LECTURE 22 (23/02/2023)

96] Smelting

- Reduction smelting → carbon (we have covered this)
- Matte smelting

Reduction Smelting

(i) carbon : (done)

(ii) Metallothermic Reduction

(a) Thermite Reduction (also called Thermit Welding)

examples: $Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3$

$2MgO + Si \rightarrow 2Mg\,(v) + SiO_2$

(Pidgeon Process)

$2V_2O_5 + 10Al + 6Fe \rightarrow 6\,Fe\text{-}V + 5Al_2O_3$

$MoO_3 + 2Al + Fe \rightarrow Fe\text{-}Mo + Al_2O_3$

Kroll Process: $TiCl_4 + 2Mg \rightarrow Ti + 2MgCl_2$

$UF_4 + 2Ca \rightarrow U + 2CaF_2$

(iii) Reduction with Hydrogen

$WO_3 + 3H_2 \rightarrow W + 3H_2O$ (800-1000°C)

should be pure

(Powder)

$MoO_3 + 3H_2 \rightarrow Mo + 3H_2O$

97] **Matte Smelting**

↓

Sulphide ore is heated in furnace at high temp.

↓

in presence of flux ⟶ part of S gets oxidized as SO_2

↓

Matte: consists of $Cu_2S + FeS$

Thermal concentrating process : Matte → 40-55% Cu

(FeS gets differentially oxidized to FeO)

⇓

$$FeS \rightarrow \underset{}{FeO} + \underset{(Flux)}{SiO_2} \longrightarrow \underset{(Slag)}{FeO \cdot SiO_2}$$

We should have → Proper grade of matte ⟶ i.e. there should be proper % of Fe

Converting

If too low then not enough heat generated

If too high then there is a lot of heat ↓ But also too much slag formed & ~~can't be~~ separated from Cu efficiently

98] **Production of Iron and Steel**

⇓

When Iron ore treated ⟶ gives Pig iron ⟶ which gives steel

{ Thus steel & Iron are closely related }

Why Iron is most important metal :

(NOTE) : { 95 % Fe
5 % All other metals (Al, Cu, Pb, Zn, ... etc)

Reasons :

1) Abundance — O } non-metals (∵ not imp.)
Si }
Al — 8 %
Fe — 4.6 %

2) Fe can be produced much more easily compared to other metals (including Al)
↓
(Iron has been produced for about 3000 years)
↓
whereas, for Al : < 200 years
↓
the commercial production of Al began largely from 1880s after electrical applications

3) Excellent mechanical properties
↓
Also, it is magnetic

99] Production of Iron & Steel

We first make Pig Iron ⟶ & then steel
⇓
this is useless in itself
↓
but is needed to make steel

Why steel cannot be produced directly from Iron ore?

Iron ore: $Fe_2O_3 + 3C \rightarrow 2Fe + 3CO$

$\Downarrow$

thermodynamically the redn is feasible only above $1000°C$

(& slag itself needs to be $> 1400°C$ to be molten)

3.5 – 4.5 % C dissolves in the Fe during this process in an unavoidable manner

Similarly:

$SiO_2 \rightarrow Si \Rightarrow 0.5 - 1.5\%\ Si$
$MnO \rightarrow Mn \Rightarrow 0.5 - 1.5\%\ Mn$
etc.

} these also dissolve in the Fe

$\Downarrow$

$\therefore$ Ultimately we get 91 – 93 % Fe

which we call "Pig Iron"; it is useless by itself

Can either be refined further to get Cast Iron

Or, be used to make Steel

LECTURE 23 (28/02/2023)

100] Iron and Steel Production

Iron ore — Pig iron — Iron making
Pig iron → steel — steel making

101] # Iron Making

1. Iron Blast furnace → most commonly used (95% cases)
2. Direct Reduction
3. Low shaft furnace
4. Electrothermal process

102] ## Iron Blast Furnace

Reasons for use:

