Technological Changes in Blast Furnace Iron Making in India since Last Few Decades

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Abstract: ***India as a 4th steel producer in the world has resulted due to adaptation of new technologies in the field of iron and steel making since from the last few decades. Keeping in view for increasing quality of hot metal and its production rate, efficiency of the furnace operations with keeping clean environment, adaptation of few newer technologies and practices in the area of Blast Furnace iron making are selected for this paper. Selected areas are described with salient features such as burden preparation including different raw materials such as iron ore, coke, lime stone, sinter/pellets etc, burden distribution including bell less top charging design, furnace structure design, cast house design and practice with multi tap-hole and runner, furnace cooling system design changes with staves cooler, use of carbon refractory materials in hearth lining, hot blast quality improvement, efficiency enhancement of gas cleaning system, automatic process control and taking care of environmental challenges. The present paper deals with the salient features of the above said changes adopted for the improved productivity and efficiency of the furnace operation in the field of Blast Furnace iron making process.***

Keywords: Blast furnace, Indian Iron Making, technological changes, productivity

1. Introduction

India is the 4th largest steel producer in the world. India produced 76.715 million tons of crude steel in the year of 2012 where world steel production was 1510.223 million tons against 72.7 million tons of steel in the year of 2011 where world produced 1490.060 million tons of steel. World Blast Furnace Iron (BFI) Production in the year of 2012 was total 1100.674 million tons by 38 countries in which India produced 42.258 million tons occupying also 4th position in the world, whereas World Direct Reduced Iron (DRI) Production in the year of 2012 was total 55.361 million tons by 11 countries in which India produced 19.799 million tons occupying 1st position [1] (Figure 1). It is being expected that Indian steel production will grow 10% during 2010-2013 [2]. For achieving this demand India is also increasing their internal generation of steel. For better quality of hot metal (steel), increase the use of quality burden by applying effective technology for its beneficiation and for achieving lower cost of steel production, increasing the efficiency of furnace production by introducing newer technology. But to sustain into international market, Indian steel maker also have to produce low cost and high quality steel. For those reasons major changes are to be adopted in technologies and their uses.

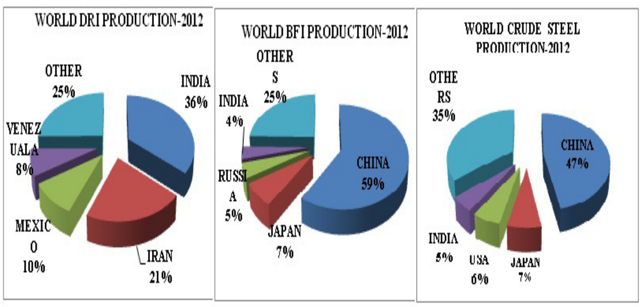


Figure 1: Crude steel, BFI and DRI production in world

The Indian steel industry can be divided into two distinct producer groups: Major producers: Also known as integrated steel producers (ISPs), this group includes large steel producers i.e. Steel Authority of India Limited (SAIL), Tata Steel, Rashtriya Ispat Nigam Limited (RINL), Jindal Vijaynagar Steel Limited (JVSL), Essar Steel and Ispat Industries. SAIL, TISCO and RINL produce steel through the blast furnace/ basic oxygen furnace (BF/BOF) route that uses iron ore, coal/coke as the basic input mix. Essar Steel, Ispat Industries employ electric arc furnace with sponge iron, melting scrap or a mix of both as input. ESSAR has installed 1.73 MPTA capacity blast furnaces in December, 2010. JVSL uses COREX, a revolutionary technology using basically iron-ore and non coking coal [3]. As present, Blast furnace technology is the only commercialized and successful technology for iron production, which is being used as a chief raw material for production of quality steel, rather than any other process developed till date. From year 1880 to about 1950, most of the developments were observed in the field of furnace design and its engineering. There were no significant changes were happened in the process technology because of, a) Lack of knowledge in the area about physiochemical and metallurgical aspects of the blast furnace reaction. b) Application of metallurgical thermodynamic and kinetics of the reactions were not known, c) The blast furnace was like a 'blackbox' and its internal state was not known except some information from inputs and outputs. But letter on around 1930, knowledge of metallurgical thermodynamics was came into notices, and in 1950, the knowledge of kinetic and transport phenomena was came up. At the last a major breakthrough was occurred at the end of 1950, when a running blast furnace was rapidly chilled by blowing cold nitrogen through its tuyere in Japan.

