Working Principle of Blast Furnace

Ajeet Kumar

DGM- Blast Furnace, DSP

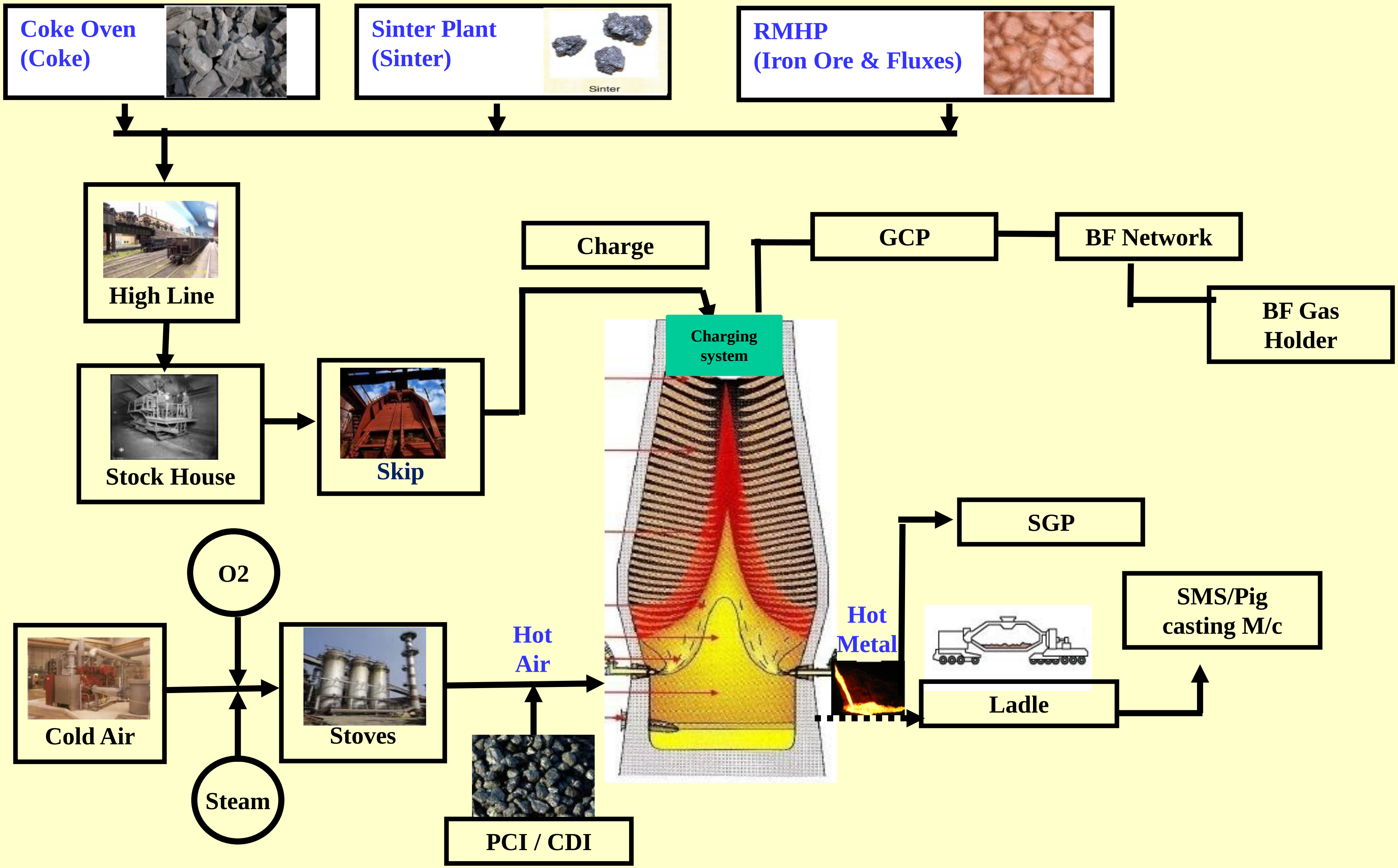
Technical Data of Blast Furnaces of DSP

Parameter	Unit	BF#2 KAMALA	BF#3 SARADA	BF#4 DURGA	SHOP
Annual Hot Metal Production Capacity	Tons	720000	768000	912000	2400000
Useful Volume	M^3	1400	1400	1800	4600
Working Volume	M^3	1204	1204	1539	3947
No of Stove	Nos	3	3	3	
No of Tuyeres	Nos	18	18	20	
Top Charging Equipment		Double Bell	BLT	Double Bell	
Slag Granulation System		Not available	INBA Type	Russian Dehydrator Type	
Gas Cleaning System		Conventional ESP	Venturi Scrubber	Conventional ESP	

Major Section of Blast Furnace

- Stock House and High line
- Blast Furnace & Stoves
- Slag Granulation Plant
- Gas Cleaning Plant
- Coal Dust Injection
- Pig Casting machine
- Ladle Repair Shop

Process Flow of Blast Furnace



Major Raw Material Analysis (%)

- Coke

ash	Moisture	VM	M40	M10
17.0 $\pm$ 0.5	4-5	0.6	80-82	7.5-8.0

- Sinter

Bas(Cao/Sio2)	Al2o3	Feo	Fe	Mgo
1.70 $\pm$ 0.5	2-2.5	8.5-9	57.0	2-2.5

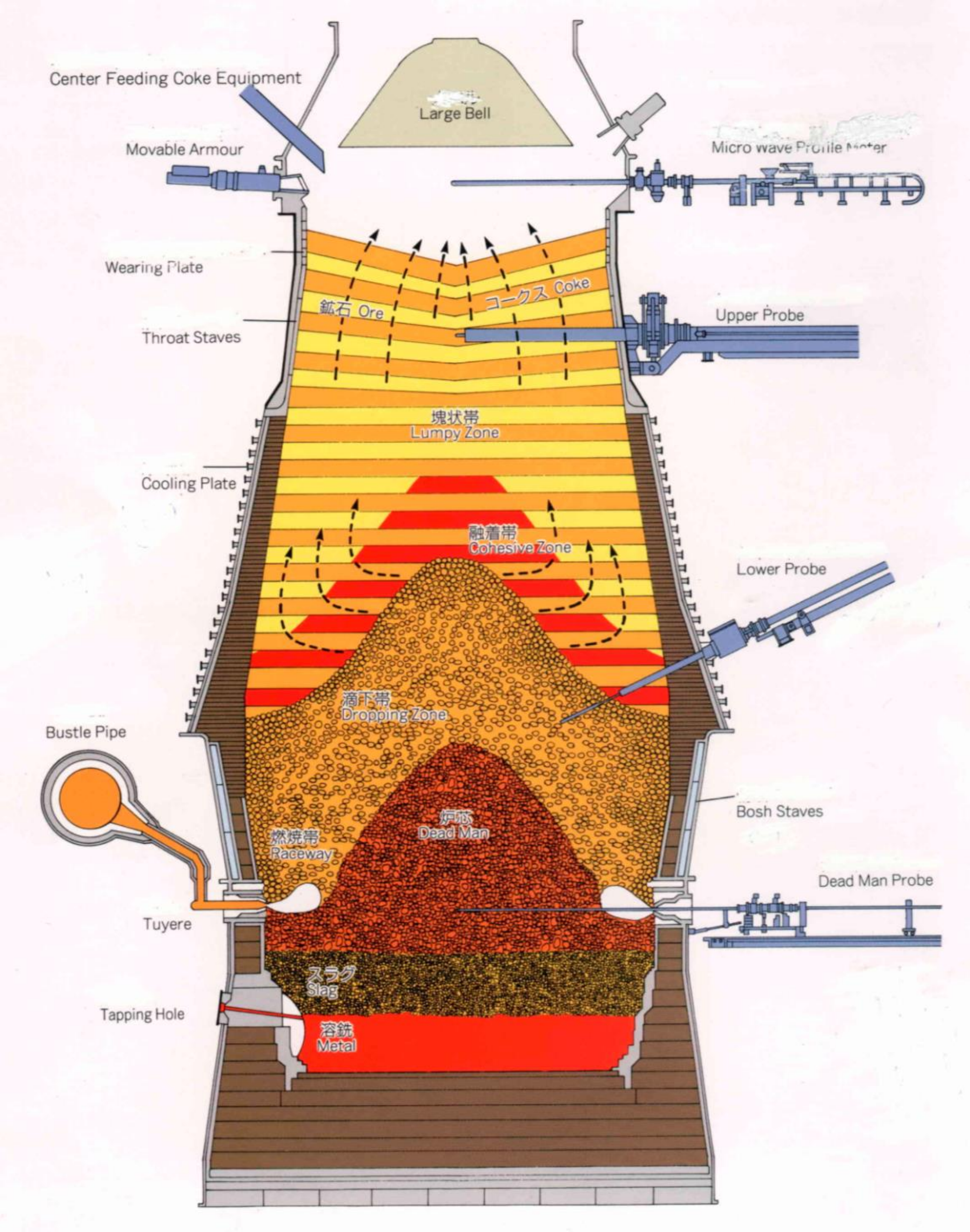
- Iron Ore

Al2o3	Sio2	Fe
2-2.5	2-2.5	62-63

BLAST FURNACE – An Introduction

- **Blast furnace is a counter current reactor for production of hot metal. In the reactor, the iron ore (consisting of Fe_2O_3,SiO_2 & Al_2O_3) is reduced and melted by hot reducing gases.**
- **Iron ore/Sinter/Pellet, Fluxes (Lime Stone etc) and coke are charged from the top while hot air blast is blown into the lower section through Tuyers.**
- **Hot Carbon Monoxide rich reducing gases produced by burning of coke reacts with iron ore to produce iron (HM). Alumina, Silica etc in Ore reacts with Lime and produce Slag floating on Hot Metal**
- **Blast furnace capacity is varying widely (200 M^3 to 6000 M^3) to produce Hot metal of 500 TPD to 14000 TPD.**
- **World production of Hot metal from Blast furnace route is ~1.9 billion tons/year**

BF Internal physical Profile



ZONES WITHIN A FURNACE

- With the dissection of some operating BFs a clear understanding of process has developed.

- Regardless of size, shape, raw material & operating conditions, all furnaces showed distinct regions.

- A furnace can be divided in 5 zones.

- Shapes & size of zones may vary.

ZONES WITHIN A FURNACE

- **Granular (Lumpy) Zone**

  Burden particles remain as discrete particles with ore and coke in roughly defined layers.