(i) > 10000 tons of PI / day can be produced → High Production Rate
(since single furnace has such ~~large production rate~~
&
thus cost of production is low)

(ii) Great degree of heat utilization — shaft furnace

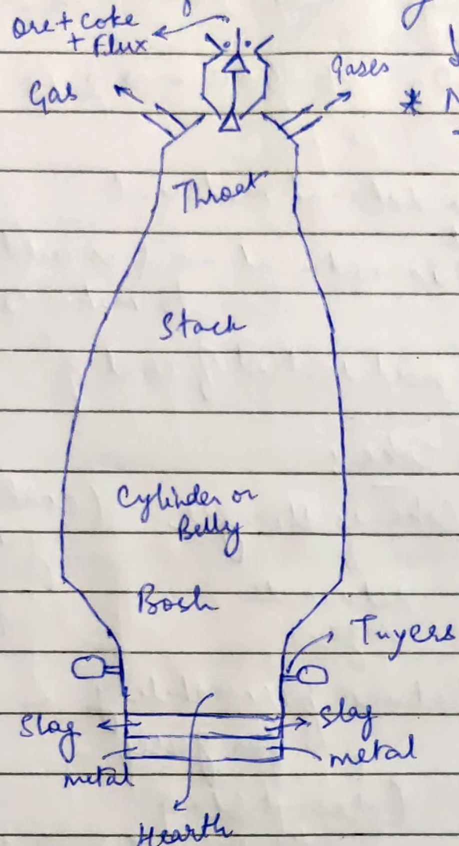
(iii) Pre-heating of air
↳ to high temp. → > 1000 °C
(from source of calorific value of gases from furnace itself)

Drawbacks / Limitations are:

(i) High capital investment
(ii) Suitable size
↳ fine-agglomeration required
(iii) Use of coke rather than coal

103] Functions of Blast Furnace

→ Reduction of Iron oxide by CO gas



↓

* NOTE: Air is blown at very high speed
↓
so that it can rise up the furnace (which may be ~300 ft tall)
↓
that is why this is called "Blast" furnace (since air is blasted into it)

104] Raw materials:

Iron ore, coke, flux, air

Iron Ore: Hematite – Fe_2O_3 – 70% Fe
Magnetite – Fe_3O_4 – 72.4% Fe

Overall, Iron ore – 50–65% Fe
60–65% Fe (in India)

{ 80–85% Fe_2O_3
15–20% gangue minerals }

NOTE: If particles of Iron ore are too fine → they will be blown away → thus lumps are needed (25–50 mm)
⇓
made using agglomeration → Sinter, Pellets

105] **Coke:** Source of carbon
↓
burns to form CO
which further reacts with Iron oxide

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

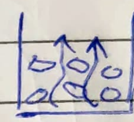
Coke is NOT a natural material
↓
Coal is natural → & is used to make coke

Why is coke used instead of coal?

→ Coal vs Coke:

1. Coke is stronger (coal would get crushed under weight & form powder)
↓
~~retains its~~ size

2. Retains permeability for gases (doesn't block the passage) → Since it retains its shape as lumps (as it doesn't get crushed)



3. Coke is porous
4. When coal is heated for conversion to coke
↓
the volatile organic materials get removed (eg: Sulphur)
(by volatilization)

106] **Flux:** (Basic flux) CaO — provided by limestone ($CaCO_3$)
SiO_2

$$CaCO_3 \rightarrow CaO + CO_2$$

$$CaO + 2 \cdot SiO_2 \longrightarrow CaO \cdot 2SiO_2$$
(slag)

{Pure silica has v. high viscosity
↓
But after combining with CaO → viscosity is reduced
↓
Can flow easily & thus be removed more easily too}

107] Oxygen (air) : 21% O_2
Tuyeres

Air is reqd. to burn carbon & form CO
(lot of heat is produced in this process)
↓
which helps melt Iron (the "charge")
& also melt the slag
↓
which collect at bottom of furnace.

