Blast furnace productivity and the influencing parameters

Blast furnace (BF) is a process of iron making. During mid eighties BF technology got established and left behind other technologies of iron making. Since then continuous developments are taking place in this technology to make it more productive and economical. Even today it is offering very stiff opposition in the development of alternative iron smelting processes.

The blast furnace is a counter current reactor in which the reducing gas is produced by the gasification of the carbon of the coke with the oxygen of the hot blast injected via tuyeres in the lower part of the furnace. The reducing gas flows upwards reducing the iron bearing materials charged at the top of the furnace.

Blast furnace process consists of a multivariate system which is subjected to a large number of inter-influencing variables affecting the performance of the blast furnace. It is necessary to isolate the inter-influence of the variables to understand the role played each variable on the performance of the blast furnace. The performance of a blast furnace is determined by many parameters out of which productivity is the major one.

The blast furnace productivity is the quotient between possible gas throughput per unit of time and required specific gas generation for one ton of hot metal (HM). Hence an increase in the productivity on the one hand requires an increase in the gas throughput, which implies improvement in the furnace permeability and on the other hand a reduction in the specific gas requirement, which means a reduction in the specific consumption of reducing agent. Blast furnace productivity is usually expressed in tons of hot metal produced/day/Cum of working volume. In some countries, in place of working volume, useful volume is considered. There are many factors which influence the productivity of a blast furnace. Major amongst them are described below

- Raw materials – Besides fuel/reducing agent, there are basically two types of major raw materials are charged in a blast furnace.

1. The first one is iron bearing materials which are sinter, pellets and calibrated iron ore (CLO). The higher is the iron (Fe) in these materials means lower gangue material is going inside the furnace which needs to be fluxed for slag formation. Hence higher Fe content helps in the reduction of slag volume. As per thumb rule 1 % increase in the Fe content increases the BF productivity by 1.5 %n to 2.5 %.
2. The second raw material is the different type of fluxes (lime stone and dolomite). Lime stone and dolomite when charged in the blast furnace gets calcined inside the blast furnace. This calcination reaction needs heats which result into increase in the specific fuel consumption. If these fluxes are charged through sinter or pellets then the calcination reaction takes place outside the blast furnace and the blast furnace working volume is more effectively used by the iron bearing materials. This in turn improves the blast furnace productivity. Generally reduction of 100 Kg of flux in the burden improves the BF productivity by 3-5 %.
3. For achieving higher productivity in a blast furnace it is essential that burden material provides high permeability and homogeneity across all furnace temperature and reaction zones. Further the burden material should have high reducibility to promote short retention time. Burden materials should also have low content of tramp elements such as zinc, lead and alkalies to avoid process disturbances.

4. Blast furnace productivity greatly depend on the quality of sinter. Sinter should have optimum grain distribution, high strength, high reducibility, high porosity, softening temperatures greater than 1250 deg C, constant FeO content in the range of 7-8 % and constant basicity.

- Fuel/reducing agent – Two types of fuels/reducing agents are used in the blast furnace. These are metallurgical coke (BF coke) which is charged from the top and pulverized coal/ natural gas/ coke oven gas/oil/coal tar which are injected at the tuyere level.

1. BF coke influences the productivity of BF in many ways. High ash content in coke means charging the furnace with more slag forming materials which are to be fluxed to form slag. This results into higher slag volumes. As per thumb rule 1 % reduction in the ash content of the BF coke results into improvement in the BF productivity by 0.8 % to 1.5 %. Other properties of the BF coke which affects the productivity are CSR (coke strength after reaction), CRI (coke reactivity index), and micum indexes (M40 or I 40 and M10 or I 10) (Fig 1). These parameters affect the permeability in the stack and the mechanical strength of the coke at the tuyere level. M40 represents crushability of the coke and M10 wearability. Higher values of CSR and M40 and lower values of CRI and M10 result in improvement in the BF productivity. Sulphur content of the BF coke has also got its affect on the BF productivity. A decrease of sulphur content of coke by 0.1 % improves the BF productivity by 0.7 % to 1.2 %.

2. Fuel (pulverized coal/ natural gas/ coke oven gas/oil/coal tar) injected at the tuyere level is normally accompanied by oxygen enrichment of the hot air blast. The injection of oxygen to the air blast reduces the specific flow of the gas causing a reduction in the top temperature and an increase in the adiabatic temperature (RAFT) in the tuyeres. These effects are compensated by the injection of substitute fuel. Thus a combined injection of oxygen and fuel at the tuyere level increases the productivity of the blast furnace. Every 1 % of oxygen enrichment of hot blast improves the productivity by 2-0 % to 2.5 %

- Control of burden distribution plays an important role in the improvement of the productivity of the blast furnace. The burden distribution control ensures a stable burden descent, adjusts the flow of gasses in the wall (this avoids high heat loads without generating inactive zone) and helps in achieving a good solid gas contact.
- Decreasing the silicon content in the hot metal has a positive effect on the blast furnace productivity. Decrease in the silicon content is achieved due to better ore-coke relation and movement of cohesive area downwards. This generates a lower volume for the transfer of silicon to the hot metal. Decrease of silicon content in the hot metal by 1 % improves blast furnace productivity by 4 % to 12 %.
- Properties of slag has considerable effect on the blast furnaace productivity. Lower specific volume of slag of lower viscosity improves the productivity of the blast furnace.
- Tapping practice has an importanrt role to play in achievement of high productivity in a blast furnace. Good tapping practice will involve good tap hole length, timely opening of the tapping, control of tapping speed, proper hearth drainage and closing of tapping after furnace becomes dry. Quality of tap hole mass is very importanr for good tapping practice.

- Automatic process control improves the furnace productivity since it minimize consumption of reductant, avoids furnace process disturbances such as hanging, slipping, scaffolding, gas channeling etc through an immediate counteraction by the system, stablizes hot metal and slag parameters etc. the effect of automatic process control on the blast furnace productivity is in the range of 3 % to 5 %.
- Blast temperarure is other parameter which influence the productivity of the blast furnace. Blast furnace productivity will improve by 1 % with the blast temerature increasing by 100 deg C.
- High top pressure also improves the productivity of the blast furnace. With every increase of top pressure of the blast furnace by 0.1 Kg/Sq cm there is an improvement in the productivity of the blast furnace in the range of 0.5 % to 1.5 %.
- Decreasing of fines content in the charge materials improves blast furnace productivity in the range of 0.4 % to 0.7 %.

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Problems in Iron and Steel Industries

1) Capacity Utilisation is not properly done. Compared to the different countries in world, Iron has very less Production efficiency, In SAIL based company the production is only 80-90%. The maximum efficiency is attained in TATA Steel which is 100-105%.

2) Man power requirement is more than other countries

3) Energy consumptions is much higher than other countries

4) Quality of raw material is poor

Production:
India - 74 million tonnes
China - 700+ million tonnes
World - 1500+ million tonnes

Thus the overall cost is more

⇒ Indian Raw material (T-455)

Indian iron ore → 60% Tfe (Total fe)

Pure Ironoxide (Fe_2O_3)

$Fe_2O_3 = 2(Fe) + 3(O)$
$= 2(56) + 3 \times (16) = 160$

$\therefore$ $60\%\ TFe = \frac{112}{160} \times 100 = 70\%$

$40\%\ TO_2 = \frac{48}{160} \times 100 = 30\%$

If 70% → 100

$\therefore$ 60 — ?