- **Cohesive Zone**

- **In this zone ore exists not as a solid nor liquid but as a softened mass.**

- **Coke appears as gaps or slit between ore layers (Coke slits or coke windows).**

ZONES WITHIN A FURNACE

- **Active Coke Zone**

- **This zone contains loosely packed coke, feeding the raceway and droplets of iron & slag dripping into deadman and hearth.**

- **The zone has no characteristic that forms its boundary.**

- **This is an area left by the boundaries of cohesive zone, raceway & deadman.**

ZONES WITHIN A FURNACE

- **Raceway**
- **This is the region where coke is burned.**
- **It is a semi void region with rapidly moving coke being burned to generate heat and reducing gases.**
- **Its outer boundary is determined by the energy of momentum of the blast causing semi void.**

ZONES WITHIN A FURNACE

- **Hearth & Deadman**

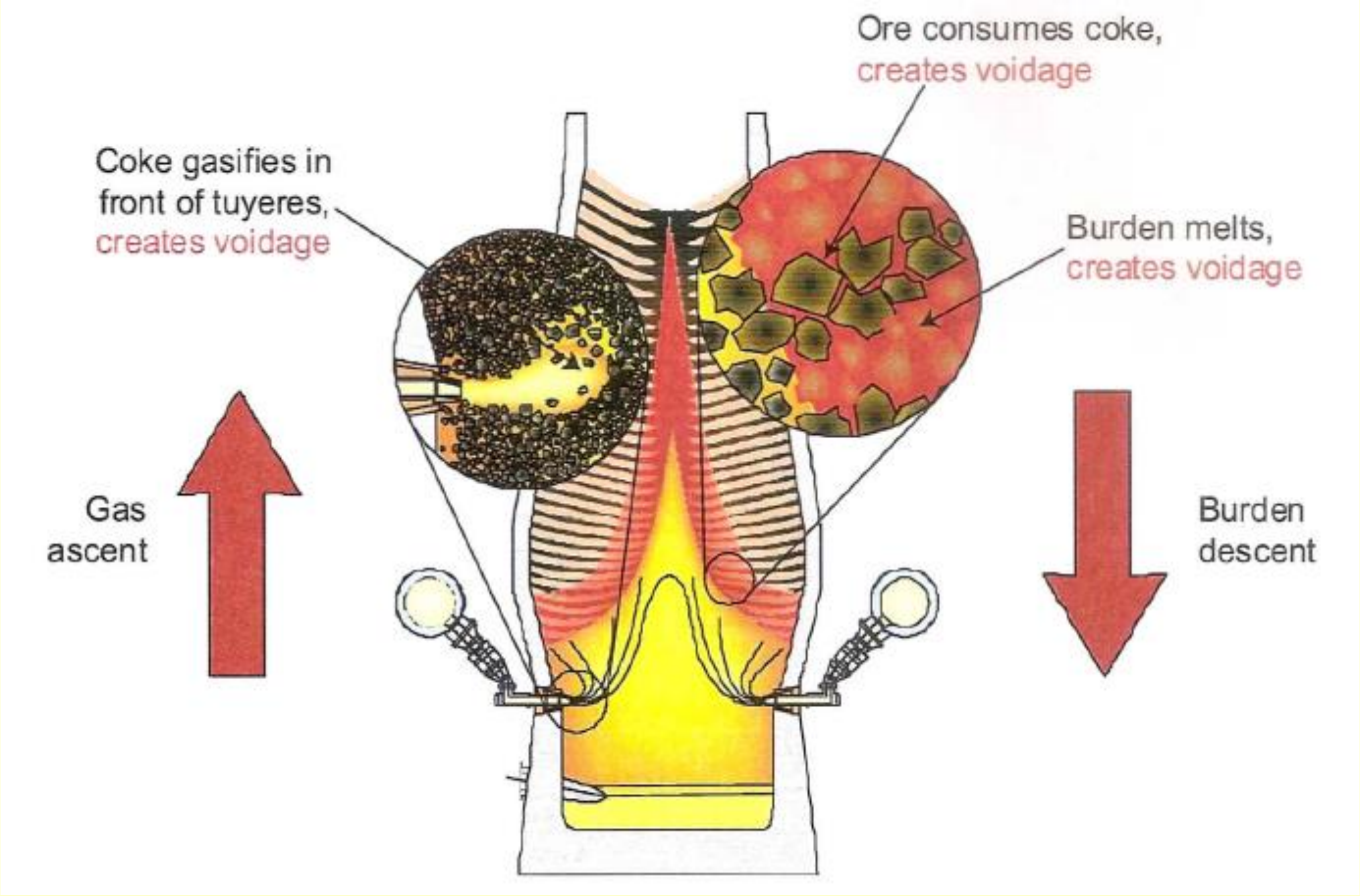
- **This is an area of densely packed coke through which iron & slag drip and collect in hearth.**

- **Molten liquid may be fully or partially dispersed among the coke.**

BLAST FURNACE AS REACTORS

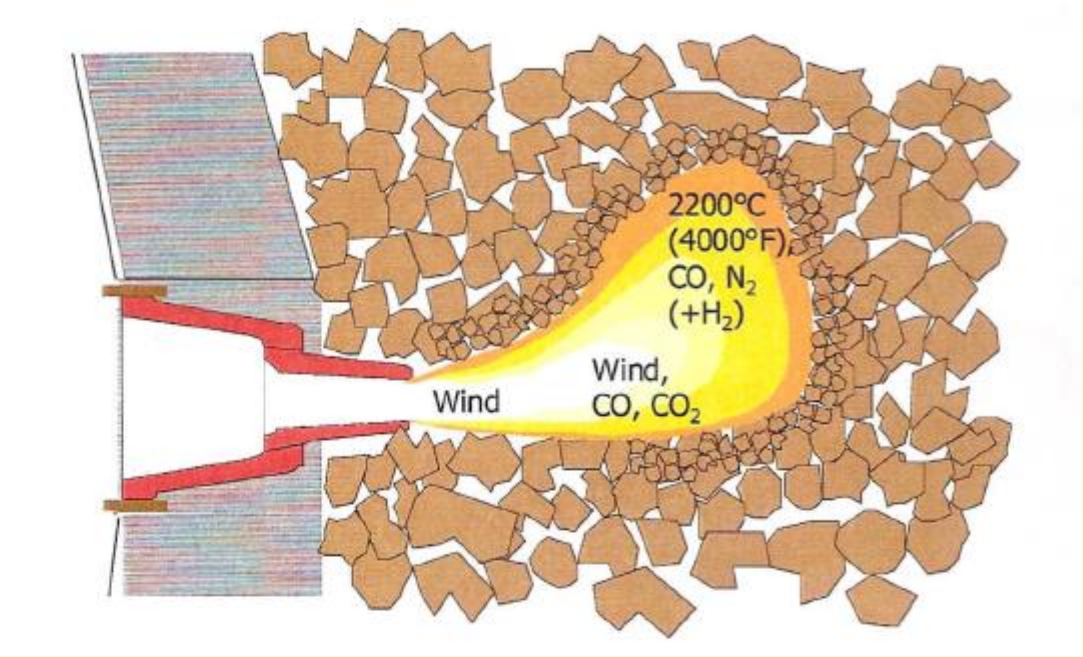
- BF can be considered as **two stage reactor**, separated by the pinch point region (~1000 ^{0}C).
- Above this region is the "**Low temperature Zone**" or preparation zone.
  - Drying & Preheating of solid
  - Reduction of iron oxide to wustite
- Below this region is the "**High temperature zone**" or melting – smelting zone.
  - Reduction of wusite to iron
  - Smelting of hot metal & slag
  - Coke combustion

BLAST FURNACE -Main driving mechanism



The driving of blast furnace is due to creating of space by burning of coke in front of tuyeres and melting of burden ,which is filed by downwards movement of burden due to gravity.

BLAST FURNACE- Tuyere Raceway



The hot reducing gases (CO & H2) are produced by burning of coke/CDI by oxygen of Hot blast air in front of tuyeres called Raceway.

BLAST FURNACE REACTIONS

- **When O_2 first hits the coke in tuyere raceway, it reacts immediately to form CO_2 which further reacts with coke to form CO.**

$$C + O_2 \leftrightarrow CO_2$$

$$CO_2 + C \leftrightarrow 2CO$$

$$2C + O_2 \leftrightarrow 2CO$$

Tuyere gases then rises through active zone; transferring heat to descending coke & iron / slag droplets.

BLAST FURNACE REACTIONS

- **Following reactions take place in lower portion of the blast furnace:**

$$CO + FeO \leftrightarrow Fe + CO_2$$

$$CO_2 + C \leftrightarrow 2CO$$

$$FeO + C \leftrightarrow Fe + CO$$

(This reaction is known as Direct Reduction and it is endothermic in nature)

BLAST FURNACE REACTIONS

- **Following reactions take place in middle portion of the blast furnace:**

$$FeO + CO \leftrightarrow Fe + CO_2$$

This reaction is also called Indirect reduction

- **Rising gas then reduce Magnetite (Fe_3O_4) to wustite (FeO).**

$$Fe_3O_4 + CO \leftrightarrow 3\,FeO + CO_2$$

- **In the upper most portion of BF, reduction of hematite to magnetite takes place**

$$3Fe_2O_3 + CO \leftrightarrow 2\,Fe_3O_4 + CO_2$$

Effect of Hydrogen

- **Two Sources**:
  i) Dissociation of moisture in the blast air

  $$C + H_2O = CO + H_2$$

  ii) Combustion of auxiliary fuels injected at Tuyeres.

  Coal : $CH_{0.6} + 0.5\ O_2 \rightarrow CO + 0.3\ H_2$

  Oil : $CH_2 + 0.5\ O_2 \rightarrow CO + H_2$

  Natural Gas : $CH_4 + 0.50_2 \rightarrow CO + 2\ H_2$

Advantages of Hydrogen

- Hydrogen has greater reduction potential at temperature above 817^0C
- Rate of reduction is more with H_2

Effect of Hydrogen

- Regeneration of H_2 is less endothermic

$$H_2O + C = H_2 + CO$$

- Than regeneration of CO

$$CO_2 + C = 2\ CO$$

- Presence of Hydrogen decreases bosh gas density as its molecular weight is less (2) compared to CO and N_2 (28).

Change of phases in BF process

- In upper portion, agglomerates are reduced by gases topochemically, the outer shell is converted to metallic iron, wustite and gangue materials, while inner shell is wustite and gangue.
- At higher temperature, the metallic iron & wustite undergoes a grain growth and some melt is generated, which result in retardation in reduction, softening and cohesion
- Furthermore at still higher temperature, considerable amount of molten slag with low melting point extrudes from the particles ,filing the void, causing decrease in voidage and thereby higher pressure drop in cohesive layer
- Finally, due to carburization of metallic iron, the agglomerates melt down and separation of metal and slag takes place.