Since slag & iron are immiscible
↓
& have differing densities
↓
thus slag floats above iron
↓
& can be removed separately from different tap holes.

{NOTE: There are two tap holes for slag, and one for iron
↓
bcz viscosity of slag is still high & comes out slowly}

108] <u>Furnace profile</u>

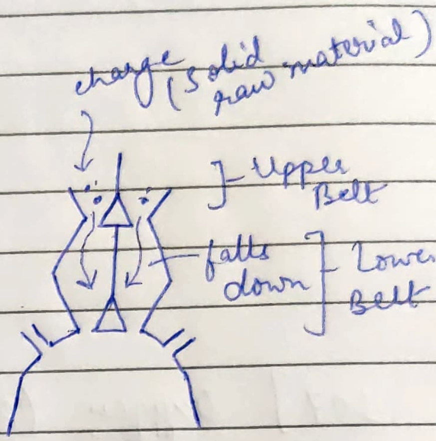
↓

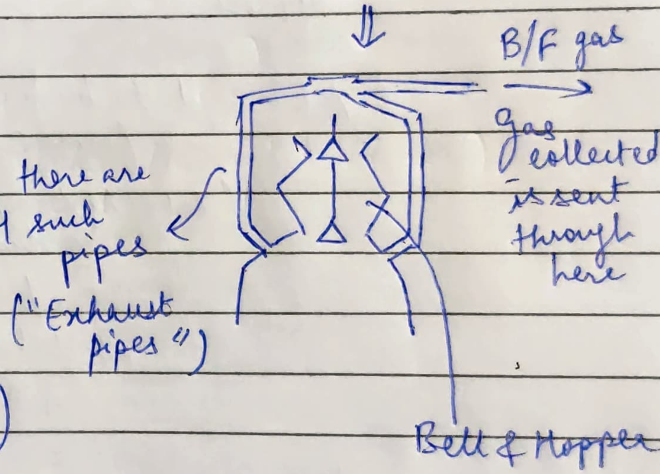
Charging system

→ There are two charging systems :

↳ Bell and Hopper

or, Cup and cone

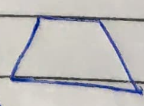


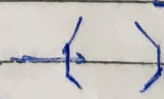


LECTURE 24 (02/03/2023)

109] <u>Furnace profile</u>

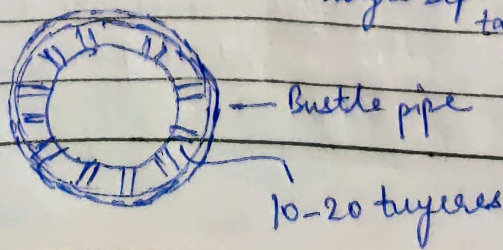
Throat — Armour plate

Stack — Frustum 

Belly ⟶ 

Bosh → here max^m. temp. is maintained

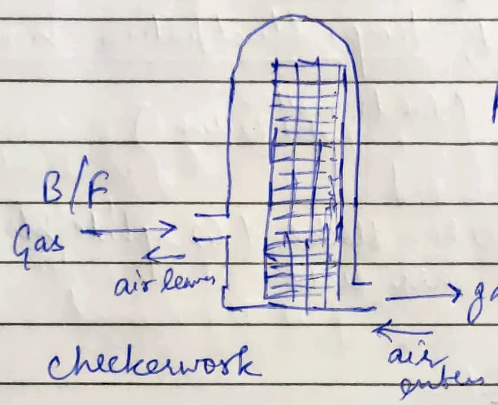
Hearth → from here diff. layers are removed through separate tap holes



110] <u>Accessories of the Furnace</u>

Hot blast stoves
↓
pre-heat the blast to 700 – 1200 °C (which saves the consumption of coke
↓
as air is already pre-heated)

3 stoves < 2 : on gas
1 : on blast



25-30% CO

Regenerative system (i.e. can be heated repeatedly)

111] <u>Lining of the blast furnace</u>
↓
to prevent damage of steel plate of which furnace is made of

<u>Armour plates</u> : Steel plates used to prevent damage from molten ore

<u>Fire-clay</u> : 30-40% Al_2O_3
(upto 50% is added when used in lower portion (near belly))

Super-duty fire bricks : 50 – 65% Al_2O_3

Bosh area

↓

water cooled copper plates used

↓

for cooling & to increase life of the furnace refractor

Hearth → temp. may be equal or less than in Bosh area

↓

But, temp. fluctuation is max^m.