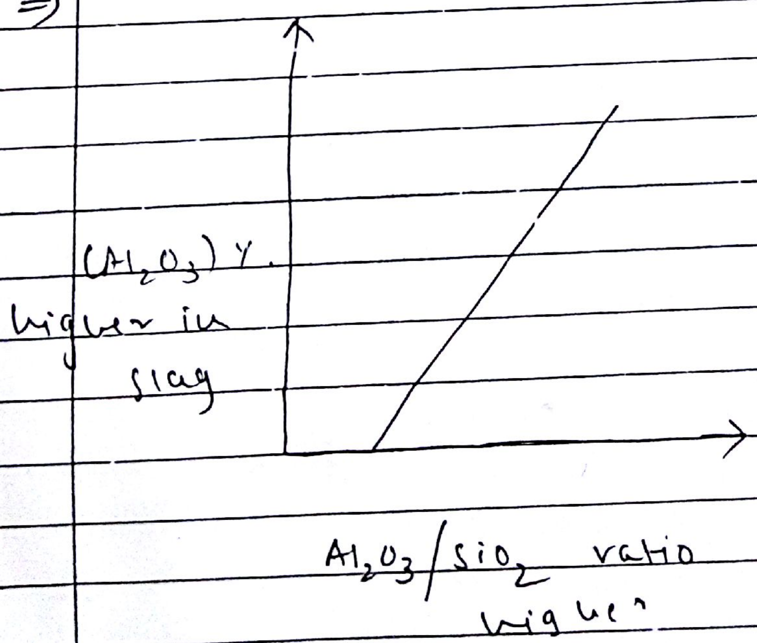
Therefore TFe % = 85.5%

Iron ore has 60% TFe

but there is a major drawback of Iron ore with respect to gangue content

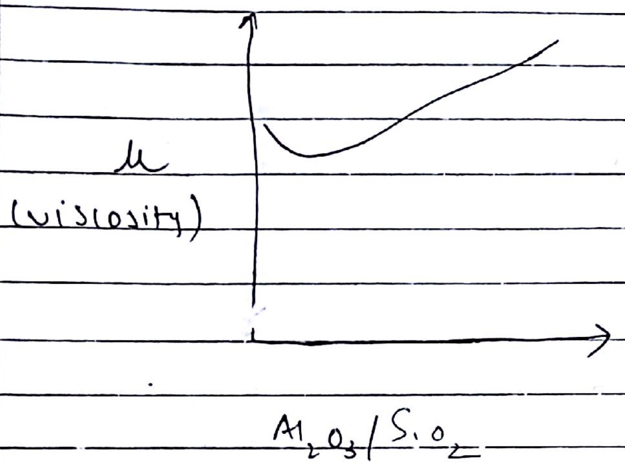
That is $\frac{Al_2O_3}{SiO_2} > 1$ (2–3.5)

⇒



Due to this, viscosity of slag increases which leads to more energy / fuel required to melt & increase purity

Also this leads to higher volume consumption in the furnace & decreases the useful volume of the furnace for metal.



⇒ Indian coal

Indian coal have high ash content and due to this process cost increases

If ash increase 1% then the coke rate increases upto 1-2% coke rate and leads to ~~that~~ decrease in productivity upto 2-3%.

~~And~~ this leads to composition problem which leads to other defects i.e. increase in phosphorous and sulphur content

Increase in gangue content by 1% will lead to increase in coke rate by 1.75%.

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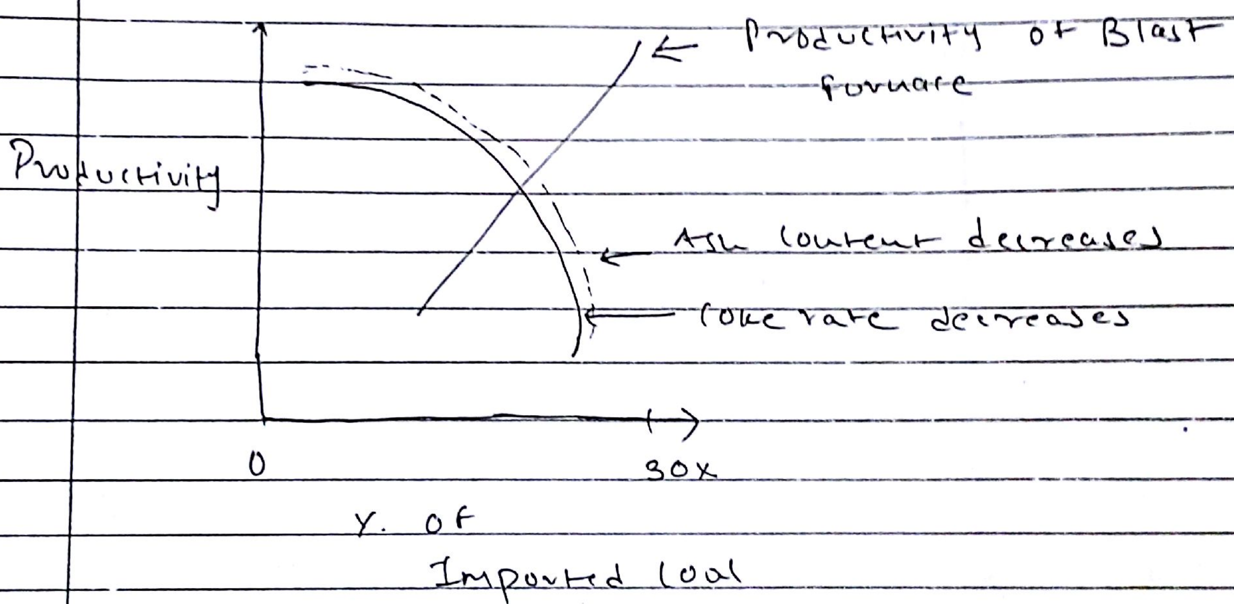
Remedy:-

To overcome this problem coke from Indian origin is mixed with imported coke which have ash content lower than 10%. Approx 30-40% imported coal is mixed during the coal blending.

∴ Overall ash content decreases



⟹ Question arises, why not to use 100% imported coal.

Indian ore has $\frac{Al_2O_3}{SiO_2} > 1$; to compensate ratio to become below 1, SiO_2 from ash content may work but if 100% imported coal is used very less ash content

SiO_2 will be less so the ratio <1 is not possible

To make 100% imported coal, external SiO_2 content should be added

Indian limestone should contain <1-2% SiO_2

Productivity in India 1-1.25 t/m³/day

* Improvements & Developments in BF

The Basic aim is to increase the Productivity and also to economically produce the hot metal

And also to reduce coke rate & increase the productivity

1) Hot-metal production rate should be increased to 8000-10,000 t/day

2) Coke rate from (700-800 kg/thm) decreases to (450-470 kg/thm)

Coke - 270-275 kg + coke in tuyeres - 175-225 kg

Productivity level - 2.5-3 t/m³/day

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3) F/C availability range 95-98% for charge materials

4) low Si in hot metal (< 0.2%) & In india (0.75-1.25% Si)

5) life of refractory lining of Blast furnace → 15 years or more

6) Better quality of coke is used for low ash content

7) Use of agglomarates like sinter or pellets

8) High yield limestone & Dolomite with low alkali content

9) Slag rate should be low
(↓ ash content
↓ Gangue content)

⇒ Developments

1) large capacity furnaces

2) Better Prepared Burden

3) Better distribution of charge in the Furnace

4) B/F gas injection in the stack region

5) Higher Blast rate and temperature

6) Humidify the blast

7) Fuel injection

8) Oxygen enrichment of the blast

9) lime dust injection through the tuyeres

10) High Top pressure

2,4
bell-less

=> Useful volume

1000 m3 → 5000 m3

In vizag steel 3200 m3

Daily Production

1930	1000 t/day
1950	2000 - 3000 t/day
1970	6000 t/day
Nowadays	12000 t/day

Hearth dia

5.6m - 1925-30
8.9m - 1950-55
12m - 1970
Now 15m (Japan)

Production capacity

0.8 - 1.0 t/m3/day
>2.5 t/m3/day

=) Increase the quality of coke.

larger the BF it requires better quality of coke

1) Better properties & blending of coke

2) Use of low volative coal

3) Preheating of coal blend before charging

4) faster rate of carbonisation at higher temp

5) Faster briquetting of charge

6) Manufacture of formed coke

7) Mech. stabilisation of coke oven batteries

8) Dry quenching of hot coke in N_2 or CO_2 atmosphere

9) Compacted coke oven charge by stamp charging

⇒ Imported coal

Ash content

Japanese	coal	<10%
Australia	coal	11-30%.
Canadian	coal	5-7%.
Indian	coal	19-25%.