BLAST FURNACE PERFORMANCE
Key Enablers

- **Improved Permeabilty:**
  - Higher strength of Lump and sinter (TI,RDI,RI)
  - Less Fines input (-10mm of lump,-5mm of sinter)
  - Higher % of Prepared Burden (Sinter + Pellet)
  - Optimum Coke strength (M_{10}, M_{40}, CSR)
  - Low slag volume(Al_2O_3 & SiO_2 of Input)
- **Reduction & thermal potential of gases:**
  - CDI, Other auxiliary fuel, if any
  - Hot Blast Temperature (HBT), O_2 enrichment
- **Improved refractory and cooling system**
- **Probes & models for better understanding/control.**

Optimisation of BF process

KEY PROCESS :

- **Burden distribution**
- **High top pressure**
- **Use of higher HBT**
- **Oxygen enrichment**
- **Nut coke (15-25/30/34 mm) charging (@25-40 kg/thm)**
- **PCI injection**

Burden Distribution

- **Burden distribution plays a very important role in improving the operation of blast furnaces. It determines the rate of gas flow, solid gas contact, location and configuration of cohesive zone and characteristics of deadman zone, thereby affecting the productivity, fuel consumption and quality of hot metal.**
- **Optimum burden distribution in BF is must for achieving a high driving rate, better gas utilisation and thus low fuel rate, smooth burden descent and low thermal load on the wall without causing excessive build up.**

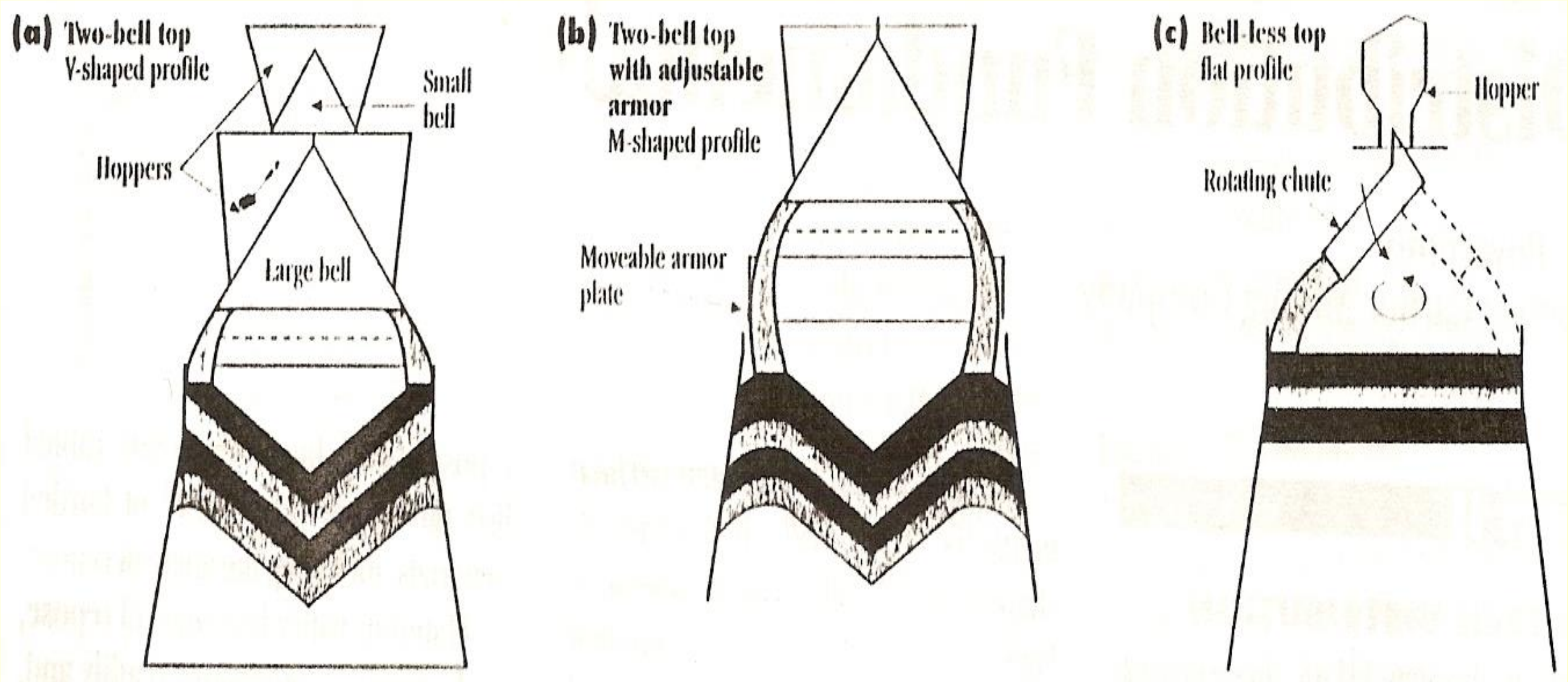
- **Permeability of the individual layers of the burden depend on shape, size range and void fraction of the particle in bed and can be increased by suitable shape, close size range and minimizing the fines.**
- **The permeability across the radius of furnace can be controlled by proper burden distribution, stock level adjustment and selection of suitable coke base etc.**

Different type of charging equipment has been used in SAIL plants and these are as follows:

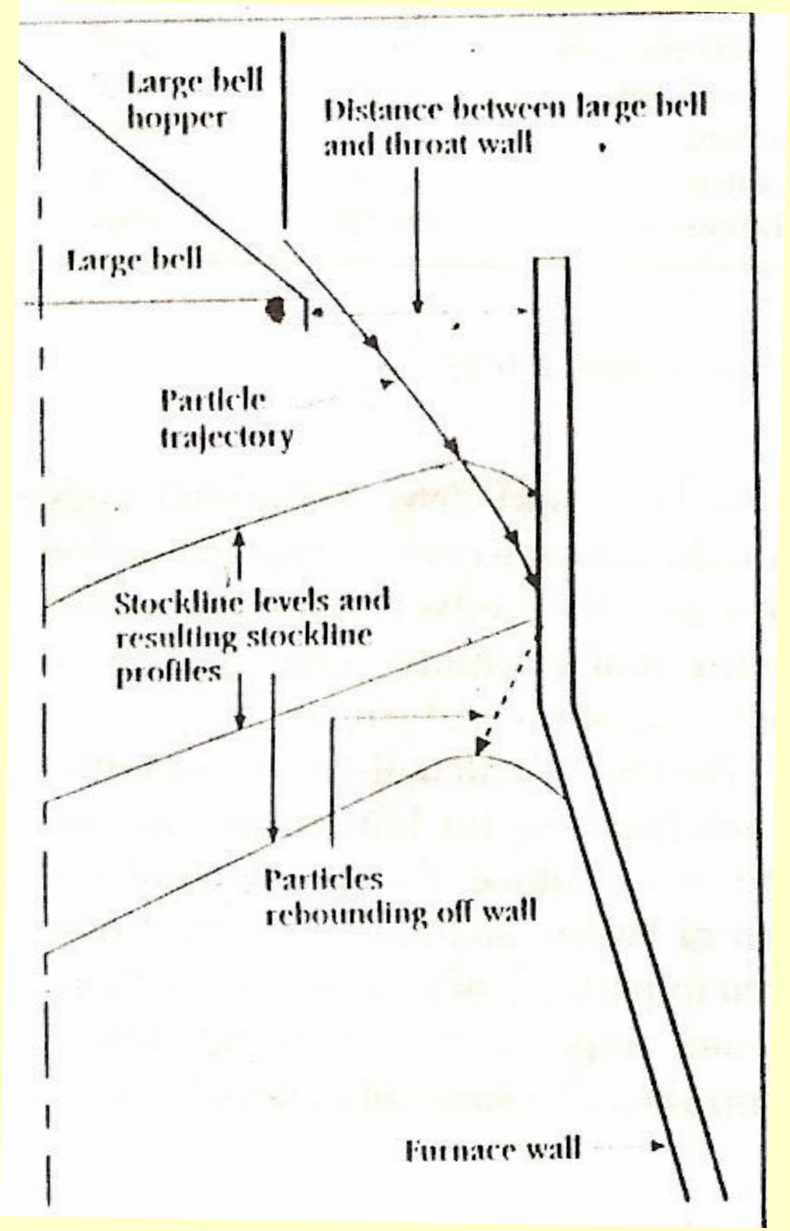
- **Two bell charging system**
- **Movable throat Armour(MTA)**
- **Bell less top (BLT)**

BLT is very flexible and helps in achieving a wide range of charging pattern i.e. point charging, sector charging and ring charging