After chilling, furnace was sectioned and samples were collected from different zone for physical and chemical examination [4]. After a span of time, several changes based on the previous experiences were made in the field of Raw Materials, Burden Distribution, Blast Furnace Design, Furnace Cooling Systems, Furnace lining refractory Material, Water Cooling System, Hot Blast Quality, Gas Cleaning System, Process Control, Casthouse Operations and also in Environmental impacts. Above changes were described briefly in the following sections.

2. Major Fields of Developments

2.1 Raw Materials

2.1.1 Bed permeability

For the better gas/solid reaction, better bed permeability required inside the reactor. It will be affected by the materials as well as its size fractions [5]. In early age only lump materials (Iron Ore/charcoal/coal/Limestone) of wide size ranges were used in the Blast Furnaces as a feeding material. It was observed that the bed permeability inside the furnace was not so good, because of the less utilization of reducing gas inside the reactor which was visualized by the analysis of blast furnace top gases. To avoid these problems, raw materials are being started to screen out to meet the narrow size range as feed materials.

2.1.2 Iron ore

India has sixth largest reserves of iron ore in the world. World's reserves of iron ore is around 150 billion tons having 47% average Fe contain. The proven reserves of hematite iron ore in India are around 12 billion tons including which high grade (>65% Fe) about 13%; Medium grade (62-65% Fe) about 47% and rest are low grades. The magnetite deposit in India is almost 11 billion tons in western region [6]. Due to existence of ore quality, suitable communication is required before its use in the blast furnace. To increase the metallic concentration and to remove gangue material, efficient mineral beneficiation process was developed.

According to Indian Bureau of Mines, Nagpur ,the total output of 208 million tones of ROM in which, lump iron ore constituted 82.2 million tones or about 39.5%, fines 125.1 million tones or about 60.2% and concentrates 0.7 million tones or about 0.3% of the total output of iron ore lumps [7]. During mining operation of raw materials generates almost 10-15% fines /slimes every year. These huge amounts of fines were not used in early days. But now a day it is being given preferences for obtaining iron rich ore fines. For this improvement in forced to the industry for the grinding of iron ore for better liberation of the iron content. Over a period of time so many companies have adopted suitable beneficiation process to use these huge amounts of losses to agglomerate and produce sinter and pellets to use its valuable Fe content as Blast Furnace feeds. -6 mm to 100 mesh size ore is being used to produce sinter. And below 100 mesh fines are being used to form pellets.

Use of Sinter and pellets inside the Blast Furnace as a feed material ,decreases the cohesive zone thickness due to narrow softening melting ranges as well as gives better bed permeability due to its porous structure. Today's trend to use fluxed sinter/pellets which gives the less energy requirement inside the Blast Furnace due to limestone got calcined outside the Blast Furnace during making of fluxed sinter/pellets [8]. 1% increase of sinter in burden can reduce coke rate up to 1.5 kg/THM. Pellets give better bed permeability due to spherical shape and better gas-solid contact for its highest surface area/volume ratio, but cracks develop for its high swelling index during its reduction stage which could be nullified by using self reductant pellets where low grade coal is being used for the same [9]. Alkali loading inside the blast furnace (at the temperature ranges between 1173K-1373K) [10] also can be minimized by using pellets / sinters, due to heating at above 1373K during hardening of pellets or sintering , alkali vapors comes out during making fluxed sinter or pellets. Because of several advantages to use of sinter and pellets in the Blast Furnace, use of lump ore is being drastically decreased from 100% to 35% at 1970 and around 10% at present condition [11].