(due to molten metal falling)

↓

∴ Carbon blocks (Graphite blocks) are used

112] Inside the Furnace

> 900°C

⇓

$CaCO_3 \rightarrow CaO + CO_2$

⇒ V. high temp → Carbon (coke) reacts with air → CO formed $\xrightarrow{\text{reacts again}}$ CO_2

→ CO_2 & Nitrogen gas rises up & reduces Iron oxide

Why high temp? (1800°C)

↓

1) Red^n of Iron oxide only occurs at high temp.

(& good kinetics also needed)

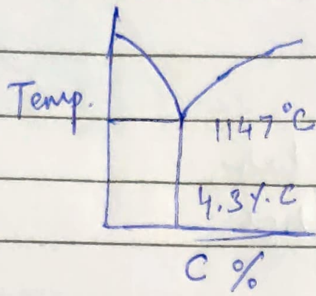
2) Melting of Iron ore & slag

NOTE: At high temp., molten iron dissolves carbon from coke

↓

* this reduces the melting pt. of Iron

(Iron itself has M.P. of 1535°C)



Carbon (C) → dissolves 3–4 %

$SiO_2 \rightarrow Si \rightarrow$ 0.5–1.5 %

$MnO_2 \rightarrow Mn \rightarrow$ 0.5–1.5 %   (92–95% Fe)

$P_2O_5 \rightarrow P \rightarrow$ 0.2–0.5 %

↓

all this must later be refined

NOTE: Carbon doesn't "melt"
↓
it can only burn
↓
thus it remains in solid form

113] Coke grid present
↓
provides interstices
↓
which provides passage for movement of air

Coke consumption
↓
400–500 kg/ton of Pig iron

Coke consumption:

(1) Pre-fluxed sinter & pellets

(2) High blast temp.

(3) Uniform gas distribution → Burden preparation

{NOTE: We want to reduce coke consumption
↓
since it
1) is the most expensive material here
↓
2) due to its scarcity (limited availability)}

(4) Injection through the tuyeres
↓
coke breeze, tar, plastics

{ NOTE: "coke breeze" is different from coke
↓
it is not used in furnace
↓
it is a waste material & thus can be used here }

LECTURE 25 (03/03/2023)

114] Due to high temp. → C dissolved in Fe { lowest temp. of Fe–C alloy is at eutectic : 1147°C at 4.3 wt% C }

Similarly other impurities such as Si, P, etc. get their oxides partially reduced & dissolved in the metal

115] Iron dissolved is hardly 93% Fe
↓
Coke is burned at contact with hot blast and forms CO_2 gas → releasing enormous energy.
↓
coke remains solid, giving mechanical support → where all other things are molten
↓
& provides coke bridge for air to pass

Coke rate is critical
↓
to reduce it: fused sinter or pellets are used
↓
high blast temp. is used (upto 1200°C temp. produced by stoves)
↓
Uniform gas distribution by equal burden distribution
↓
Injection of carbonaceous materials like coke breeze, tar, plastic, etc.