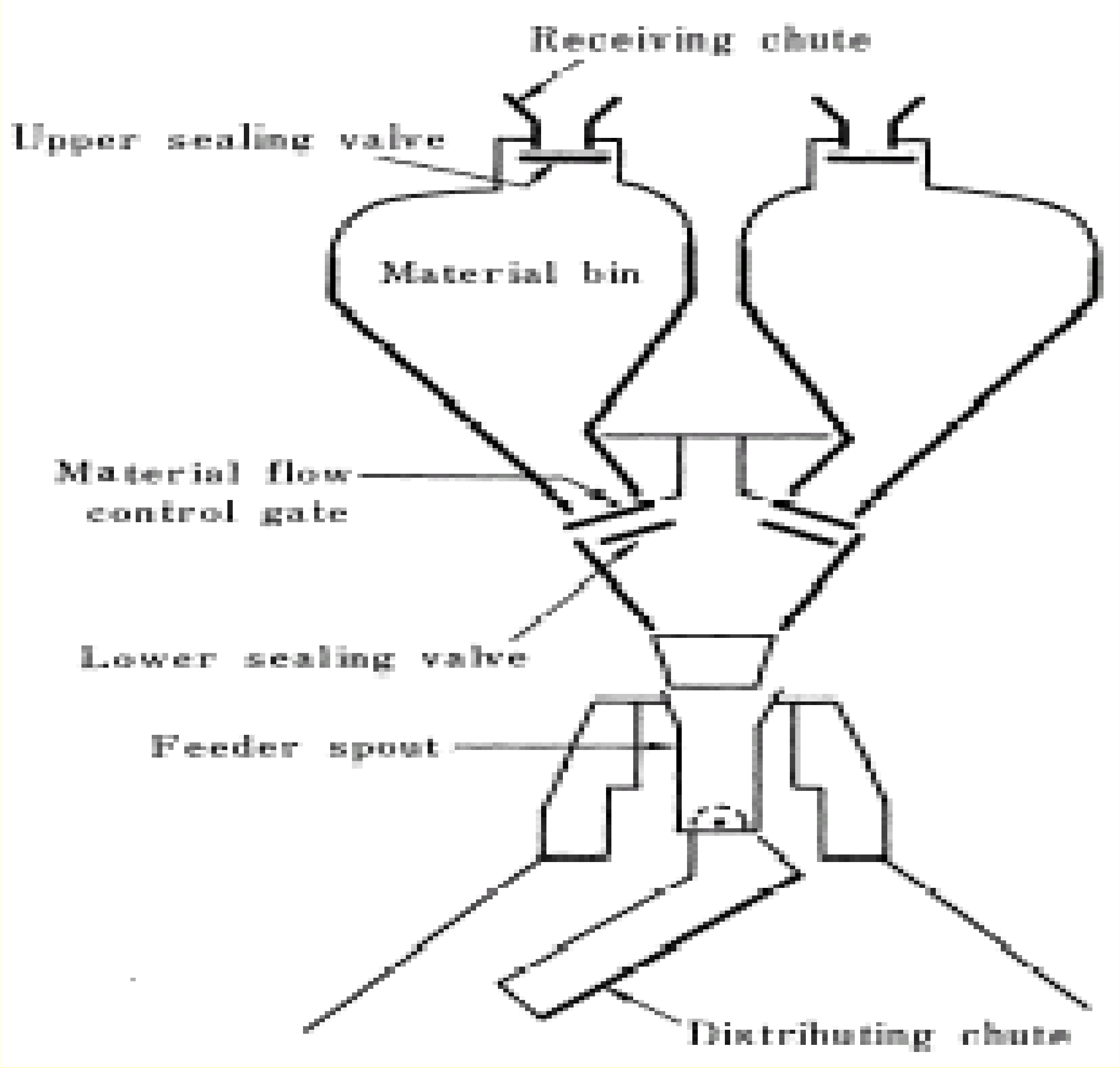
Different Charging System



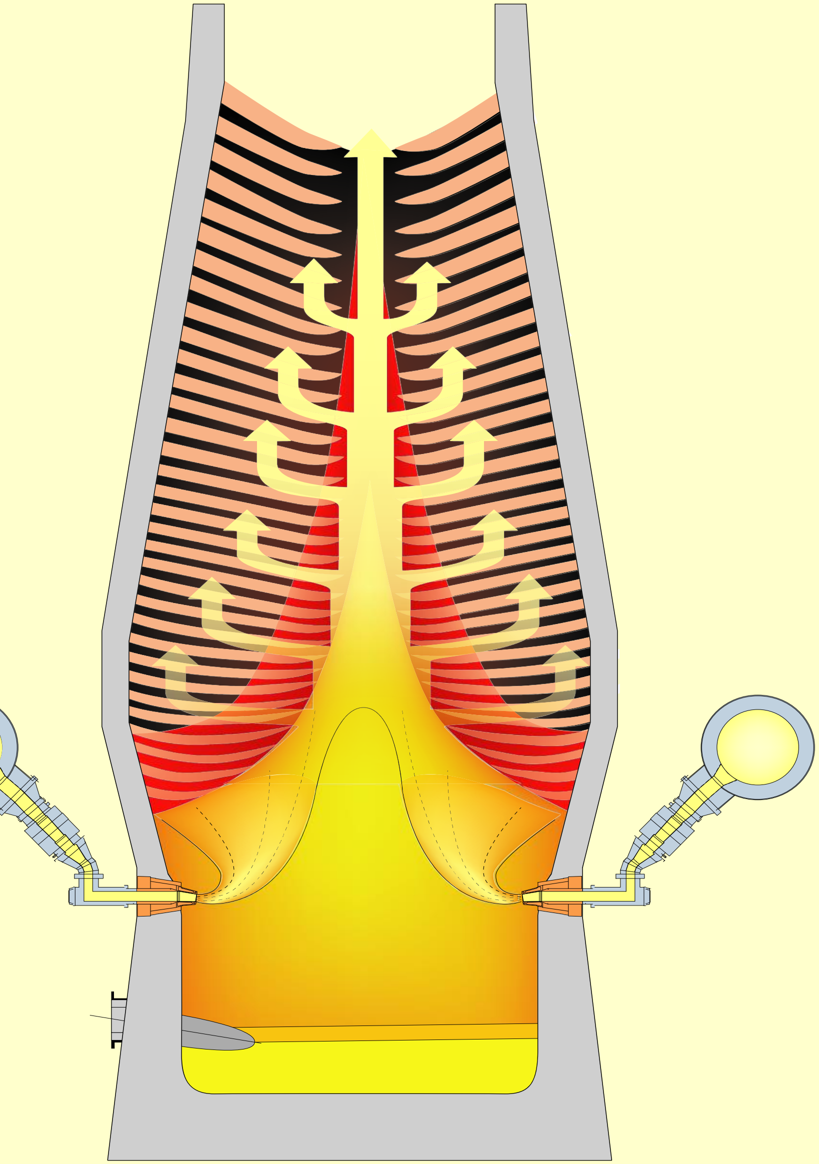
Trajectory in Two Bell Charging



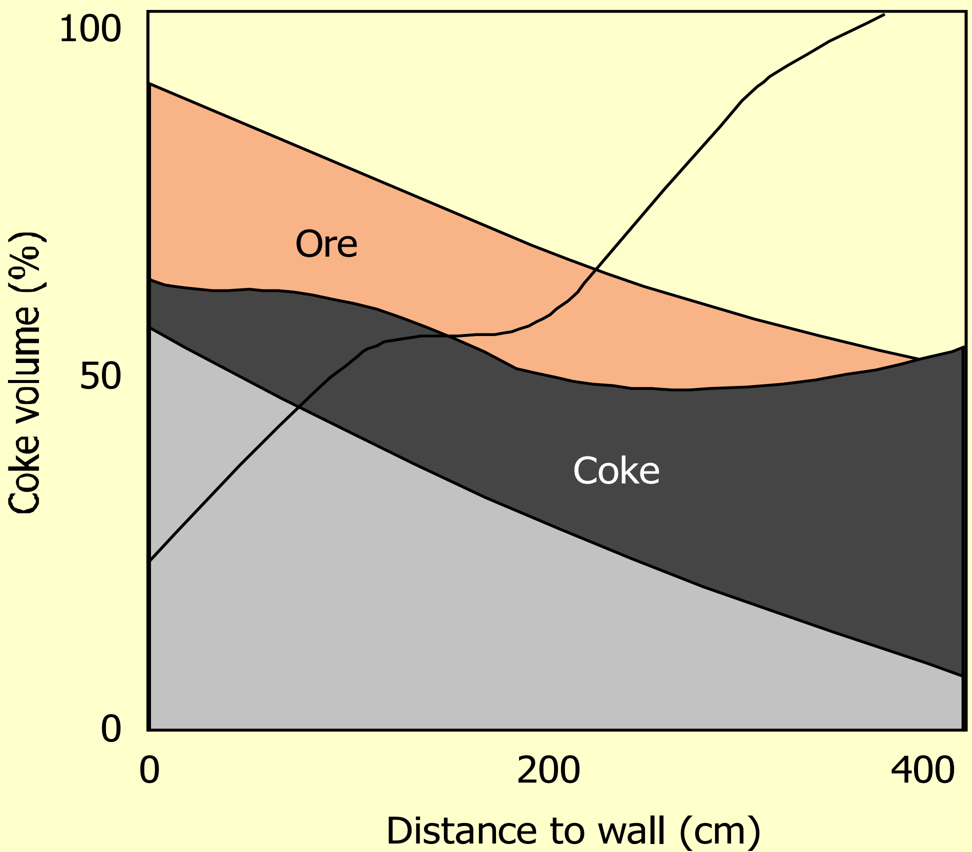
BLT Charging



Central working furnace



- Low heat loads to wall; low root of melting zone
- Gas escaping through center; stable burden descent



High Top Pressure

- **In conventional BF, the top is almost open to atmosphere and if more air is blown a stage will come when BF gas velocity exceeds the critical limit of flooding and fluidization resulting in irregular furnace operation.**
- **BF can take more blast if linear gas velocity is reduced with the help of HTP, which can be achieved with the help of suitable valves and seals. An increased hot blast pressure will be required at bottom to maintain the same pressure differential.**

- **In case of high top operation , for a constant blast volume the average gas pressure in BF and thereby the density of gas will increase with corresponding decrease in linear velocity of gas ; as a consequence the greater mass or volume of blast can be blown resulting in a increased productivity.**
- **Permeability resistance index (PRC), $k = (Pb^2 - Pt^2)/1.26Vb^{1.7}$**

  Where Pb, Pt,Vb are Blast Pr, Top Pr & Bl.Vol
- **Further it is estimated that blast volume increases by 15-20% if HTP is increased from 1.0 to 2.0 kg/cm^2.**

Advantage of HTP

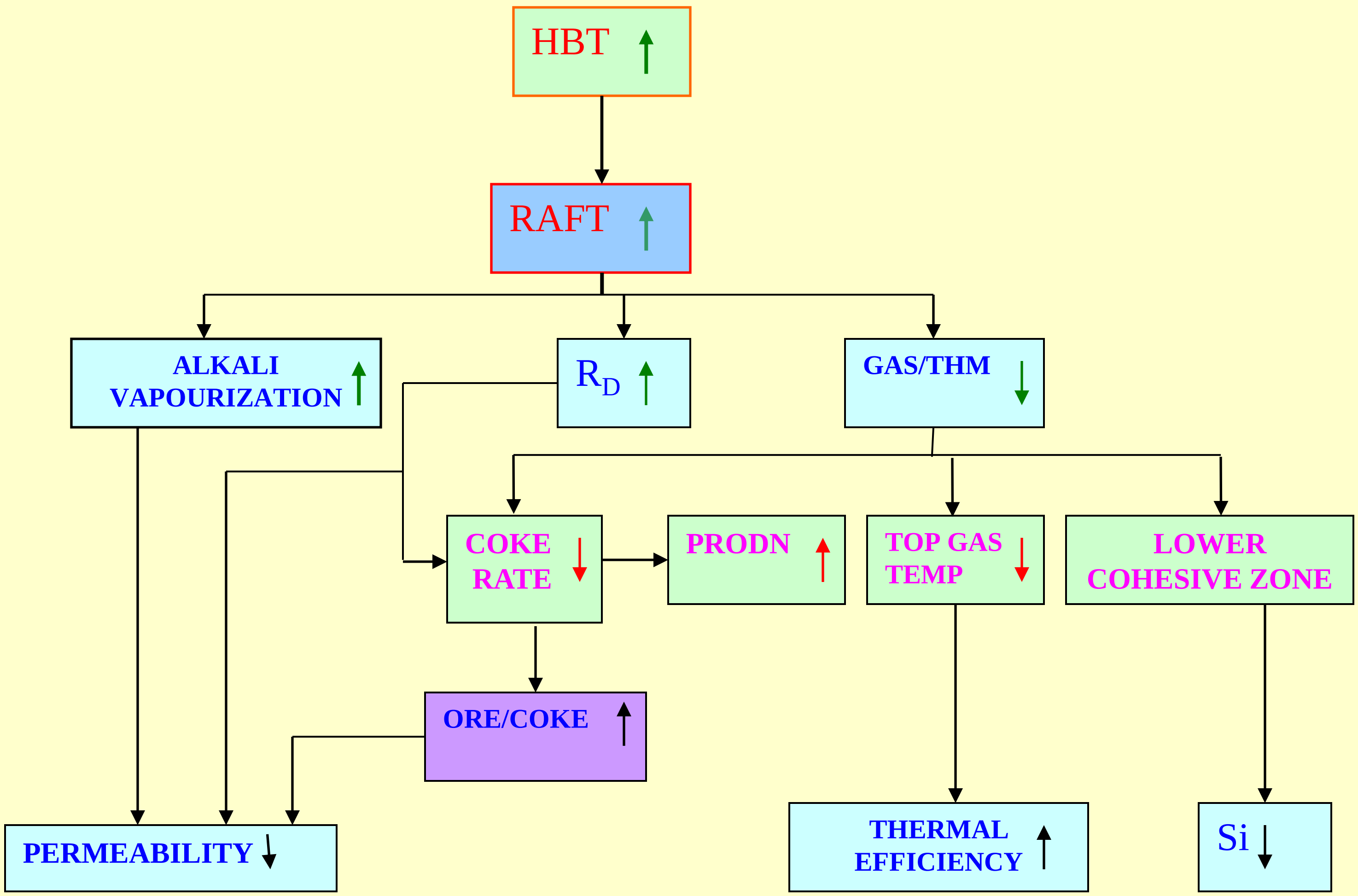
- Improved gas solid contact
- Increased reduction rate with improved gas solid contact
- Less fluidization of fines
- Less flooding tendency
- Increase in metal & slag drainage rate

