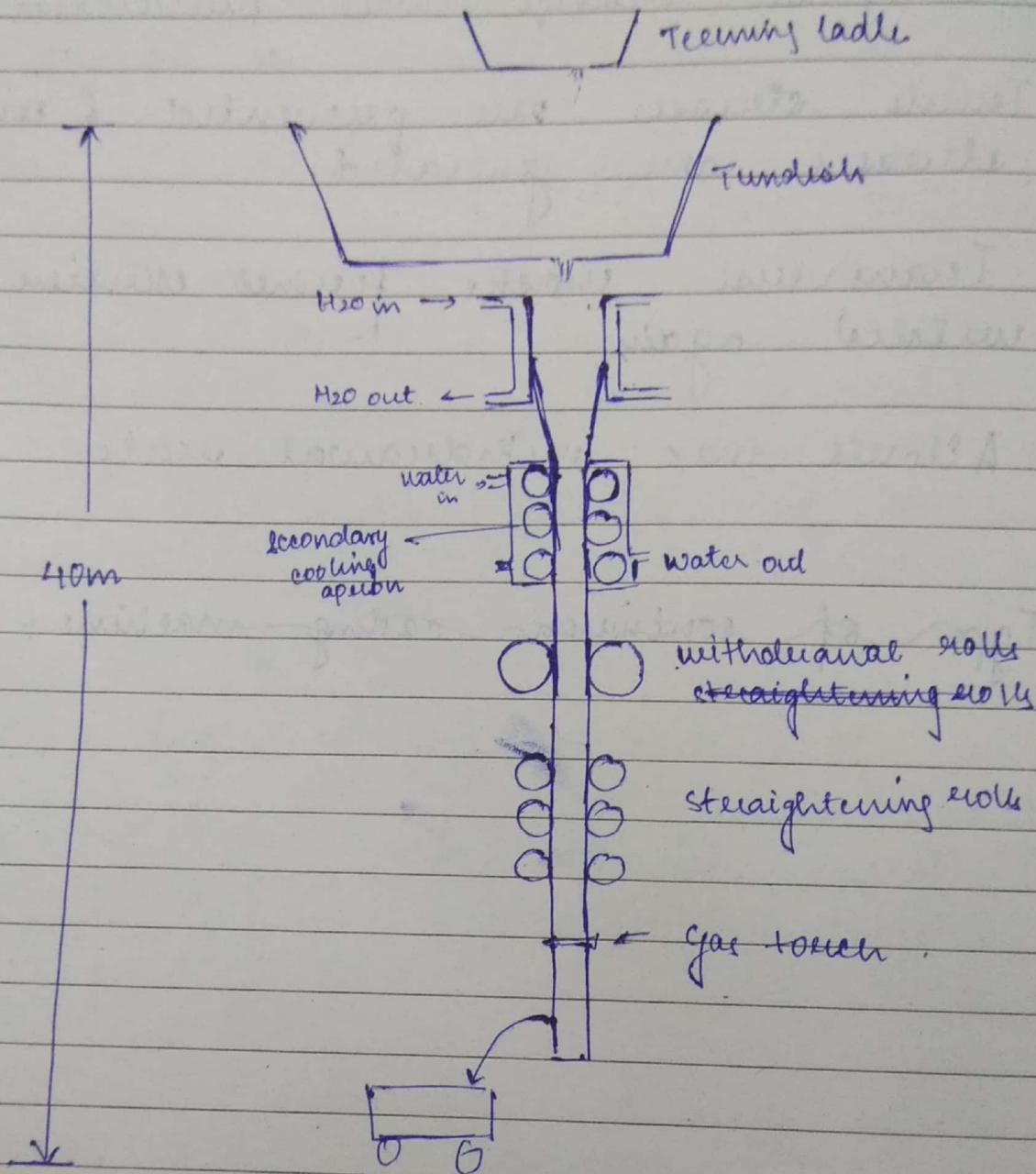
Advantage of negative stripping:

- i) Transverse cracks are prevented.
- ii) Tensile stresses are prevented & compressive stresses are generated.
- iii) Transverse cracks formed earlier are welded again.
- iv) Allows max withdrawal rate.

Type of continuous casting machine.

Type of continuous casting Machine.

I. vertical mold, vertical discharge:



only 10% of heat is extracted in the mold.
Its only purpose is to make a skin.

When it comes out of secondary cooling apron it is completely solidified.

Withdrawal / pinch rolls pull the casting.

Straightening moulds to keep the casting straight. Then there is moving gas torch. A mould turns the cut casting by 90° it is loaded in a cradle & taken to other places.