⇒ Formed coke:-
Synthetically prepared coke from the non coking coal

Procedure:

Non-coking coal
↓ Pyrolysis | In an inert atmosphere (700-800°C)
→ Char
→ Volatile matter
  → liquid (tar)
  → gases

Char + Binder (tar) + Flux (optional)
↓ catalyst
Briquet —curing (100-200°C)→ Formed coke

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→ **Advantages of formed coke.**

1) Use of non coking coal

2) Uniform size & shape (Briquetting)

3) Good permeability

4) Addition of flux help

→ **Disadvantages of formed coke**

- Very costly material

- Production cost high

  Coke - 3200 Rs / ton

  Formed coke - 4700 - 5000 Rs / ton

3) Better distribution of Burden materials

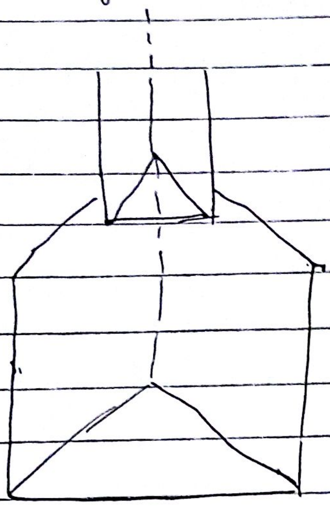
BF counter current solid-gas flow

So materials should have good permeability

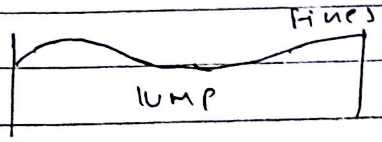
Rate of production & Rate of Reduction

Rate of heating

→ 2-bell charging system

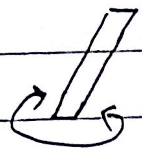


$\rho_{ore} = 5.6\ g/cc$
$\rho_{coke} = 1.5\ g/cc$
$\rho_{LS} = 3.0 - 3.5\ g/cc$



- NKK's four bell top
- Bell-less top system

→ Chute



17·7. Charging Devices for High Top Pressure

In spite of the developments in successful throttling and pressurising the big bell hopper, the conventional McKee-type two bell charging system poses serious problems of gas leakage through the joints of bells and improper sealing. Leakage here causes abrasive cutting and soon destroys the sealing function of the big bell with its hopper. This not only restricts the top pressure but may even in due course of time nullify the benefits gained through the high top pressure operation. The blast furnace designers should provide equipment to operate effectively at top pressure upto 3 kg/cm^2 gauge with adequate life. Many devices, including hard facing of the bell and its hopper set, have been mooted and tried in practice. However the problem of excessive wear on seats and rapid deterioration of effective seal could not be satisfac-torily solved. The developments have been rapid after adopting the design philosophy of separating the two functions of charge holding and distribution on the one hand and gas sealing on the other. In essence it means that hard surfaced seats are used for bells, gates, chutes, etc, which handle flowing materials while soft seats, kept out of way of flowing materials, are used as seals. Based on the above philosophy a number of designs for top charging, to whatever extent feasible, have been developed. The development of top charging devices, while catering high top pressure maintenance, have always kept the goal of achievement of better distribution of charge in the furnace, as was its primary aim earlier, as an equally important function. A few of these modern designs, especially developed for high top pressures have been described below.

17·7·1. Tops With Only Bells

In these designs the functions of distribution of charge and ensurance of pressure tight gas seals are both achieved by the use of only bells. The conventional McKee top design is improved while retaining the concept of revolving distributor to distribute the charge more evenly. The typical examples are the Paul-Worth/CRM top and the NKK's four bell top.

Paul-Wurth/CRM Top

A line sketch of this design is shown in Fig. 17·10. The big bell arrangement is same as in the McKee top while an additional small bell, called the seal bell, is attached just below the charge small bell. Since the sealing bell is different the small bell alongwith its hopper can rotate to receive the charge at various points along its periphery. The sealing bell fits tightly to the large bell chamber and hence the small charge bell is outside the purview of high top pressure. In operating this device the charge is initially put in the small bell hopper, receiving the skips at various preset angles. During charging the seal bell is closed. After one charge is put in the small bell hopper the seal bell is lowered to break the seal. The charge small bell is then lowered to drop the charge on the big bell. The distance to which the burden small bell is lowered, from the seal bell, is adjusted such that the sealing surface remains out of the trajectory of sliding material and it is thereby protected. After dropping the charge the small bell is raised to close its hopper and then the seal bell is raised to seal the big bell chamber, the pressurisation and depresurisation of which is carried out as described earlier.

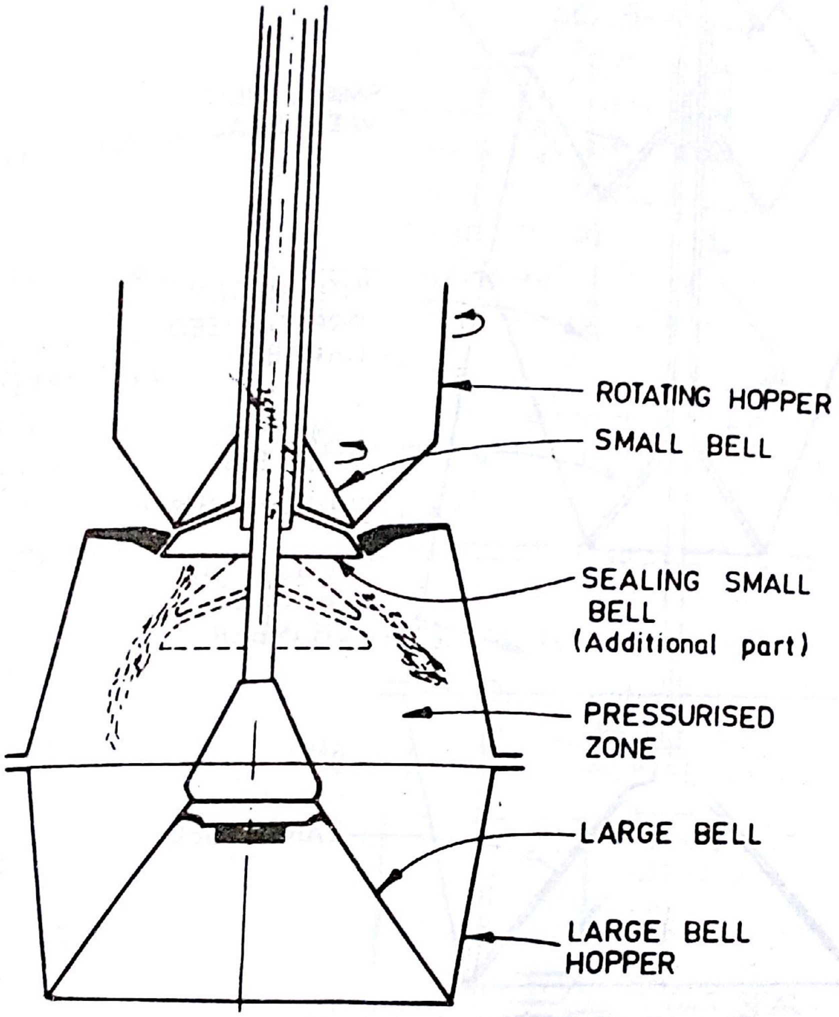


Fig. 17·10. Paul-Wurth/CRM top.

NKK's Four Bell Top

A line sketch of this design is shown in Fig. 17·11. In this two additional bells are interposed between the rotating small bell and the large bell. The middle bell holds the charge and also seals the large bell hopper for high top pressure. The small bell carries only the seal and because of which the large bell chamber is always under pressure and hence its wear is relatively much less. The CRM large bell, for certain proportion of time, is under full furnace pressure which eventually can cause severe wear but such is not the case in the NKK four bell design.

Both the CRM and the NKK top designs are such that the charge particles may find way in the sealing area, causing some gaps through which high pressure gas leaks with resultant wear. These designs therefore cater equipments for rapid changing of the bells alongwith.