Use of higher HBT

- **Higher HBT brings in an increased supply of sensible heat through blast,as a result decrease in amount of tuyere carbon/thm**
- **Use of higher HBT results into saving of coke and increase in productivity**
- **There is a limit to which blast furnace can accept a higher HBT depending upon the raw material quality, so normally a coolant is used along with it.**
- ***SAIL is having HBT of 900-1200^{o}C*.**

सेल SAIL

Effect of HBT on BF



Oxygen Enrichment of Blast

- O_2 enrichment increases coke burning intensity.With 1% increase in oxygen in air, the CBI goes up by 4.7%.
- O_2 enrichment of blast reduces the amount of N_2 in the air and consequently decrease the volume of air required for burning 1 kg of coke

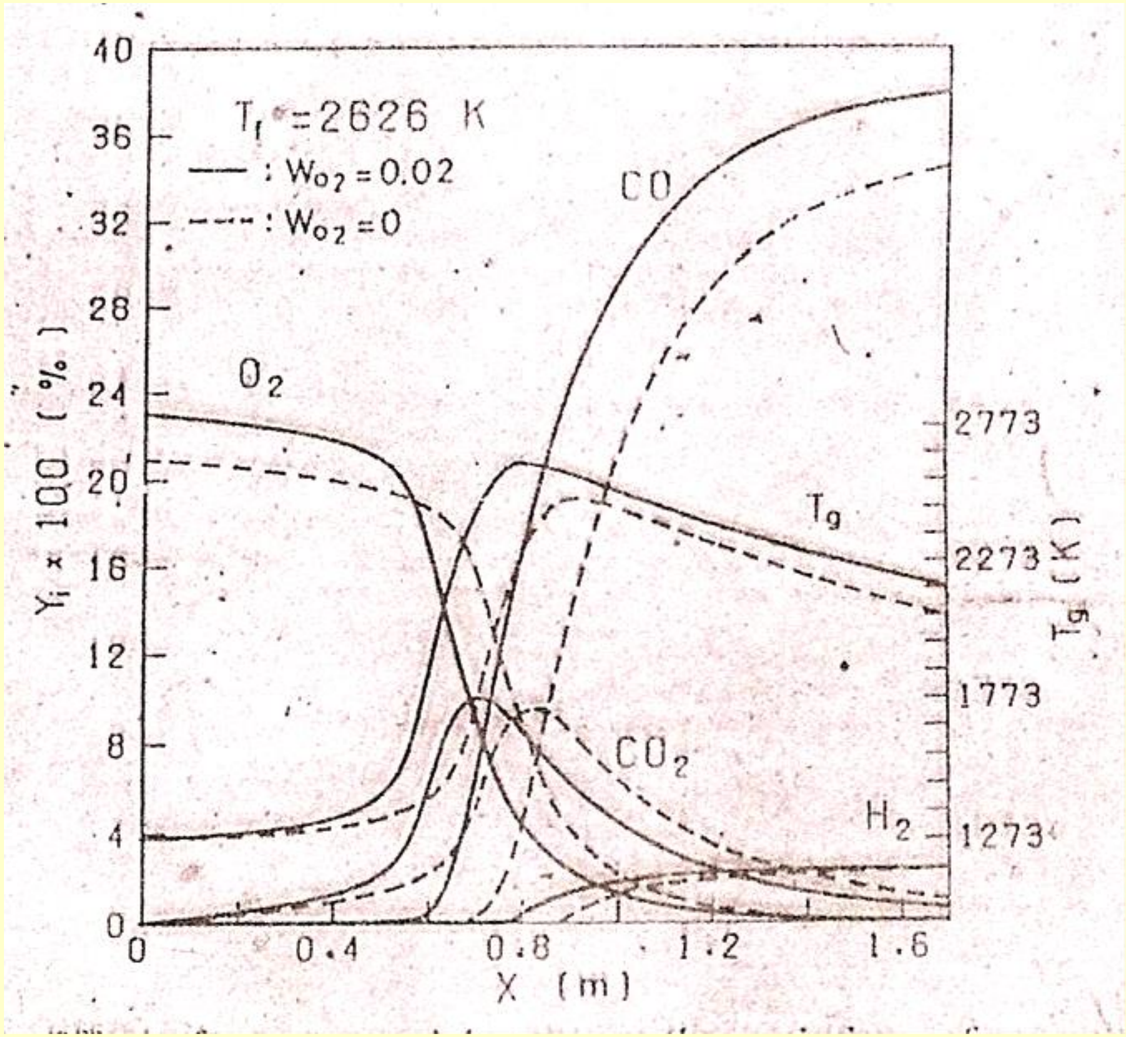
O_2 %	Bl.Vol. $Nm^3/kg.C$	Tuy.G.Vol. $Nm^3/kg.C$	CO in Tuy.G. %
21	4.44	5.37	34.71
25	3.73	4.66	40.0

- **Oxygen enrichment results in increase in flame temperature so it must be accompanied by some coolant.**

- **O_2 enrichment also shift the temperature gradient in front of tuyere towards the tuyere nose**

SAIL is using O_2 enrichment of 1.0-6.0% in most of the blast furnaces.

Effect of Oxygen Enrichment on Raceway



Use of nut coke (10-25 mm) alongwith ore & sinter

- **Due to softening-melting, the ore layers become impermeable to gases. Therefore, the gases can pass only through the coke 'slits' in the cohesive zone. While passing through the coke slits, a sudden change in the direction of the gases takes place. This causes a large pressure drop, about 40-50% of the total pressure drop along the furnace height, to take place across the cohesive zone. The nut coke/ore mixing helps in arresting this pressure drop.**

Use of nut coke (10-25 mm) alongwith ore & sinter

Mechanism of SM in layered bed :

1. **At about 1250^{o}C, the softening starts due to the formation of liquid slag when unreduced FeO in the iron ore lump reacts with the gangue and slag is fluid because of high FeO and fill the voids of the ore layer.**
2. **At a higher temperature, say 1350^{o}C, the FeO – rich slag is extremely fluid, its flow down into the coke layer and FeO gets reduced by the direct reduction.**

Use of nut coke (10-25 mm) alongwith ore & sinter

3. The iron thus formed dissolves carbon, which causes a lowering of its melting point and iron starts dripping. On the other hand, the slag suffer a loss in fluidity due to a decrease in its FeO content as well as joining of coke ash released during direct reduction. The ore and coke layers are least permeable and the pressure drop rises to a maximum.

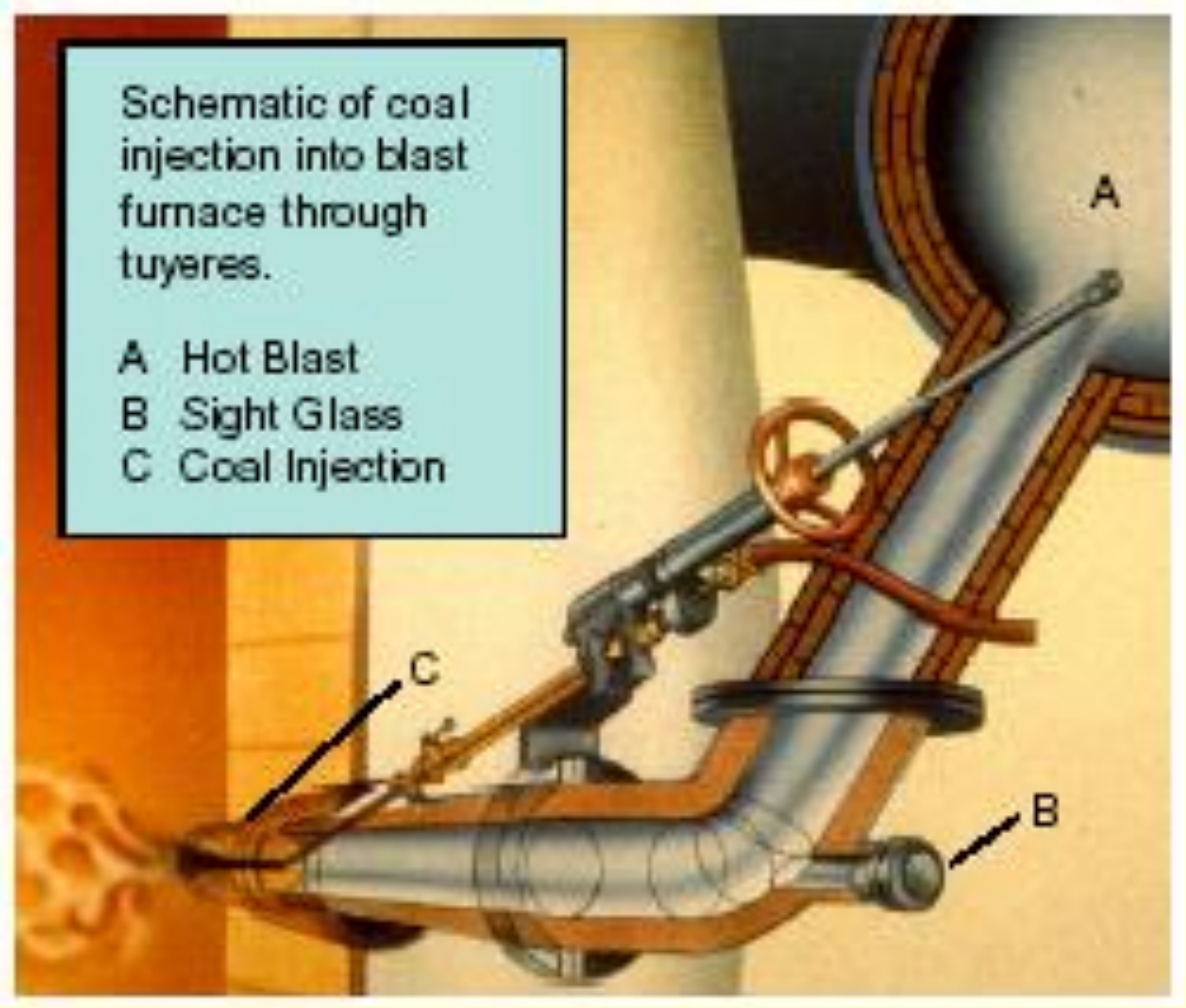
Advantage of nut coke alongwith ore & sinter

1. Presence of nut coke in ore layer helps for in-situ reaction with FeO thus saving the coke layer from ill-effect of direct reduction.
2. It helps in accelerating the melting of iron due to earlier commencement of carburization.
3. Slow down the rate of loss of permeability of the ore layer because of creation of voids

COAL INJECTION

Coal injection in blast furnaces has been widely adopted for decreasing the coke rate to the lowest possible extent commensurate with furnace thermal balance and favorable raceway condition. Coal injection has substituted the function of coke to a large extent. However, coke still still has a very important role to play in maintaining the desired permeability inside the furnace and thus a certain minimum amount of coke cannot be replaced by coal injection.

CDI in Tuyere



Important aspects of CDI

Some of the important aspects of blast furnace with coal injection include:

- **Coal combustion**
- **Coal quality for injection**
- **Lance design and positioning**
- **Raceway profile**
- **Burden distribution and heat losses**

Coal Combustion

The coal combustion, as a physical-chemical process, has to be completed in the extremely short residence time of the coal in the raceway, in the order of 20-50 ms.