116] <u>Hot Blast air</u>: It is preheated (from 1000°c) upto 1200°c and is delivered through tuyeres ↓

& there the temp. is 1800°C–2000°C (due to combustion of Carbon to CO_2) ↓

But CO_2 is unstable at this temp. & reduces to CO gas & it moves up with Nitrogen ↓

CO is utilized for reduction of metal & at the tuyeres, CO is 35% & N_2 is 65%

the Fe is melted along with slag & gets collected into hearth

{ continued on next page
[5 pages attached as printout (from Manish Verma's Notes)] }

* Liquid product disposal → Both molten metal & slag is removed from top holes. for metals there are fewer holes than slag

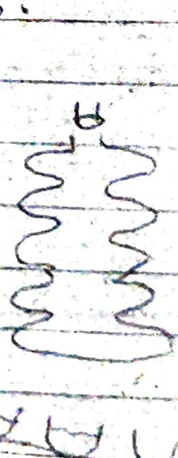
Three product of Blast furnace → are removed

1) Gases + Dust → (CO, CO_2, N_2) from the top and passed through gas cleaning systems like electrostatic precipitator. The dusts are FeO dusts then the gases are sent to stoves.

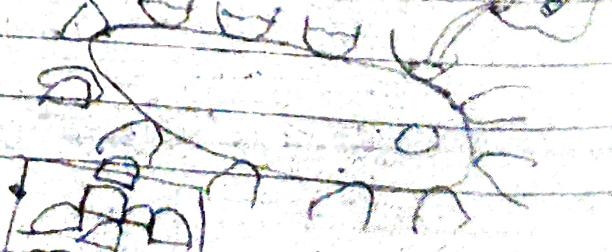
2) Liquid slag → Removed from the upper tap holes. It is disposed as a waste product but nowadays they are used in production of cements, etc by quenching and grinding to be used in cements. It is also used for construction of the roads.

3) Liquid metal → Also taken out from tap holes.
(i) Cast in pig beds (Sand beds)
(ii) Cast in pig iron casting machine
(iii) Sent to steel making shops or SMS.

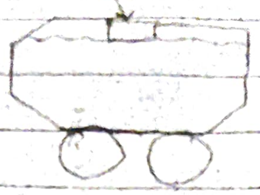
* Sand beds are used and the shape of these looks like piglets stacked feeding (Old days)



* Pig Casting ~~Furnace~~ Machine



* to Steel making shops → It is transferred to shops from using Transfer ladles



which prevent any heat loss and is taken to the shops hot and safe.

☒ Reactions taking place in the Blast Furnace :→

Bottom hot gases rises and reacts with the charges to produce molten iron.

Chemical Rxns → (i) Reduction of Iron oxides.
(ii) Combustion of coke. - $C + O_2 \longrightarrow CO_2$
Highly exothermic Reaction. Used to raise temp ~~from~~ to 1800 upto 2000 and $CO_2 \longrightarrow CO$ stable.

(i) - Reduction of Fe oxide takes place to form Fe metal and CO_2 which then again converts into CO and reacts with ~~Co~~ Fe oxide.

$$2Fe_2O_3 + 3CO \longrightarrow 4Fe + 3CO_2$$
$$CO_2 + C \longrightarrow 2CO$$
} "Indirect"

(Less likely)
* Direct reduction → $Fe_2O_3 + 3C \longrightarrow 2Fe + 3CO$.
This property is much less probable than gas solid Rxn because it is Solid - Solid Rxn

$\boxed{\text{☆ Direct Vs Indirect.}}$: Mentioned above

* It is a cyclic process. $CO \xrightarrow{FeO} CO_2$, $CO_2 \xrightarrow{C} CO$
CO dont form at lower temperatures.

as the gases move up, CO percentage decreases and CO_2 level increases and the reduction potential of gases decreases.

$CO_2 + C \xrightarrow{>1000°C} 2CO$ (Boudouard Reaction) (Carbon Gasification Rxn)

around 800 - 850°C ~~co~~ Reaction does not occur

* Calcination of Limestones → $CaCO_3$ gets decomposed when the temp. of solid charge gets above 900°C and CaO forms to combine with silica to form the slag.