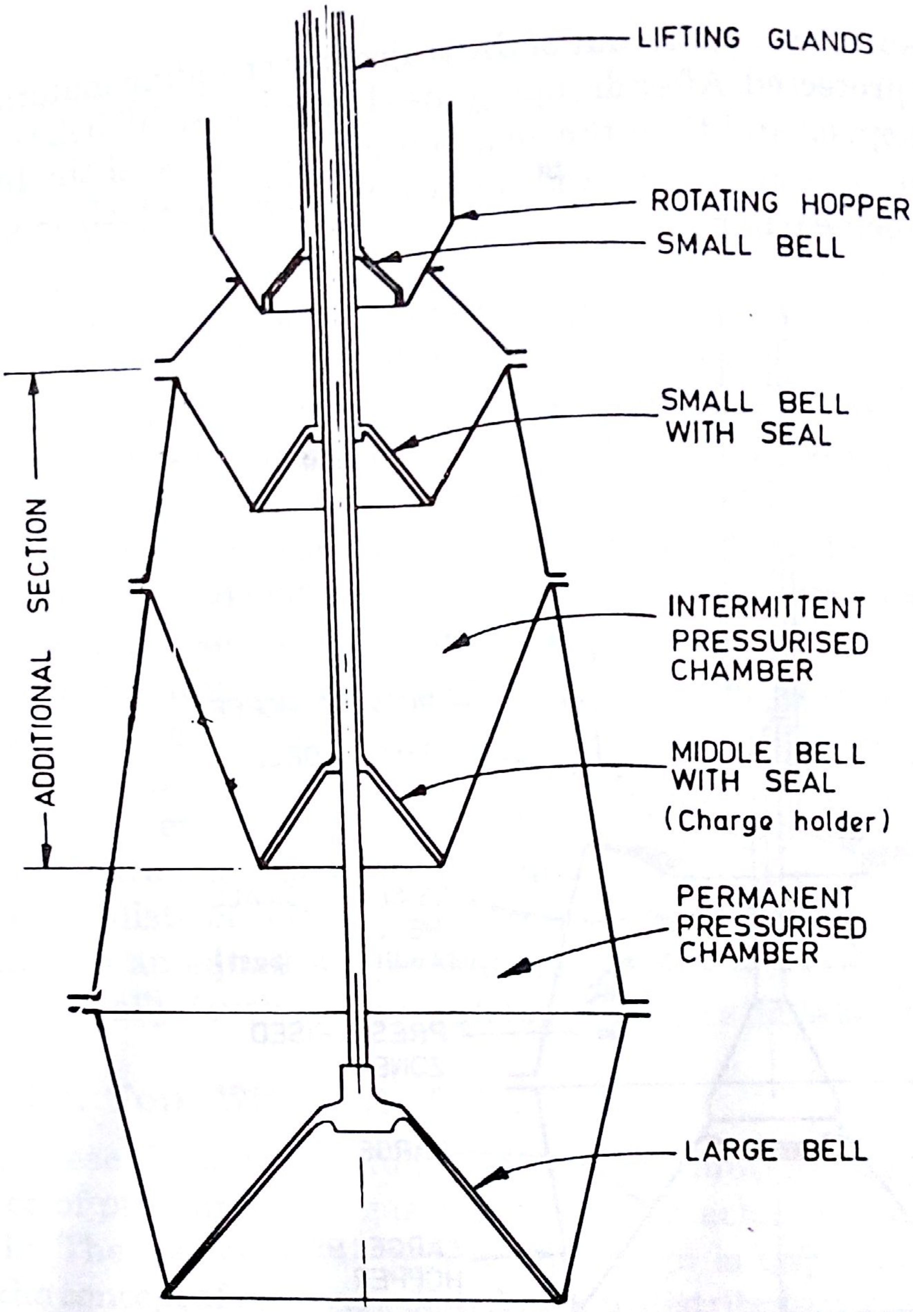


Fig. 17·11. NKK's four bell top.

17·7·2. Tops with Bells and Valve Seals

The IHI-top as shown in Fig. 17·12, the Yawata-top as shown in Fig. 17·13, the McKee Head Wrights on top as shown in Fig. 17·14, and the Demag-top as shown in Fig. 17·15 are the best known design in this group. Valve seals are provided to obtain effective seals. These designs can be adopted on even the existing furnaces with minimum of disturbance to the large bell, top structure, gas mains and other existing parts of the furnace top structure. The seals are so provided that the large bell chamber can operate permanently pressurised to about the furnace pressure, thereby minimising the wear on the large bell seatings. The gas seal valves swing down and out of the way while dropping the charge and then quickly return to close and form a gas tight housing around the bell.

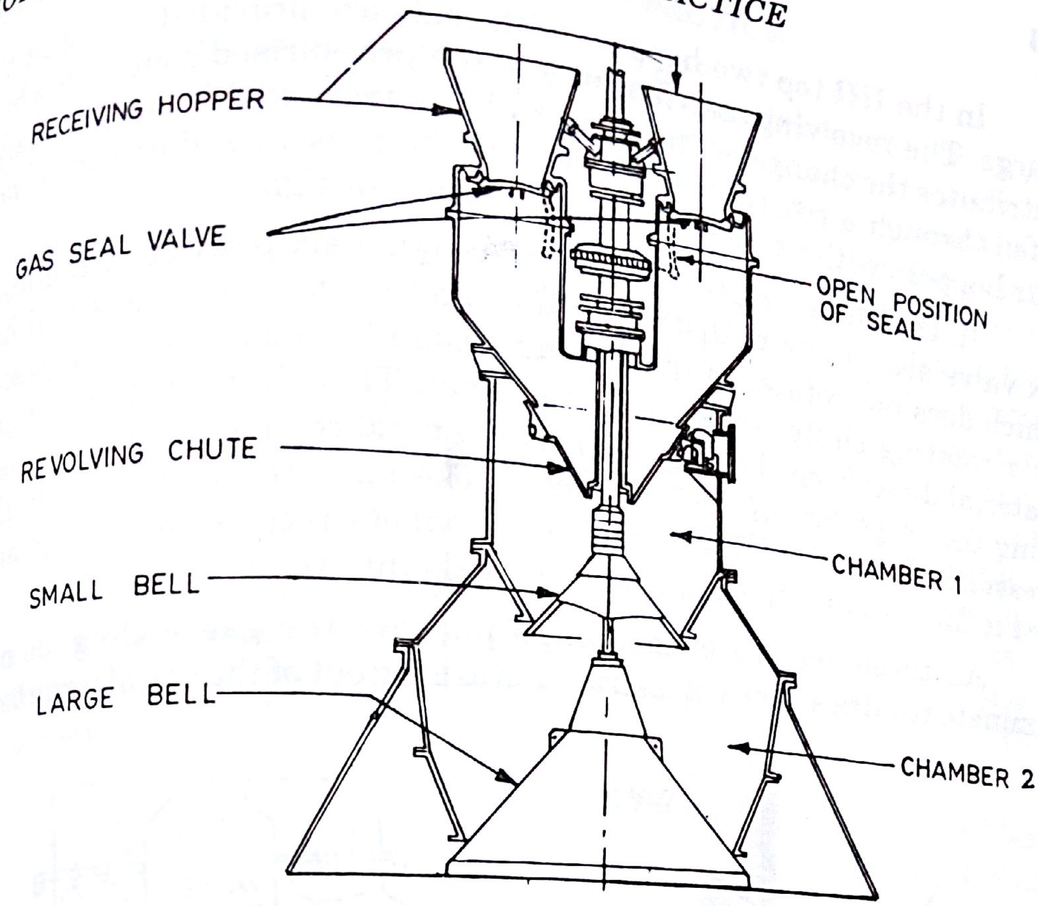
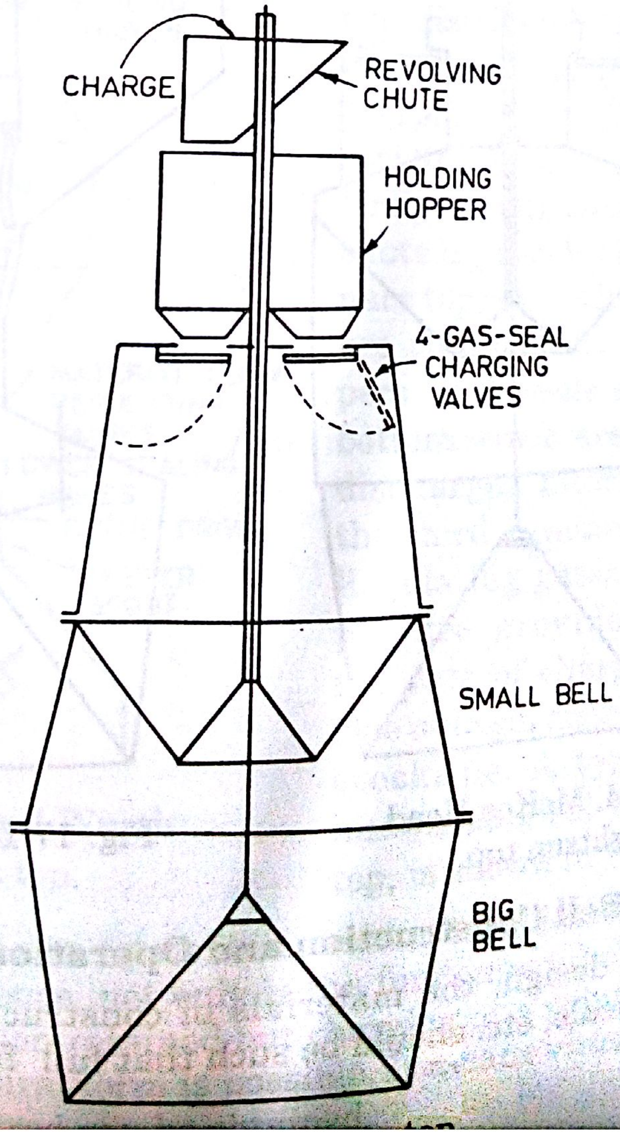