The different stages of coal combustion are:

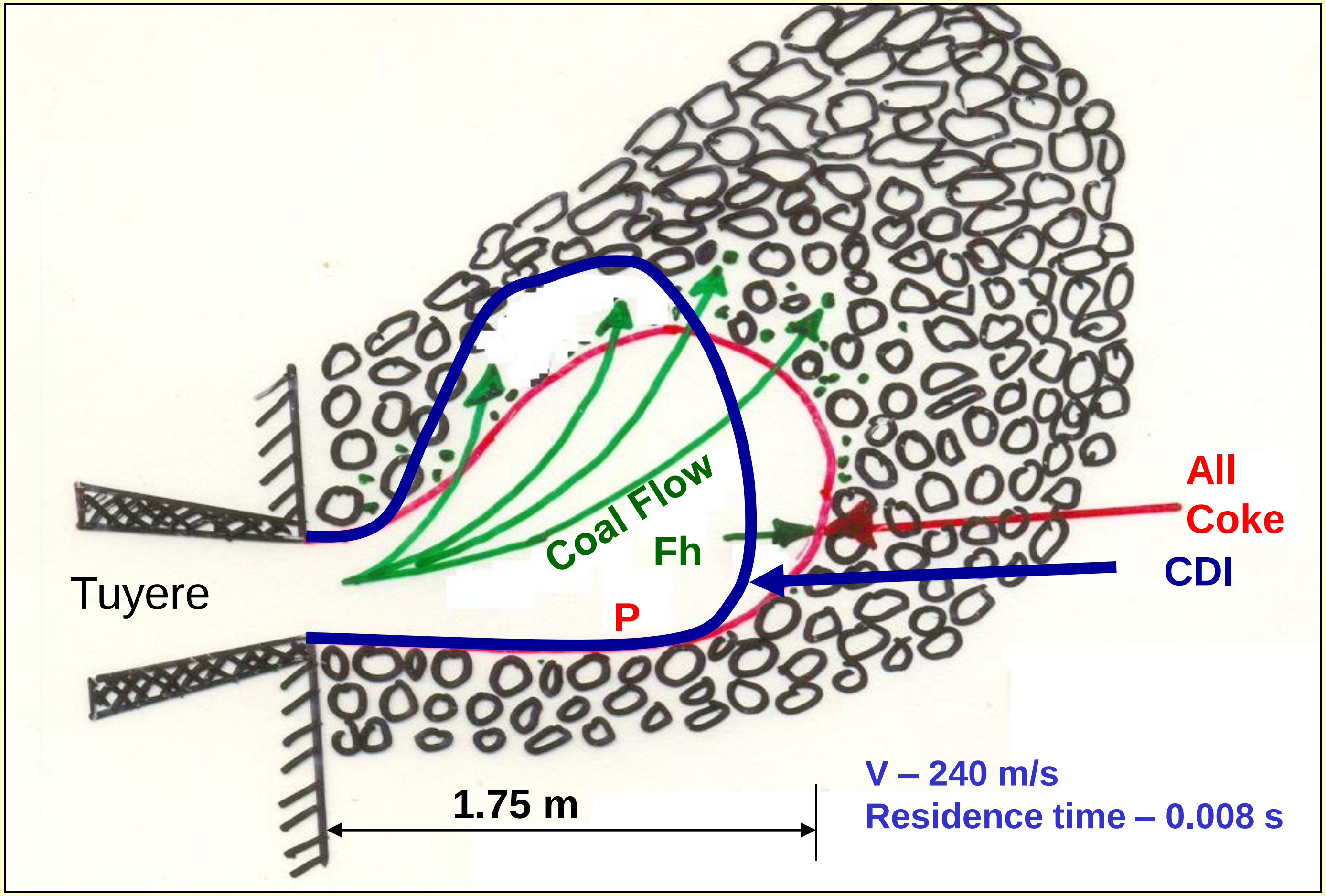
- Heating of coal
- Burning of VM
- Burning of remaining char

Coal Combustion

Depending of the particle size, coal composition, heating rate and the amount of available oxygen for combustion, these stages take place simultaneously or separately.

The combustion efficiency is strongly influenced by the VM & size of coal

What happens when Coal is injected



Steps of Combustion

- Heating of coal
- Breaking of bonds
- Combustion of VM
- Combustion of char & assimilation of ash

Coal Quality for injection

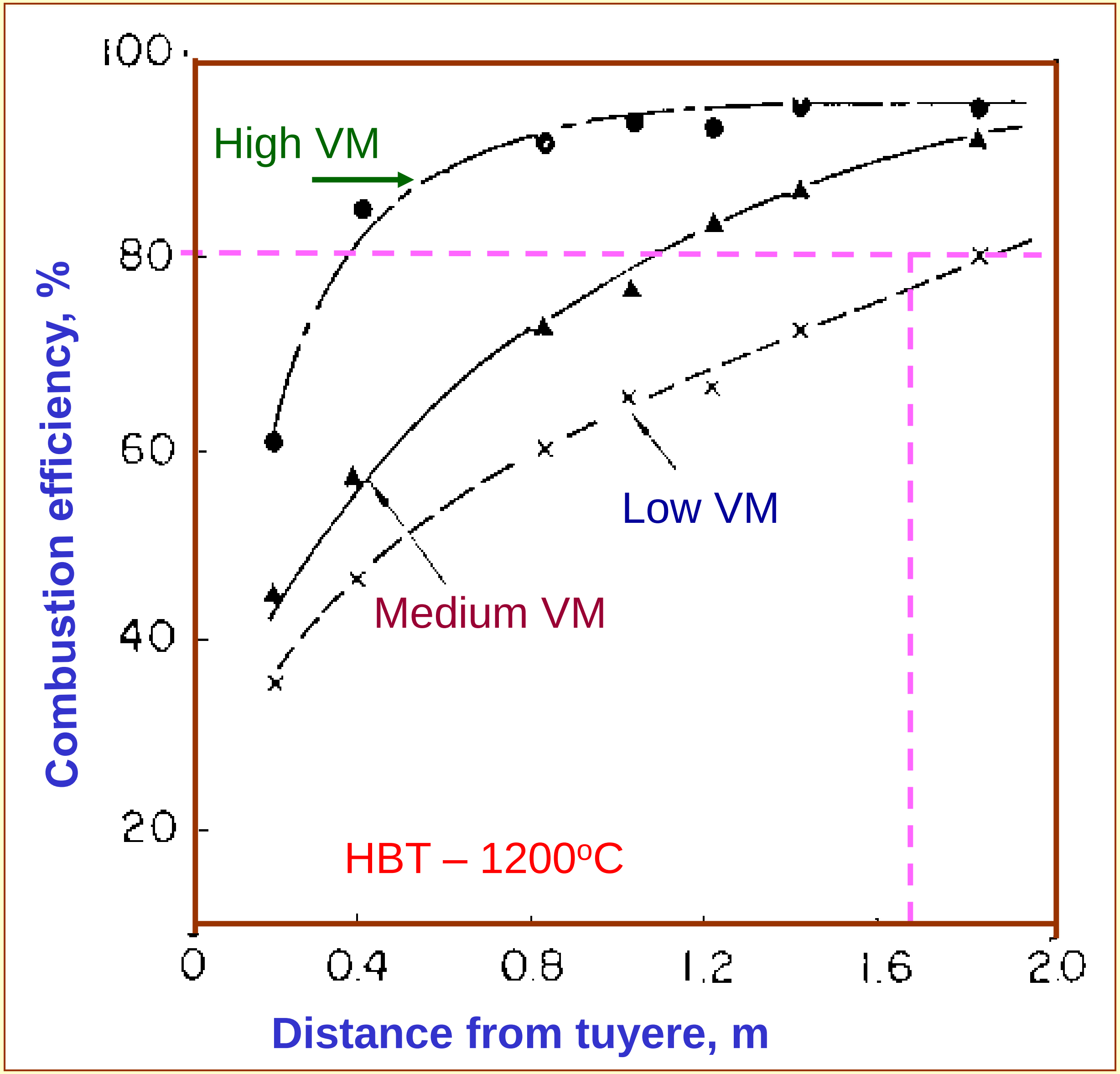
In order to predict the coal behaviour in the preparation facilities and during pneumatic transport and injection in the blast furnace, the following are required:

- Size distribution
- Hardgrove Index
- Chemical and petrographic parameters
- Calorific value
- Combustibility

COAL ANALYSIS

	PARAMETERS	DESIRED RANGE
1.	Carbon, %	60-70
2.	Sulphur, %	0.4-0.65
3.	Phosphorous, %	0.025-0.075
4.	Hydrogen, %	4.5-5.5
5.	Oxygen, %	3.8-7.0
6.	Nitrogen, %	1.8-2.5
7.	Volatile Matter, %	20-35
8.	Ash, %	9-12
9.	Coal Dust Moisture, %	$\leq$ 1.5
10.	Coal Dust Fineness	80%<90µm
11.	Hard Grove Index	50-80
12.	Calorific value, kcal/kg	6800

COMBUSTION EFFICIENCY OF DIFFERENT VM COAL



Low VM coal (15-20)

High replacement ratio

- Low combustibility

High VM coal (> 30%)

- Low replacement ratio
- High combustibility

Lance design

Lance design and position has a significant influence on coal combustion efficiency and gas profiles in Raceway.

To enhance the contract between coal particles and oxygen different type of lances are developed and some of these are:

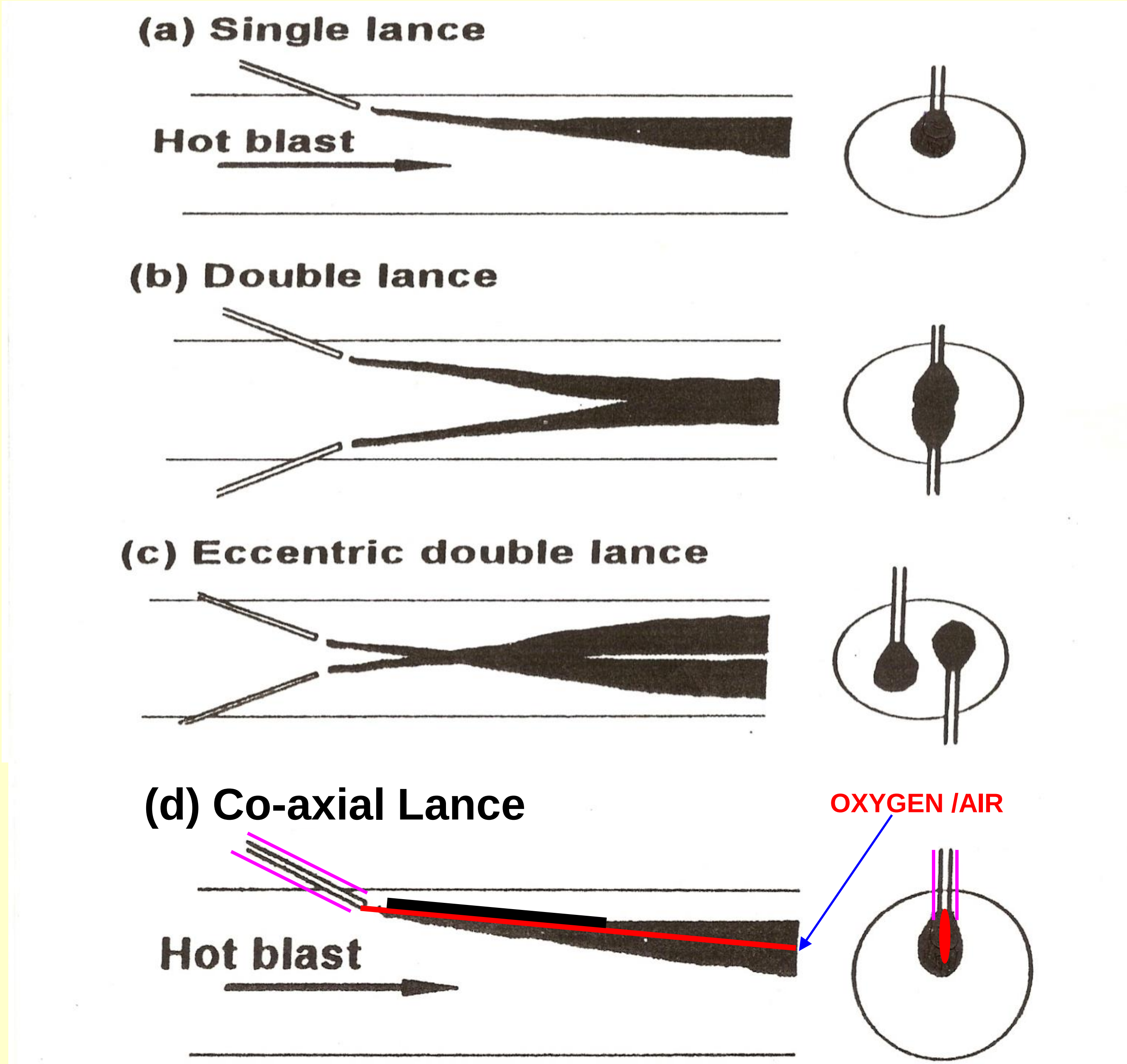
- Single lance
- Double lance
- Ecentric double lance
- Co-axial lance
- Multiple injection (coal with NG or Oil)

Lance design

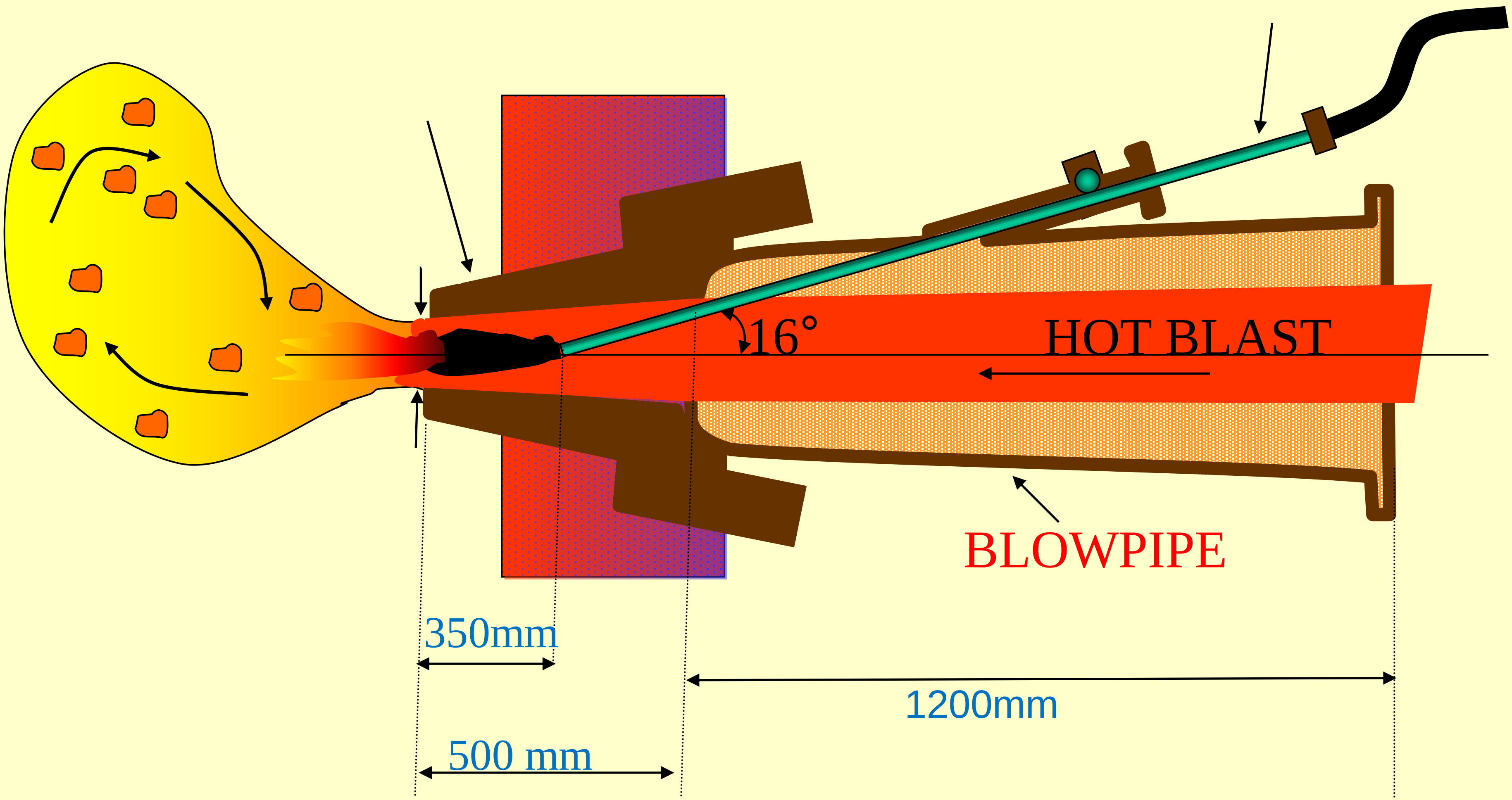
Use of double lance/Co-axial lance and optimization of distance of lance tip from tuyere nose helps in achieving of higher rate of coal injection (>125 kg/thm).

SAIL blast furnaces are equipped with single lance ,located normally at distance of 350 mm from tuyere tip. Chamfered lance had been used to increase the combustibility.

Lance design



Injection Lance Arrangement In BF



RACEWAY PROFILE

Coal injection causes the peak of combustion, represented by the peak of CO_2 in the raceway to shift towards the tuyere nose. This shift of combustion peak causes increased gas flow along the wall and an inactive central zone.

Enhance coal combustibility, optimisation of lance design and predominant central working condition within the furnace improve operations at high injection rate.

Quality control – Si & S in hot metal

- **For production of quality steel through BOF-CC route, superior quality of hot metal with low Si & S is required**
- **Desired composition of hot metal at DSP :**

  Si : < 0.80 %

  S : < 0.045%

- **For production of low Si & low S hot metal, it is essential to identify and optimize various key parameters**
  - *Raw material quality*
  - *Burden distribution*
  - *Blowing condition*
  - *Slag chemistry*
  - *Cohesive zone behaviour*

Possible Source of Si in Hot metal

- *Input Materials, i.e. Iron ore, Sinter, Pellets etc*
- *Coke Ash*
- *CDI Coal*
- *Additives added into fce*
- *Metal /slag interface*

Mechanism of Si- transfer in Hot Metal

- Silicon monoxide gas is produced by “in-situ” reduction of silica in coke ash/ raw materials during combustion of coke in front of tuyeres

$SiO2$ + C (coke) $\rightarrow$ SiO (g) + CO (g)

- Silicon monoxide gas thus generated further reacts with carbon of the descending metal droplets in the region between bosh and the hearth with contact of hot metal

C (metal) + SiO (g) $\rightarrow$ Si (metal) + CO (g)

Possible means for suppression of Si - transfer in Hot Metal

- Lowering of RAFT for retardation of $SiO_2 \rightarrow SiO$ reaction
- Decreasing activity of SiO_2 in the slag by increasing the slag basicity
- Increasing hot blast pressure so as to suppress the generation of SiO to get low silicon
- Optimal control of heat input by adjusting burden ratio
- Keeping stable hearth condition

Possible means for suppression of Si - transfer in Hot Metal .. contd.

- Complete drainage of liquids from fces (Dry casts)
- Decrease tap to tap time to minimise the liquid /metal contact time
- Optimization of slag chemistry with respect to MgO and other constituents to maintain desirable slag viscosity
- Controlling burden distribution along with maximizing prepared burden, raceway parameters and gas distribution
- Optimizing stock level, reducing hanging, scaffolding and controlling alkali burden by periodic alkali flushing thereby achieving stable operation of blast furnace

Mechanism of S - transfer in Hot Metal

- Sulphur enters in the furnace through coke
- Sulphur in the coke ash is in the form of CaS, which reacts with SiO to give SiS in the combustion zone

$$CaS\ (\text{coke ash}) + SiO\ (g) \rightarrow SiS + CaO$$

- Some CS may also form by the reaction

$$CaS\ (\text{coke ash}) + CO\ (g) \rightarrow CS + CaO$$

- The contribution of other sulphur bearing volatiles are negligibly small

Possible means for suppression of S - transfer in Hot Metal

- **Sulphur transfer in hot metal can be suppressed by**
    - *Increase in temperature*
    - *Increase in V-ratio (CaO/SiO2) of slag*
    - *Increase in MgO content in slag*
    - *Low Al2O3 content in slag*
    - *Lower oxygen potential i.e., lower FeO content in slag*
    - *Higher slag volume*

Techno – Economics

At a glance, the effect of various operating parameters on blast furnace performance indices in terms of production & coke rate are as follows:

Change in Operating Parameters	Change in HM Production, %	Change in Coke Rate, %
1% decrease in furnace stoppages	+1.3	- 0.5
100^{o}C increase in hot blast temp.	+ 2.0	- 2.0
0.1 atm increase in top gas press.	+ 1.0	- 0.5
1% decrease in coke ash	+ 2.0	- 2.0
1% decrease in M_{10}	+ 2.0	- 2.0
1% increase in Fe in burden	+ 1.5	-1.5
1% decrease in burden fines (-5mm)	+ 1.0	- 0.5
10% decrease in not-dry working	+ 0.3	- 1.0
1% decrease in off-rod working	+ 0.1	- 0.2
10% increase in sinter in burden	+ 2.0	- 2.0
1% O_2 enrichment	+ 2.0	-
10 kg decrease in lime stone rate	+ 0.4	- 0.3