Limitation:

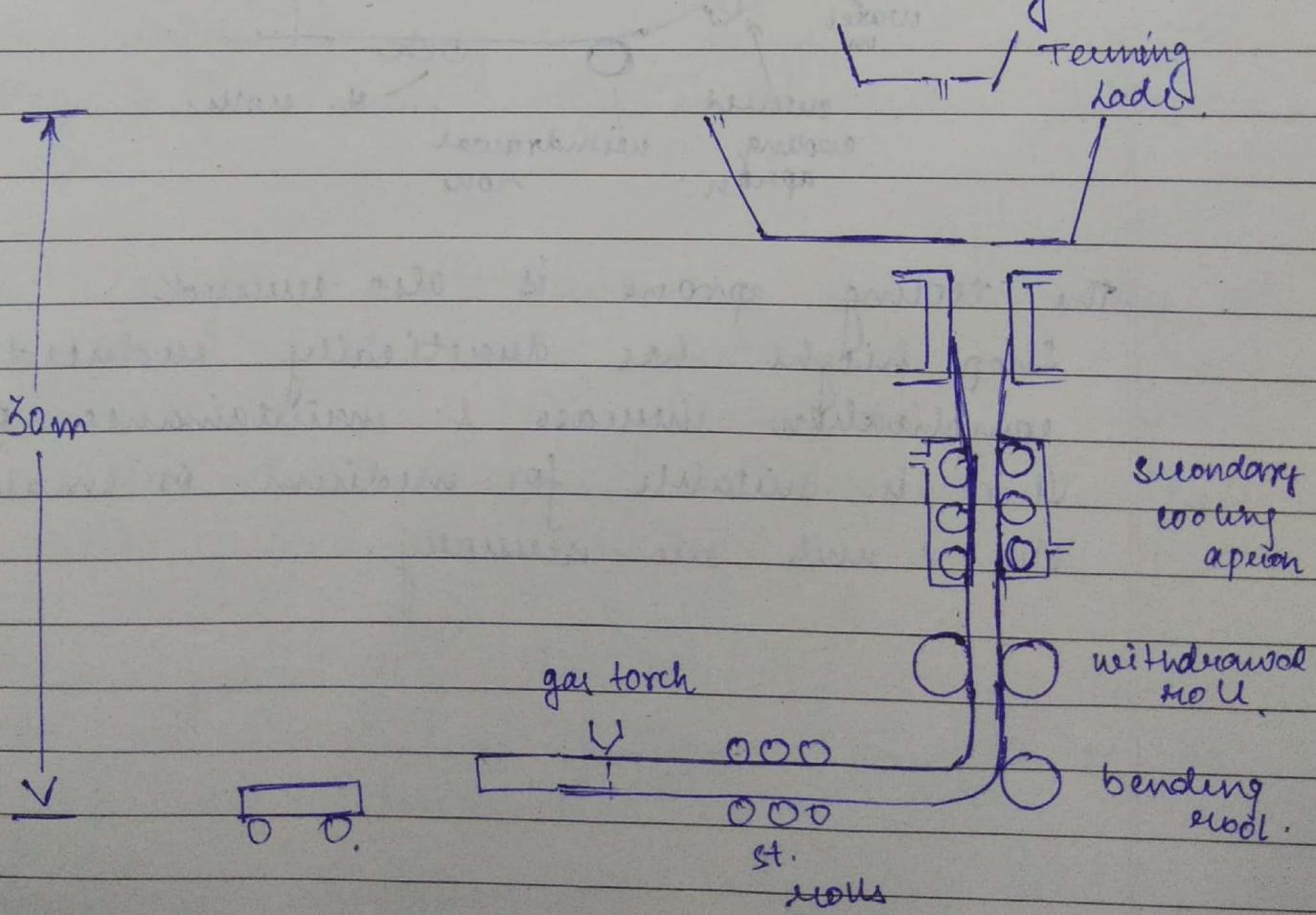
- i. Shop floor height is too much

&

Merit:

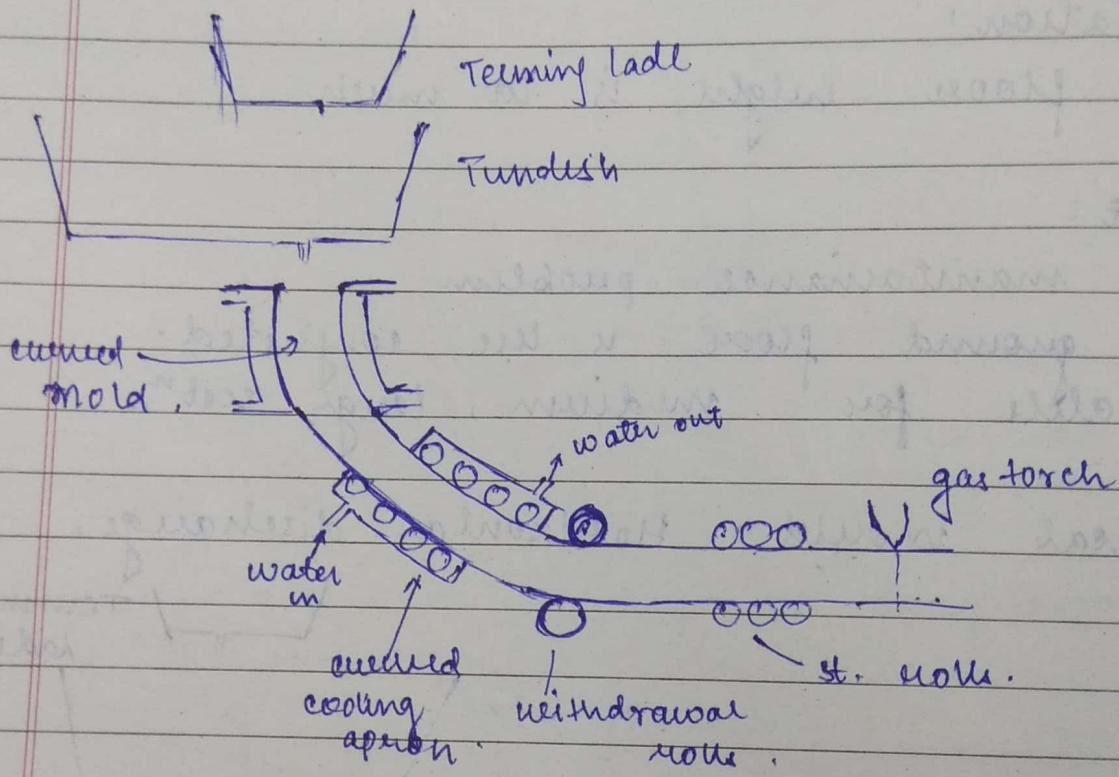
1. Low maintenance problem
2. The ground floor is less congested.
3. Suitable for medium, large castings.

II. Vertical mould, Horizontal discharge.



- * Shop floor height is reduced by 30'.
- * Since it can't bend large castings, it's suitable for medium sections only.
- * ↑ in maintenance problem

III. Curved mould, horizontal discharge



The 'cooling apron' is also curved.

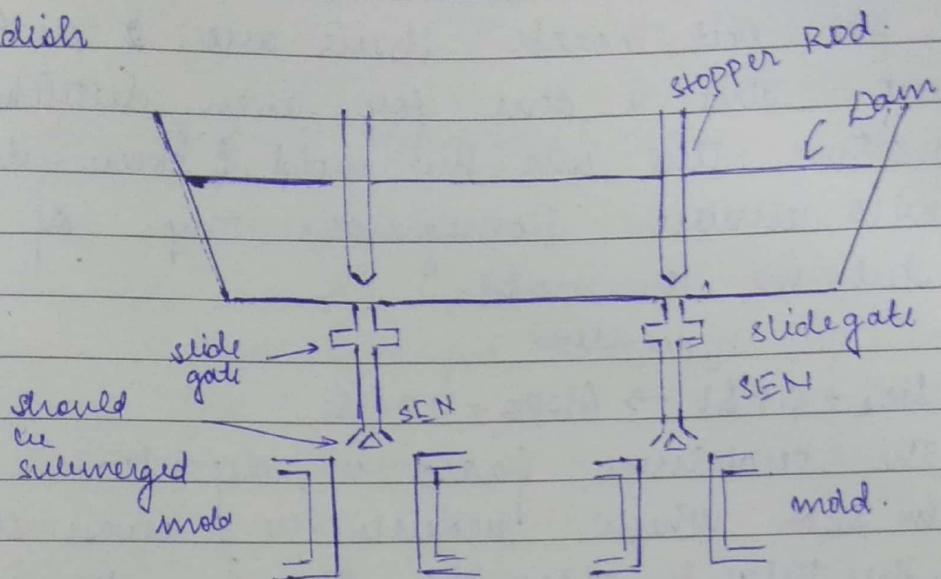
Shop height has drastically reduced complication increase & maintenance problem. This is suitable for medium or small castings. Min 2 units are necessary.