Fig. 17·12. IHI-top.



In the IHI top two hoppers with seals are provided to admit the charge. The revolving distributor is in the pressurised zone and which distributes the change on the small bell. Contrary to this design, charge is fed through a rotating chute, outside the pressurised chamber, *via*. four hoppers with valve seals in the Yawata design.

In the McKee Head Wrightson design a six position chute feeds six valve seal inlets to distribute the charge evenly on the small bell which does not rotate. In the Demag design the small bell is replaced by a rotating chute under the lower seal. This chute distributes the material directly on the large bell. The central rod for raising and lowering the large bell is replaced by a yoke operated from outside the pressurised chamber. Two valve seal hoppers receive the charge and feed it through another pair of lower seals into the rotating chute.

All these designs even though improve the gas sealing, do not eliminate the drawbacks of distribution arising out of the use of large bell.

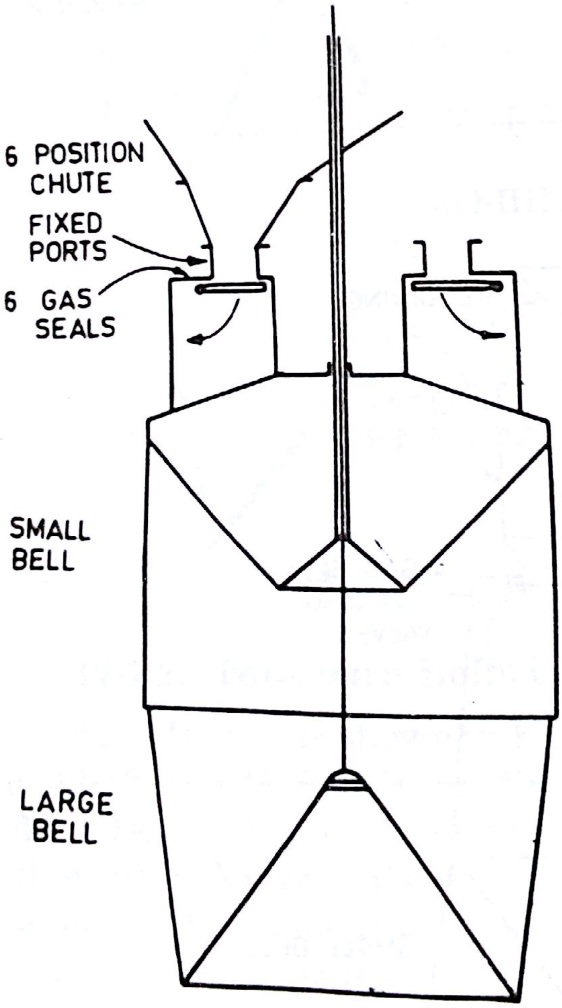


Fig. 17·14. McKee Head Wrightson top.

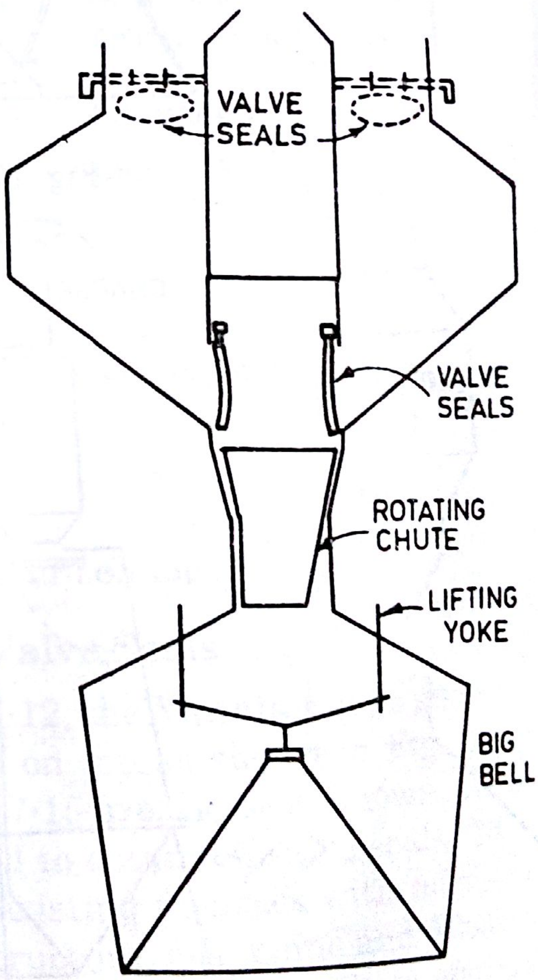


Fig. 17·15. Demag top.

17·7·3. Bell Construction and Operation

The top design, the materials of construction of particularly the bells, the seals, etc. should be such that full furnace campaign is obtained without major intermediate repairs and replacements. In particular, the large bell and its seat should at least last for the whole campaign since with increasing size of the furnace the problems associated with its manufacture, installation and maintenance are escalating rapidly. On a modern furnace with hearth diameter of 14 m the large bell diameter might be around 7·5 m and it would weigh nearly 200 t. Such a unit is lifted into position and if intermediate repairs, during the furnace campaign, are required special hoists are required to lift such a bell at nearly 80 m above the ground level, let alone the actual repair problems. Hence the design as a whole should be sound enough to last as long as possible, the objective being full campaign of the furnace. The latest trend therefore is to dispense with the bells altogether or use smaller bells and additional mechanical devices to distribute the charge uniformly in the furnace at high top pressure with minimum of maintenance problems. These are discussed in the following section.

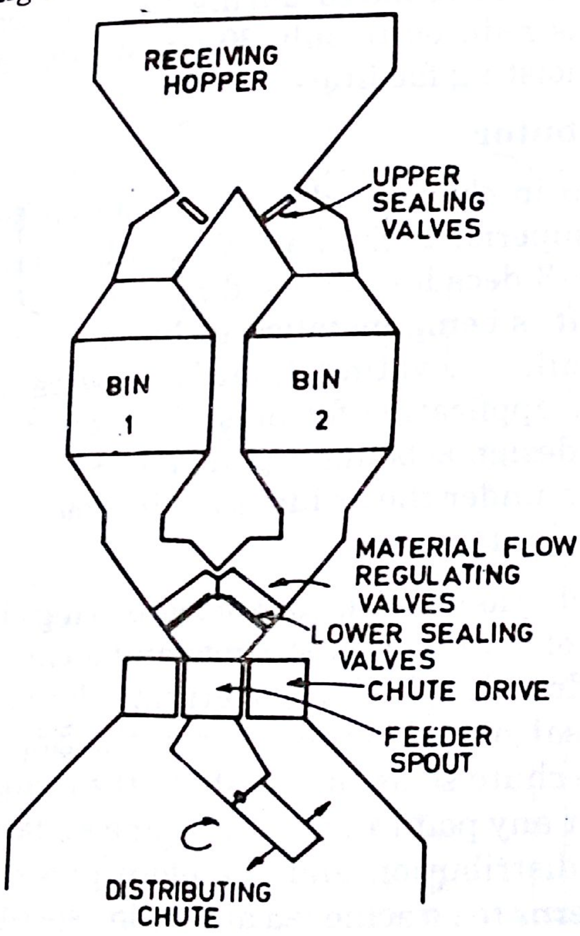


Fig. 17·16. Paul-Wurth bell-less top.