Best Ever Performance: Production

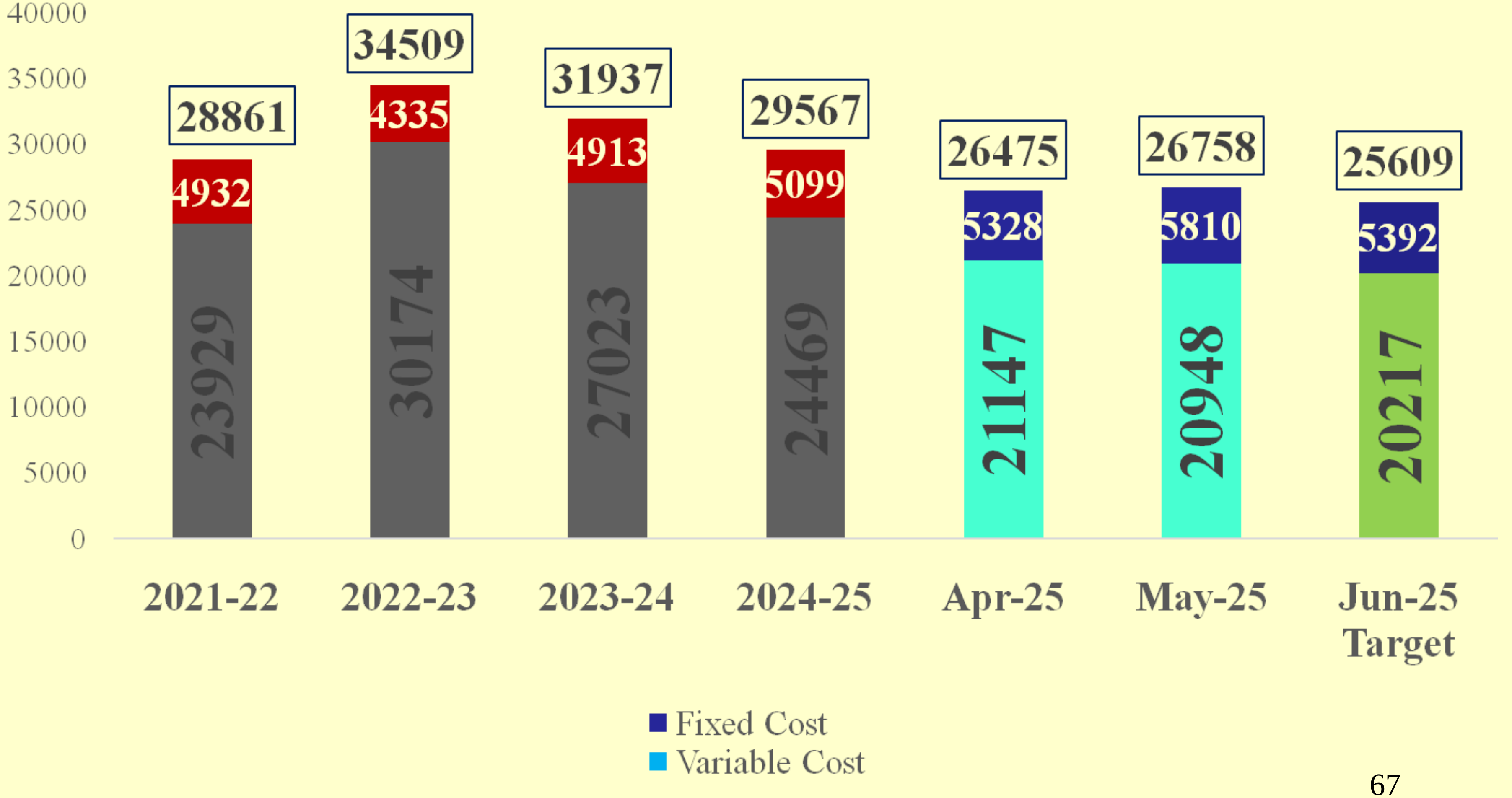
Description		BF#2	BF#3	BF#4	SHOP
Daily		2856	2950	3352	8435
		24.03.2022	06.06.2018	01.04.2022	22.03.2025
Monthly		79684	76588	88958	240073
		Mar-2022	Apr-2023	Mar-2023	Mar-2023
Yearly		843033	838280	972129	2570060
		FY 2022-23	FY 2018-19	FY 2023-24	FY 2023-24

MAJOR TECHNO-ECONOMIC PARAMETERS: 2025-26

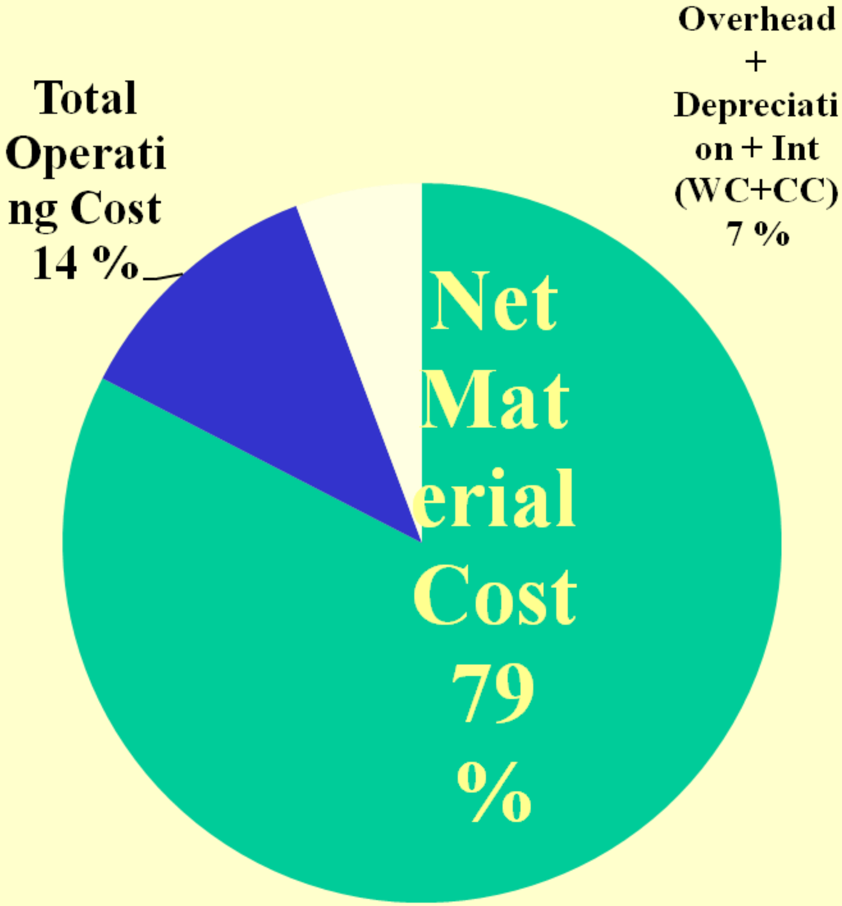
PARAMETERS	UNIT	2024 - 25	2024 - 25	2025 - 26
		ABP	ACTUAL	ABP
Productivity,	t/d/m3	1.95	1.792	1.97
COKE RATE	KG/THM	440	456	441
CDI RATE	KG/THM	74	65	78
NUT COKE RATE	KG/THM	22	22	19
FUEL RATE	KG/THM	536	544	538
SINTER IN BURDEN	%	70	69.1	69.2
SCREEN LOSS	%	11.0	10.7	11.0

COST TREND – Hot Metal

(Rs/T)



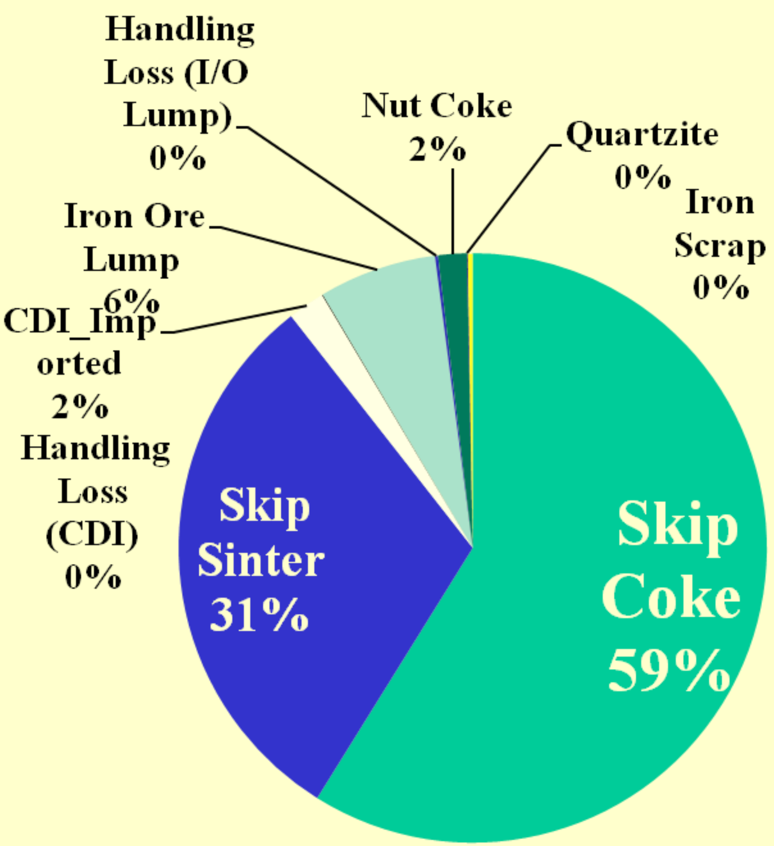
Breakup of Cost of Hot Metal in May - 2025



Cost of Hot Metal (Rs/THM)	
Net Material Cost	21202
Total Operating Cost	3670
Overhead + Depreciation + Int(WC+CC)	1886
Total Cost of Hot metal	**26758**

Goss Material Cost (Rs/THM)

May - 2025



Material	Unit Price	Impact on cost of hot metal	Usage
	Rs/T	Rs/THM	Kg/THM
Skip Coke	27833	13555	487
Skip Sinter	6059	7040	1162
CDI_Imported	13989	467	33
Handling Loss (CDI)	13989	10	1
Iron Ore Lump	2887	1487	515
Handling Loss (I/O Lump)	2887	38	13
Nut Coke	14890	360	24
Quartzite	1772	13	7
Iron Scrap	20948	62	3
Total Material Cost		23031	

Credit for By products and Scrap		
BF Gas	1206	1423
Iron Scrap	20948	94
Granulated Slag	1000	253
BF Slag	186	19
Molten slag	440	40
Total Credit		1829

Net material Cost (Rs/THM) : (23031 – 1829) = 21202

Safety Hazards

- **Handling of Liquid Iron/Hot Metal**

- **Handling of CO gas**
- **Handling of Dust**
- **Work at Height**

Safety concern

<u>To avoid any mishap at shop, must be concern about –</u>

- Use of safety appliances / PPEs
- Use of heat prone jacket in heat prone area /cast house.
- Use gas mask while working in gas prone area.
- Use gas monitoring.
- Use your common sense.

Conclusion :

- **Increase of productivity to 1.4-2.1 t/m^3/day and decrease in coke rate to 400-500 kg/thm has been achieved in SAIL blast furnaces in the recent past by improvement in raw materials quality, process intensification measures and use of modern equipment/gadgets.**

- **SAIL blast furnaces has still a long way to go to meet the challenge of performance of European blast furnaces**

Performance of European BF

- **Productivity : 2.7 – 3.5 t/m^3/day**
- **Coke rate : 300-325 kg/thm**
- **Coal injection: 200-250 kg/thm**
- **Slag rate : 175-225 kg/thm**
- **Sinter/Pellet in burden : 90-95%**
- **Si in HM : 0.2-0.25%**

सेल SAIL