2.1.3 Coal

India is the third coal producer in the world after china and USA. Indian coal reserves 7.6% of the world and out of this 15% is coking coal, from which coke is being produced [12]. Indian coke is not suitable for Blast furnace use due to high ash content, and low rank of coal [13]. Indian coal has adverse washability for which after extensive crushing and washing, it is difficult to remove one third of ash from it. By increasing 1% of ash, coke rate is being increased to 23-25% as per Indian condition. Good coking coal but high in S content coal reserves is being found in North Eastern region (especially Assam) of India [14]. For using of these high ash and high sulphur coal, some techniques are being developed to increase the coke quality such as blending, pre heating of coal to increase bulk density resulting to improve coke strength [15]. Selective/two stage crushing, stamp charging is being used to increase the room temperature as well as high temperature properties (CRI/CSR) of coke.

2.1.4 Additives

Use of Banded Hematite Quartzite (BHQ)/ Banded Hematite Jasper (BHJ) ore (Approx analysis 35wt%-40wt% Fe, 40wt%-45wt% SiO_2, and 0.5wt%-2.5wt% Al_2O_3) [16] ,in place of quartzite to increase metallic yield and use of low grade iron ore directly inside the furnace without any beneficiation is now become a common practice for Indian Blast Furnaces specially for Mini Blast Furnaces (MBF). Use of Nut /Pearl coke with iron ore charging to decrease coke rate to a certain extent in MBF is now became a practice.

2.2 Burden Distribution

2.2.1 Distribution control

Burden distribution plays an important role as far as stable and efficient furnace operation. Heat transfer and indirect reduction are increase by increasing CO gas utilization efficiency at the furnace top and decreased the reducing agents rate [17]. This phenomenon was explained by means of Fe–C–O equilibrium diagram and Rist diagram [18]. So proper burden distribution plays a vital role for furnace efficiency and control.

In 1880, double bell charging system was introduced with vertical hoist, which was being replaced by skip hoist in 1883. But for uniform burden distribution point of view, it became failure, so that latter on in 1890; Rotary Eccentric Burden Distributor (REBD) is introduced in many furnaces top to eliminate the material preferential segregation problem. Burden distribution inside the furnace was also controlled somehow by introducing moveable throat armor in many furnaces in India. But in 1970 Paul Worth (PW) developed bell less top charging system (Fig. 2) which is now most being widely used in modern Blast Furnace in India [19] .In this system rotating chute is used to distribute materials in place of bell, and preferential distribution can be achieved.

Figure 2: Bell Less Top charging system

2.2.2 Distribution Monitoring

In early days there were no material distribution monitoring systems, to monitor the burden profile, stock line profile etc. So it could not be predicted but now a day's different kinds of monitoring system are being developed such as Heat flux monitoring equipment (under burden probe, over burden probe) to measure the heat flow in different zone of stock line. Profile meter is being using to determine the burden profile distribution inside the furnace from which we can understand the profile of M-shape, V-shape, and W-shape etc [19]. Different thermocouples at throat and stack region are fixed to measure the temperature at periphery of particular zones. Stack pressure monitoring devices are also being used to measure the pressure drop along the furnace height to understand the permeability variation throughout the stack region. Infrared probes are being used to record burden surface temperature.

2.3 Blast Furnace Design

2.3.1 Size of the furnaces

Major drawback of making large size Blast Furnace in India was the use of coke having poor strength as well as lower high temperature properties (Coke Reactivity Index-CRI/Coke Strength after Reduction-CSR). But use of high grade metallurgical coal and its proper blending [15] is being produced coke of high strength with optimum reducibility to decrease the aforesaid problems. As a result of that now working volume of the furnace as well as size are being increased. After increasing the size of the Blast Furnace it has proven that the productivity of the Blast Furnace has increased with decreasing coke rate, corresponding to the total energy consumption.

In the year 1950 average working volume of the furnace was nearly 1000m^3, which is being increased to 4000m^3 in 2010 as shown in Fig. 3. The productivity has reached a level as high as about 3.4 ton/m^3/day; production capacity has reached to 4Mtpa. Coke consumption has decreased to 450 kg/THM corresponding to total energy consumption also decreased to 12.5 GJ/THM with the possibilities of recovering 3-4 GJ/THM from the excess BF gas etc [20].