Sometimes dolomite is added. ($CaCO_3 + MgCO_3$) here then $MgCO_3$ is more readily decomposible. Both are basic oxides and can be combined with the acid burden (SiO_2, Al_2O_3) to form the slag

Direct and Indirect Reduction → Indirect (>95%) happens below the charged stack where the gas solid reaction takes place. When the charge comes near the bosh area, CO cannot pass easily so the direct reduction is more likely. Here the solid carbon reacts with un-reacted solid Fe oxides and it reduces to form the ~~[illegible]~~ Iron metal. ~~[illegible]~~ Contact with the gas is less probable here as the charge is semi liquid and mostly reduced.

* Overall reaction of Reduction of Iron oxide →

$2Fe_2O_3 + 3CO \longrightarrow 4Fe + 3CO_2$

Steps →

~~I] $Fe_2O_3 \rightarrow Fe_3O_4$~~

I] $3Fe_2O_3 + CO \longrightarrow 2Fe_3O_4 + CO_2$

II] $Fe_3O_4 + CO \rightleftharpoons 3FeO + CO_2$

III] $FeO + CO \rightleftharpoons Fe + CO_2$

Fe_2O_3 = Hematite

Fe_3O_4 = Magnetite

FeO = Wustite. (Not Natural)

* The reduction of Fe_2O_3 → It is most readily reduced at lower temp, lower CO/CO_2 ratio. Fe_3O_4 is slightly tougher and require higher CO/CO_2 ratio and temp. but FeO requires very high CO/CO_2 ratio and temperature.

By the time, Fe oxide is melted, it fully reduces. The higher temp is required to melt the metal & slag $\boxed{T > 1500°C}$.

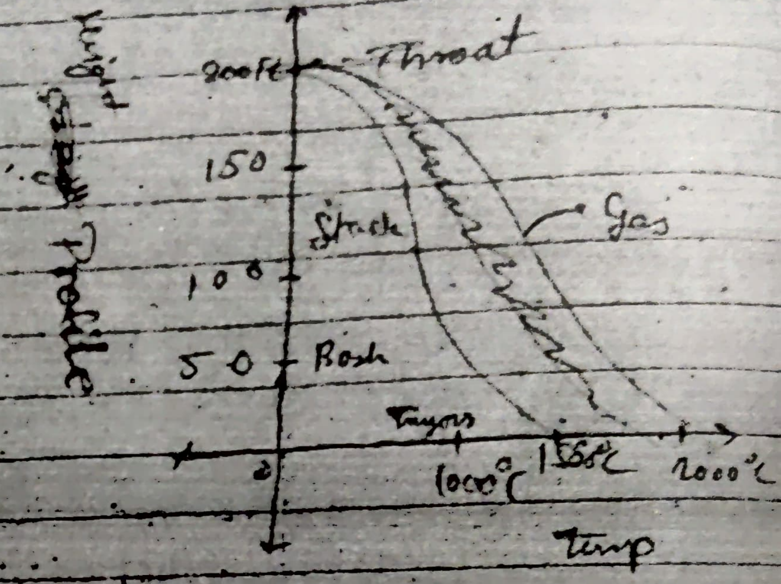
* Another method is Direct method where the iron forms in the solid form.

* Finally → In the Hearth. Molten iron (1500°C) and molten slag (1550°C) is present which is then taken out using different tap holes.

* Blast furnace can be divided heightwise into certain zones →

(I) Upper
(II) Middle
(III) Lower

(I) Stack
(II) Bosh
(III) Tuyers + Combustion
(IV) Hearth



LECTURE 26 (14/03/2023)

117] **Iron Making**

Height of B/F : 30-35 m
Diameter : 15 m
Production : 10000 ton/day

118] Iron is also produced by
↓
Alternative Iron Making processes — about 10% iron is made through these processes
↓
Reason : due to use of coke in B/F → which is a scarcity
(eg: not much coal is available in India)

Two main routes of iron making

(i) Direct-Reduction processes
↓
Fe produced as solid by solid-solid reduction
↓
This Fe is called sponge iron
(∵ it is porous)
{also it is called DRI (direct reduced iron)}

done either by:

(i) Gaseous reductant
↓
Natural gas
{- Midrex process
- HYL process}

(ii) Solid reductant
↓
Coal fines (i.e. the coal which cannot be used for making coke)
{- rotary kiln furnace
(eg: at Jindal Power & Steam Ltd; Raipur)}

(ii) Smelting-Reduction processes
↓
Fe produced as liquid by combination of solid & liquid state reduction

The most common method is :
Corex process
(eg: used by → Jindal Steel (JSW) at Bellary, Karnataka)
(→ by Essar Steel, Hazira, Surat, Gujarat)

NOTE! India is largest producer of sponge iron (DRI) & second largest producer of smelting reduction iron.

119] Steel Making

What is steel making?

Pig iron produced is very impure → P.I. → 7–8% impurity : 3.5–4.5% C, 0.5–1.5% Si, 0.5–1.5% Mn, 0.5–1.0% P + S ⋮ etc.

(and also contains alot of air)

cannot be used directly for any purpose

with a little purification → gives Cast Iron → but it has only very specific applications

For proper purification of pig iron → Done by selective oxidation of impurities

Thus, Iron Making — Reduction of Iron oxide
Steel Making — Selective Oxidation of Impurities (NOT of iron)

through this process however we can't get pure Fe → we end up with Fe – C alloy

120] Why not pure Fe is produced?

(i) Firstly, it is very difficult to produce pure iron → bcz if we try to do so → in the process, the Iron itself will also get oxidised

(ii) Also, pure iron doesn't have very good properties → Fe-C alloy has much better properties

121] What is steel?

It is an alloy of Fe & C

But it is not a specific product

{ it is Fe with varying concentration of C }

(thus we can also say: low C steel, high C steel, etc.)

* [NOTE: Beyond 2% C we generally don't call it steel
it is considered Cast Iron]

122] Classification of Steel

Can be done as per:

— composition (most common)

{ ∵ there are other ways as well }

As per composition:

(i) Plain Carbon Steel

> 90% of all steel is this type

(contains: Fe + C + Si, Mn, P)

Si, Mn, P: v. low conc.

(can be neglected as they don't influence the properties
they are small impurities which can't be removed)

(a) Mild Steel (0.03–0.25 % C)
most common

(b) Medium Carbon (0.25–0.65 % C)

(c) High Carbon (0.65 %–1.0 % C)

(ii) Alloy steel

Here: One or more elements (other than C) are added to enhance properties of the steel

{ such as: strength, ductility, electrical conductivity, magnetic properties, corrosion resistance ... etc }

corrosion resistance: the most commonly used for this is: Stainless Steel

(i) Low alloy steel (alloying about < 5%)

(ii) Medium alloy steel (is from 5–10%)

(iii) High alloy steel (> 10%)

NOTE:

Bessemer process — [Acid Bes. / Basic Bes.] — some examples of processes used

Open Hearth Process — [Acidic " / Basic "]

123] There are many ways in which product can be made:

→ Structural steel
→ Deep drawing steel
→ Forging steel
→ Rast steel

There are mainly < long products / Flat products

124] Modern Steel Making

This is > 160 years old

Sir Henry Bessemer : developed and patented a process for steel making in 1861

& in 1860's the bulk production of steel began

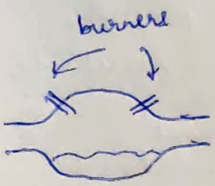
Earlier there were two main processes

Cementation process — Crucible process

* { The process for glass making was used to refine P.I. (done on small scales for steel making)

but it had the limitation that is could produce temp. at most of 1450°C

burners



Eventhough melting pt. was ~1250°C → But here as C got oxidized

C content got reduced ~> & melting pt. increased

thus, slag couldn't get removed & got entrapped

it is slightly removed by squeezing (but cannot be completely removed)

called Wrought Iron

C content is v.low but it is not completely pure iron