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Different Units of Continuous Casting :-

1) Terning Ladle

2) Tundish



Dam refers to slag dam to prevent entry of slag & few non metallic inclusion into the mold.

For Slide gate is to temporarily stop the entry of molten metal into mold.

Tundish is used to regulate the flow of molten steel & maintains a proper metallostatic head.

3) Submerged Entry Nozzles (SEN)

This is made of $\text{Al}_2\text{O}_3-\text{C}$ composite or

$\text{SiO}_2 - (\text{ZrO}_2 - \text{C})$ composite

↑
base
matrix

Matrix
takes the load

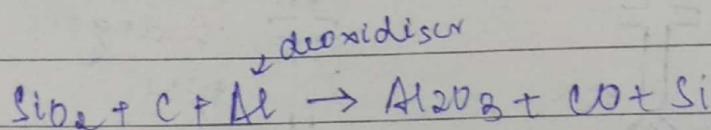
↑
reinforcement

to distribute
the load evenly
over the matrix

Functn:

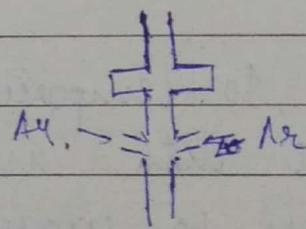
- To prevent entrapment of ambient gases.
- To prevent oxidation of molten steel.

At the exit nozzle there are 2 or 4 sideways exit. This is done for even distribution of molten steel into the mold. Even distribution will ensure homogeneous temp. of molten steel in the mold.

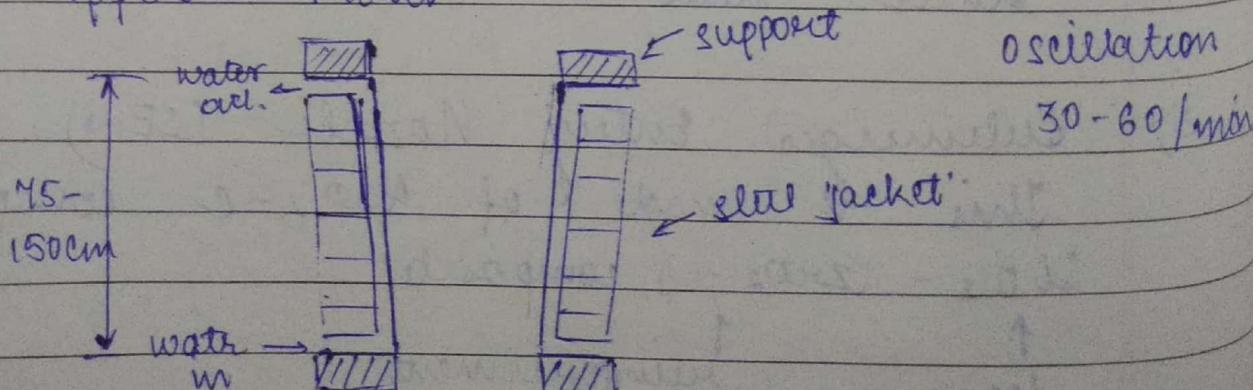


The problem faced is deposition of alumina in SEN which reduces the reuse factor of the tube & clogs it. Al in elemental form is deoxidiser used.

To prevent sticking of molten into steel & alumina Au is introduced into the tube.



4. The Copper Mold:



Mold can be made by fusing of a single Cu block. It can be made by welding Cu plates as well.

Its length is in range 45-150cm to ensure atleast 10% heat is extracted from hot metal.

~~Steel jackets at top bottom & side supports~~ are present to provide support to mold as strength of Cu is poor.

The Cu mold is tapered downwards. The taper is not straight but it increases towards the exit side. This done. The downward taper is provided to ensure continuous contact between skin & inner mold wall. This ensures faster extraction of heat.

The mold is oscillated with a freq 50-60/min

5. Mold Powder

Function:

- Its main function is to provide lubrication to the mold wall.
- It prevents oxidation of molten steel
- It may dissolve inclusions.

Requirement:

The liquidous temp of mold powder should be almost same as the temp of molten steel.

As the mold powder comes in contact with molten steel, it melts but the top portion remains solid which deposits near the side.

walls of the molds thus providing lubrication

Composition of mold powder (mold flux)

CaO → 25 - 45%

Na₂O → 1 - 20%

SiO₂ → 20 - 50%

Li₂O → 0 - 4%

MgO → 0 - 10%

B₂O₃ → 0 - 10%

MnO → 0 - 10%

F → 4 - 10%

C → 1 - 25%

MnO → 0 - 10%

K₂O → 0 - 5%

FeO → 0 - 5%

TiO₂ → 0 - 5%

C is added to control melting pt. of
mold flux.