17·7·4. Top With Only Valve Seals (No Bells) [72]

This is a unique design in which the large bell is replaced by a distributor chute which has no sealing function whatsoever. The problems of distribution associated with large bell are entirely eliminated. A rotating chute is provided inside the furnace top cone. All the materials are charged *via*. holding hoppers, with seals at its top and bottom which are charged and discharged alternately, while the third is acting as a spare. Regulating gates in each hopper are provided to control the rate of charging to facilitate uniform distribution on the stockline. A typical design, known as Paul-Wurth belless top, is shown in Fig. 17·14.

Since the chute can rotate in a circular or helical fashion and at variable angle and hence, not only is the fundamental characteristics of large bell distribution retained but charging at a point (stationary), in sequence and in spiral form is possible. It means virtually any type of distribution as desired can be obtained.

The advantages claimed are :

1. With three bunkers in the design the performance of this top has been at least equally satisfactory and comparable to any of the available alternatives.

2. Greater charge distribution flexibility with a small amount of mechanical equipment.

3. Access to any part of the system is far easier and hence one or two parts can be changed even during normal shutdown of the furnace.

4. Wearing parts are rather few and inexpensive and hence these can be regularly changed during routine maintenance.

5. The total overall height of the top can be much less.

6. Substantial reduction in investment for top construction.

7. It gives more operational safety and easy control over varying charging patterns.

Even if the whole bunker is to be replaced during the furnace campaign the total maximum lift is reduced to only 30 t resulting in reduced requirements in terms of hoisting facilities.

17·7·5. Gimble Top Distributor

This is the latest innovation in charging devices employed for blast furnaces. It is claimed to be superior to the Paul-Wurth Bell-less Top which dominated for nearly 2-3 decades superseding the earlier McKee Two-Bell charging device. It is being installed in India for the first time on BF-C of Tata Steel while renovating it, fairly drastically, in 2007. This will be the first ever application for blast furnace. It is costlier than the bell-less top. The design is being supplied by Seimens VAI. It has already proved its worth under the arduous environment of Corex, Finex and direct reduction plants.

It has a conical charge distribution device supported by rings in a *gimble arrangement*. It consists of several robust rings and a chute. This tilting chute is driven by hydraulic cylinders, operating through shafts, connecting rods and universal joints in order to drive the gimble rings. This allows any angle of the chute so as to distribute the charge as per any specific requirements at any point in the stock-line surface. This gives very precise material distribution and therefore provides almost innumerable charging patterns to be achieved at varying speeds. In fact the charge particles are literally placed wherever required, on the stockline, by this device.

17·8. Higher Blast Temperature and Driving Rate

Since part of the fuel energy in the outgoing gases is pumped back into the furnace in the form of preheated blast, the thermal efficiency of the process could be improved by increasing the rate of

17·9. Oxygen Enrichment of Blast

For every unit weight of coke burnt at the tuyere by the air blast, nearly 4–5 unit weight of nitrogen of the blast are also heated to nearly 2000°C. Although large amount of furnace gases are beneficial for heat transfer in the stack, the presence of 79% nitrogen by volume in the blast restricts the temperature generated in the combustion zone. This temperature can be increased by decreasing the nitrogen content of the blast *i.e.* by oxygen enrichment of the blast. An enrichment of only 2% (by weight) oxygen reduces the nitrogen burden by about 4 units per unit weight of coke and a higher temperature would be possible. There is however a limit to which higher temperature in front of tuyeres is desireable since any excess over that causes bridging and sticking of the stock and a higher silicon content in the pig iron. Oxygen enrichment is therefore beneficial for producing foundry iron or for smelting ferro-alloys like ferro-manganese. For basic pig iron production, excess silicon content is detrimental and hence any excessive heat release at the tuyeres must be absorbed by some other beneficial endothermic reaction. Use of oxygen enrichment upto 25% oxygen in the blast has been found to be advantageous, if it is balanced by adequate humidification. Higher level of oxygen enrichment poses several other problems which weigh more than the advantages and hence not used in practice.

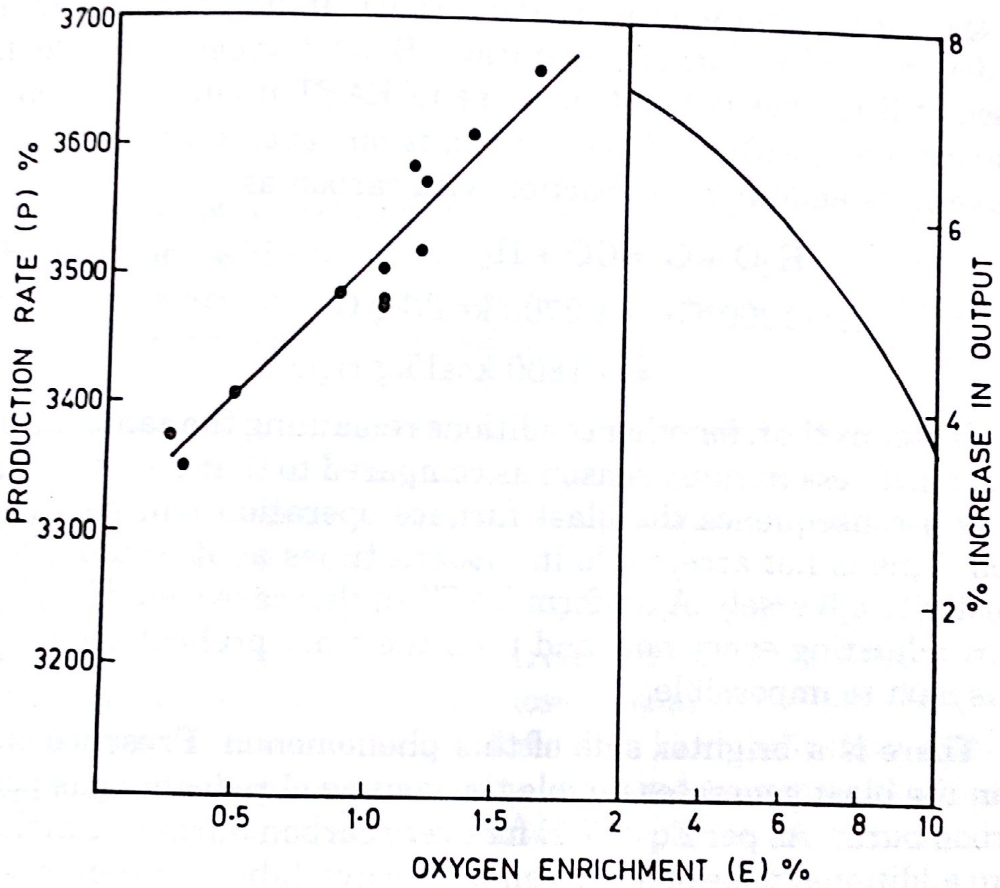


Fig. 17·18. Effect of oxygen enrichment of blast on furnace productivity.

Combined use of oxygen enrichment and humidification of blast offers a unique method of blast furnace process control. Control of blast furnace by coke rate is not effective before few hours after the change whereas variation in oxygen enrichment and humidification can control the temperature almost immediately; it can also be monitored continuously. The cost of oxygen however should permit its use in a given setup for it may otherwise work out to be costly.

For every percent increase in oxygen content, increase in production rate of about 3–4% can be obtained with a marginal saving in coke rate. The saving in coke rate is due to the cracking of moisture giving rise to hydrogen which acts as a reducing gas up in the stack. The increase in output with oxygen enrichment is shown in Fig. 17·16. It also shows that the percent returns decreases with increasing enrichment.