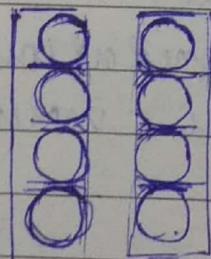
how this is made:

i) fly ash based

ii) synthetic mixture

iii) pre-fused & ground powder.

6 Secondary Cooling Apron



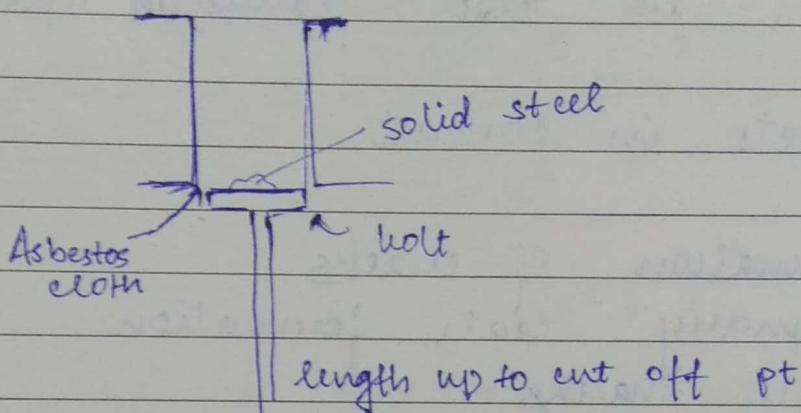
water jet

Function of rollers is to keep the partially solidified ingot straight. Water jet spray is made from the gap available with the rollers. Rest adi. of cooling must be completed before exit from roller apron

7. Pinch Rolls

The pressure applied by pinch rolls shouldn't be very high otherwise the casting may deform. Since it is still very hot if applied pressure is less then it may cause slip.

8. Dummy Bar



Dummy bar is basically a rod at the top of which a bolt is fixed. The gap between bolt corner & mold wall is filled with asbestos cloth. The length of the rod extends upto cut-off pt. in case of vertical machine. At the top of the bolt a small amount of solid steel (same comp) is placed which acts as chill facilitating directional solidification. The bolt facilitates easy withdrawal by pinch rolls. The head (bolt) must be prepared again for the next casting operation.

Difference between solidification in case of conventional casting & concast

* the rate of cooling is very fast in case of concast, the dendritic / columnar zone is limited (\therefore time is less). But the problem of segregation particularly at macroscopic level is very high. Segregation at microscopic level are also expected during hot rolling.

→ Defects in concast

- 1) Formation of cracks
- 2) Primary scale formation
- 3) Roll marks
- 4) Roll peel off
- 5) Oscillation marks
- 6) Segregation
- 7) Non-uniform width (if rolls get deflected)
- 8) " " thickness
- 9) Slag sticking to surface.
- 10) Alumina streaks

Reasons for formation of cracks:

- i) Tensile stress exceeding yield stresses at a particular spot.
- ii) Cooling rate
- iii) Stripping
- iv) Bending
- v) Withdrawal Rate
- vi) Surface finish of roller apron & withdrawal rolls.

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- vii) mold taper
 - viii) mold wall surface finish
 - ix) mold underneath
 - x) re-oxidation of steel.

→ Defect due to lubrication:

In the beginning oil ^{was} used ~~for~~ lubrication of mold. This resulted in generation of hydrogen & subsequently hydrogen pickup which causes hairline crack.

Now-a-days oil is not used, in its place mold fluxes are used.

→ Defect due to reoxidation

Concast process is not suitable for rimming steel because rimming action can't be controlled during this process. ∵ casting is very fast. ∵ Fe-Mn & Fe-Si are not used as deoxidiser (∴ they are weak deoxidisers). Hence Al which is a strong deoxidiser is used. The product of deoxidation is Al_2O_3 which doesn't coagulate, but it keeps on suspended in the melt. This results in the formation of alumina streaks during hot rolling.

Ques: How to get rid of Alumina streak?

→ The treatment is K-a. calcium treatment. Either Ca metal or Ca-Fe-Al alloy in the form of wire is introduced into the melt. This modifies the nature of

Alumina as inclusion. Now, alumina particles coagulate & thus come to the surface from where it can be removed.

How to get rid of segregation?

→ Electromagnetic stirring is applied 1.3-1.7 m below meniscus level. Electromagnetic stirring modifies the liquid flow pattern & hence solidification is also modified. This reduces the tendency to segregation.