17·11. Fuel Injection

The necessity to adopt fuel injection in a blast furnace arises from the fact that coke is not only costly but it is becoming more and more scarce and hence it should be replaced by other cheaper and readily available fuels, as far as is feasible, to run blast furnaces without impairing their efficiency. Also all coke furnace operation is affected by a higher flame temperature and formation of an inactive zone near the furnace walls. Auxiliary fuel injection tends to set right this and lead to more stables furnace operation because of additional control parameters available to control characteristics of race way. The heat producing function of coke is partially replaced by injecting auxiliary fuels in the tuyeres. They are therefore readily available for combustion in the combustion zone in front of the tuyeres. Either solid, liquid or gaseous fuels can be injected in the tuyeres. Solid fuels coal, either pulverised or in the form of slurry. Liquid fuels are either light oils, naptha or more predominantly heavy oil. Natural gas or coke oven are the gaseous fuels that could be readily injected in the tuyeres. The choice of the type of fuel for injection almost entirely depends on its availability, economy and feasibility of injection. Oxygen enrichment of the blast alongwith fuel injection is required to achieve full advantages of fuel injection.[78]

It has been already discussed in Chapter 4 that coke has two major functions inside the BF. One is as a fuel and the other is as a spacer to maintain permeable charge which allows the gases to pass through it smoothly. The function of coke as a fuel is therefore minimized, to the extent possible, by using substitute pulverized, liquid or gaseous fuels. Fuel is burnt in front of the tuyeres to generate the required thermal energy and to compensate that lost in decreasing the coke charge. The substitution of coke is also done at this level only by injecting pulverized/granular coals or gaseous/liquid fuels like natural gas/heavy oil through the tuyeres. This is one of the most potent ways of reducing coke and replacing it with cheaper and available fuel. The basic requirement is that the injected fuel must burn completely and to that extent only the replacement is possible. Any excess injection can cause damage rather than benefits by disturbing the bosh reactions and melting rate.

All coke operation is affected by higher flame temperature and formation of an inactive zone near the furnace walls. Auxiliary fuel injection tends to set right this and lead to more stable furnace operation because of available additional control parameters to control the raceway.

The choice of the type of fuel to be injected almost entirely depends on its availability, economics of its use and feasibility of injection. From this point of view only fluidized fuels can be injected. Fuel injection is fully exploited when adopted along with oxygen enrichment and humidification the blast.

The actual amount of fuel injected in any furnace in any plant depends on many factors. On some furnaces individually upto 100 kg oil or 200 kg pulverized coal or 150 Nm^3 natural gas have been successfully injecated and the efficiency has come upto expectations. The replacement ratio, kg of coke saved divided by kg of fuel injected, depends on the practice, quality of fuel and effectiveness of furnace control.

These injections affect the following furnace parameters:

(1) Flame temperature

(2) Bosh gas composition and volume

(3) The top gas temperature and CO/CO_2 ratio and hence the efficiency

(4) Operational efficiency *i.e.* the proportion of direct and indirect reduction

(5) Slag volume and its basicity

(6) Overall production efficiency

The influence of such injectants is shown in Table XVII-4[79]

Table XVII-4[79]

Effect of various injectants on BF conditions

Parameter	*Change*	*Change in flame Temp., °C*	*Change in coke rate, kg/thm*
Natural gas	+ 100 kg/thm (+ 132 Nm^3/thm)	–513	–82·6
Anthracite coal	+ 100 kg/thm	–162	–92·0
Heavy volatile Coal	+ 100 kg/thm	–218	–76·1
Heavy fuel oil	+ 100 kg/thm	–321	–98·4

The demand on heat is a net result of heat generated by its burning and consumed for ash dissolution in slag and for any moisture, taking part in the water gas reaction. Similarly the net resultant gases at the tuyere shall take part in further reactions as they rise. It is necessary to compensate this loss in flame temperature by increasing the hot blast temperature, and if that limit is already reached then, by other means like oxygen enrichment, blast temperature and so on.

More efficient reducing gas is generated at the tuyere area by disintegrating moisture into hydrogen via a reaction of the type:

$$H_2O + C = H_2 + CO \qquad ...(17\cdot1)$$

or by

$$CH_4 + 1/202 = 2H_2 + CO \qquad ...(17\cdot2)$$

These are endothermic reactions and are possible only when surplus heat is available at the tuyere area.

The replacement ratio for oil is of the order of 0·9-1·1 kg of coke per kg of oil. For natural gas this ratio is 0·75 kg per Nm^3 of gas. These are for blast temperature of 900-1300°C. Natural gas or oil genertes hydrogen, as product of burning, which is a better reducing agent in the stack as compared to CO. The H_2/H_2O ratio in the top gas does not indicate its utilization efficiency because only 4% H_2 is used for reduction. It therefore improves the productivity. Natural gas does not contribute to slag formation and the replacement ratio is also good and, hence is preferred. It has resulted in 6-10% saving in coke and increase in productivity by about 0·5-2·0% in a specific case.

Pulverised or granular thermal coal has also been routinely injected in the range of 50-200 kg/thm. The aim is to go upto 300 kg/thm in near future. The cost of coke can be brought down by 10-15%. If pulverized then 80% of coal is ground to less than 75 micron and dried to a level of less than 1% moisture. The system of injection should ensure that the desired amount of coal is injected within expected accuracy. It is claimed that the performance of injecting even granular coals (sandy in nature) is adequate. It is preferred since the cost of pulverization is far more than that of granulation. However pulverized coal injectionis more popular.

The limit of injecting PC is dictated by a parameter called '*Coal Combustion Potential*' defined as

$$\text{CCP} = \frac{\text{Oxygen supplied to raceway } \left(\text{Nm}^3/\text{hr}\right)}{\text{Oxygen required to burn injected coal } (\text{kg/hr})}$$

The ideal theoretical value of CCP is 1·0. This consumption of oxygen takes into account the humidification of the blast as well as the oxygen enrichment, since all these go hand in hand to obtain the required conditions. The reduction of coke rate by various such parameters is assessed before hand and is shown in Table XVII-5.

Table XVII-5

Assumed norms for calculating the changes in coke rates

Parameters	*Change in coke rate kg/thm*
1. Sinter +10%	−2·2
2. Blast temp +1°C	−0·14
3. High Top Pressure + 1kg/cm^2	−11·55
4. Central Working Index +1	−54·34
5. Humidity +1 g/Nm^3	−0·88
6. Coke ash +1%	+10·00
7. Oxygen enrichment +1·0%	−6·82

This is quite independent of the efforts to raise the hot blast temperature to its maximum.

The replacement ratio (RR) of the order of 0·8-0·9 has been achieved. Ash content of the coal affects the RR adversely as will be obvious from Table XVII·4. The efficiency of replacement is not just limited to its complete burning. It should also thereby result in improvemnts in bosh and stack reactions as well as heat transfer and rate of melting. One of the chief problem to be faced in PCI is its effect on *deadman*. In case of incomplete combustion the PCI can give rise to suit or char formation and may decrease the permeability of the deadman. This can have disastrous effects on hearth behaviour.

17·11·1. Pulverised Coal Injection[48, 80]

Injection of gaseous or liquid fuels through the blast furnace tuyeres for part replacement of coke was relatively easier from the point of view of engineering involved therein. But the success at these led to attempt injection of coals as these are readily and cheaply available at most places. Coal is injected through the tuyeres in cold condition (non pre-heated). It is therefore bound to influence the flame condition in front of the tuyeres. Almost all modern blast furnaces all over the world use coal injection as a matter of routine practice. The best performance has been to inject 100-200 kg/thm with resultant coke rate falling to as low as 300 kg/thm. Tata Steel commissioned coal injection unit on their 'F' furnace in March, 1991. This system is capable of injecting 150 kg/ thm.

The trials have indicated that the rate of coal injection is influ- enced by a variety of parameters which have to be adjusted to maintain or improve blast furnace performance.

Coal injection in the existing design increases the tuyere velo- city beyond the optimum 205 m/sec and as a result the tuyere diameter had to be increased from 125 mm dia to 150 mm dia to obtain optimum velocity.

Injection rate was influenced by blast pressure and blast vo- lume. For pressure below 10 psi coal could not be injected. For pressure in the range 10–15 psi injection rate was halved and for pressure above 15 psi full injection was possible. This practice eliminates the possibi- lity of tuyere blockage. Above 15 psi pressure change in blast folume in per- centage was matched by the same percentage change in the injection rate for better performance. Necessary changes had to be incorpora-ted to obtain uniform injection through all the tuyeres. The injecting lance angle had to be adjusted to 11° for efficient operation of the lance.

The coal quality has a dominant influence on the furnace per- formance. Maximum combustion of coal in the raceway is desirable. The ash content should be low and that no deposition takes place in the lance or the tuyere region. The melting point of the ash should be as high as possible but not that much so as to influence the melting chara- cteristics of the slag inside the furnace. Since coal is injected in cold condition it has a cooling effect on the raceway. Increasing injecting rate has increasing cooling effect and unless counteracted it can have adverse effect on furnace performance. Usually a high injection rate, in this respect, is compensated by proportionate increase in oxygen en- richment of the blast to obtain optimum RAFT.

The size of coal injected does influence the furnace performance. This can be studied by experimenting on coal combustion. It was found at Tata Steel that with 80% coal of –200 mesh poses no problems with respect to its size. Although a very wide range of volatile matter coal have been studied and found to be giving good results it is better to have V.M. in the range of 20–30%.

The calorific values also have an influence on RAFT. Coals with C.V. in the range of 6–7000 Kcal/kg have been found to pose no specific problems. The burden charging sequence had to be adjusted suitably to suit coal injection.

For normal practice nearly 50 kg/thm coal could be injected with replacement ratio of 0·9. With 1·4% oxygen enrichment the same could go upto 70 kg/thm with replacement ratio of 1·08. In 1994 coal injection was fitted on Tata Steel 's 'D' furnace and injection rate of 100 kg/thm with 1·5% oxygen enrichment was possible for replacement ratio of 1·0. Their 'G' furnace is latest and modern. There, 130 kg/thm could be injected with 3·0–3·5% oxypgen enrichment with a replacement ratio of 1·3. The coke rate came down to 450-500 kg/thm.

In all these the RAFT was maintained at around 1900°C. The productivity remained unchanged. As regards quality of hot metal, sulphur remained unaltered but silicon went up from 1·0 to 1·36 and which had to be brought to 1·0 by oxygen enrichment.

Tata Steel's have provided coal injection facilities on their 'D', 'F' and 'G' furnaces. Whereas on 'A' and 'B' tar injection facilities have been provided.

17·12. Lime Injection

The origin of lime injection lies in controlling the quality of bosh slag. The quality of slag produced in the bosh region has direct bearing on the productivity of the furnace. If this slag is more viscous then it affects the acro-dynamics adversely. As a result the productivity falls. Increase of bosh-slag viscosity by even 1 poise may decrease the productivity by about 0·5%.

Flux is added in the BF charge to flux the gangue of the iron ore/sinter and the ash of the coke. The entire flux requirement is met by adding limestone as a separate constituent in the charge or via sinter in part or full. Where coke ash is very high like that of in India the bulk of the slag is formed out of the ash of the coke. Major portion of this ash is released only after the combustion of coke in the tuyere region. It means that the lime proportion of the slag formed before bosh region is far too large than required to maintain the desired basicity. In other words the basicity of the slag that is formed before bosh region is very high and consequently its viscosity will be very high. Such highly viscous slag poses several problems. Firstly it trickles slowly through the coke bed. Secondly it interferes with the aerodynamics adversely and decreases the rate of upward gas flow and thereby reduces the rate of reduction of ore and rate of heating of the charge in the stack. It means directly a decrease in the productivity.

In fact the lime required to flux the ash of coke is ideally required at the tuyere level. If it can be provided at that region, then the slag formed up in the stack and in bosh will be almost the same type of slag as aimed at the end. This will not be more viscous than necessary and hence will readily trickle through the coke bed.

High ash content affects the BF operation adversely as can be seen in Table XVII-6.

Table XVII-6

Effect of variation of ash content of coke

Coke % Fixed carbon	*Ash*	*Limestone rate kg/thm*	*Coke Rate kg/thm*	*Slag rate kg/thm*	*Production rate t/day*
76	22	416	874	510	1346
72-58	26	497	972	610	1276
68-58	30	600	974	737	1197

All such slag related problems can be solved to a great extent if part of the total lime requirement can be injected through the tuyeres in a way similar to fuel injection. It will be available where it is needed most, *i.e.* to flux ash of coke. If this is resorted then part of the flux is added, more often via sinter and the rest via injection through the tuyeres. In that case no free limestone may be required in the charge material. It is the powdered lime that is injected through the tuyeres and not limestone powder. It means the heat requirement for its calcinations is met outside the BF using any alternative fuel rather than coke. The coke rate would thus also decrease proportionally.

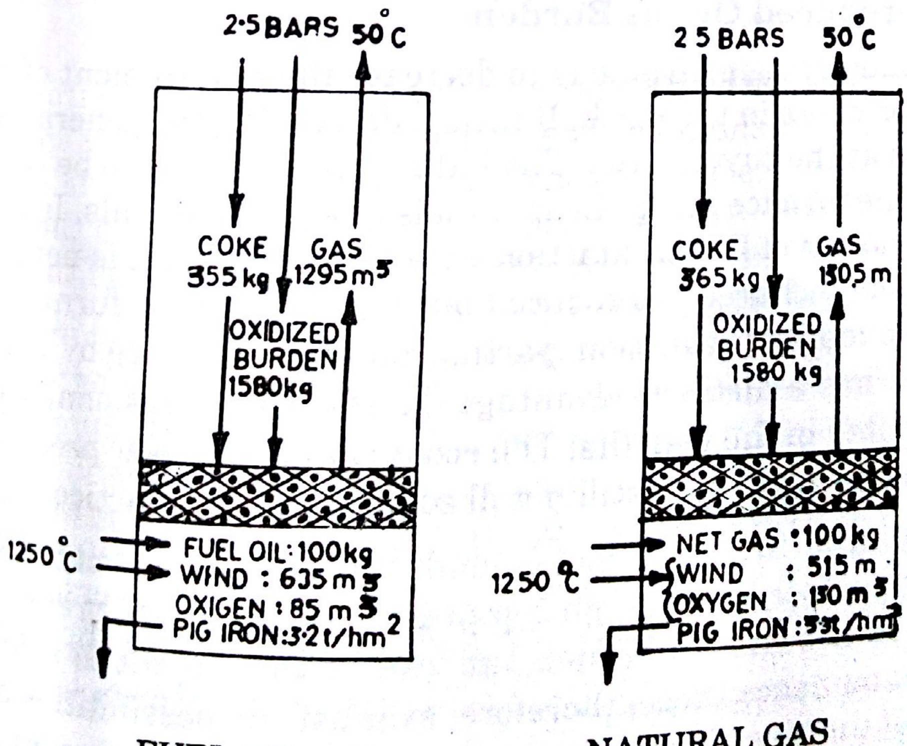


Fig. 17·19. Blast furnace operation with auxiliary fuels injected at the tuyeres with fully oxidised burden.[57]

Full scale industrial trials on a small blast furnace of the Kalinga Iron Works, Barbil, under the direct supervision of SAIL, R and D Division were carried out and have borne very good results. The same has therefore been recommended to be applied for normal blast furnaces. The advantages claimed are:

(1) It improved the bosh permeability due to improvement in mass flow rate in the bosh region.

(2) It decreased the viscosity of the slag in the bosh region with all the attendant advantages.

(3) It decreased metallurgical coke requirement in the blast furnace due to decrease in limestone-flux charged from the top.

(4) It increased the productivity of the furnace.

(5) It controlled the basicity of slag and thereby improved the quality of hot metal.

(6) The slag rate is marginally reduced.

(7) Metal sulphur content was somewhat lower.

(8) On the whole the furnace operation was more smooth with decreased hanging and slipping.

It is however surprising that it was not adopted on large furnaces even in India where the coke ash problem was very seriously affecting the productivity. In fact it is now recommended for it adoption in MBFs to decrease their coke requirements and improved productivities.