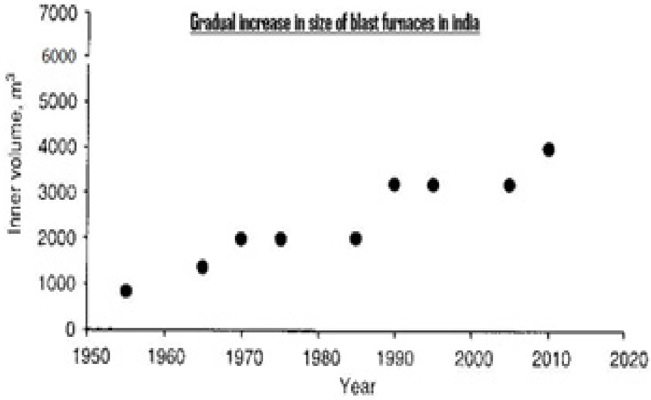


Figure 3: Increase in size of Indian Blast Furnace

2.3.2 Structure

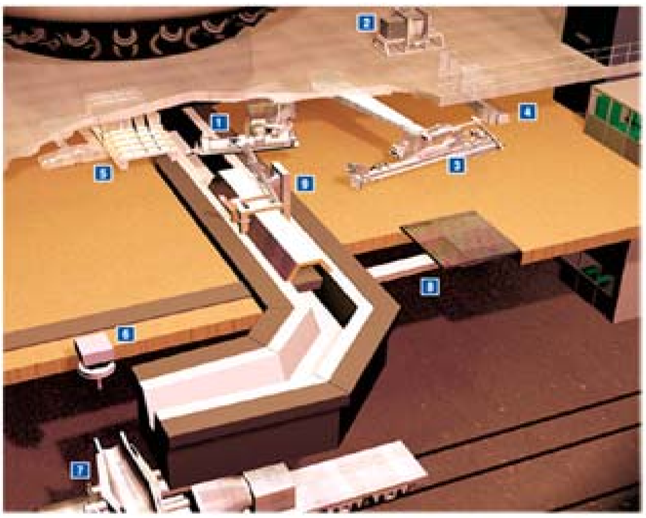
It is clearly accepted that the operation of a larger blast furnace unit is more complex than smaller unit. The larger blast furnaces have modern equipments attached for controlling environment. In addition to the physical aspects of the design (bigger, heavier etc), there are other points to be considered. The furnace shell must withstand high operating and refractory pressures, thermal stresses, burden loads and have numerous cut-outs for internal cooling water systems. The use of instrumental techniques, along with the most sophisticated design practices; ensure that a fully optimized 'thin' shell can be utilized to withstand cracking, even in the latter parts of the furnace campaign. Furthermore, the redesign of the furnace support structure has led to a substantially lighter but equally effective design. Furnace support structure design has adapted to the modern concept of so-called free-standing tower design [21]. (Fig. 4)

Figure 4: Traditional and modern design of Blast Furnace

This arrangement has been proven on many blast furnace installations all over India. The only accepted complication being the introduction of the extra restraint associated with the design standards related to the location of the site, specifically for seismic conditions. The key point to note regarding the design of the blast furnace as the size increases is that plate thicknesses need to be carefully considered to ensure that the structural integrity is maintained, including an allowance for rebuild conditions. The tower design needs to take into account of any additional stresses associated with the support of the larger furnace. As noted above, it is expected that a large blast furnace will operate at a higher level of top pressure than a smaller one. The currently accepted levels of maximum top pressure of around 3 bar is successfully used in many blast furnaces in India which can be accommodated through the application of appropriate design standards to the shell arrangement.

2.4 Casthouse Operations

The cast house is an area where considerable effort was applied to improve the working conditions for the operator (Fig. 5).



1. Clay Gun 2. Clay Gun Loader 3. Taphole Drill 4. Drill Rod Changer 5. Trough Cover Manipulator 6. Level measuring system for torpedo car 7. Tilting Runner 8. Jack Dam Drill 9. Temperature measurement and sampling

Figure 5: Modern cast house design

Modern cast-house design includes flat floors, where the runner is fully covered and is fitted flush with the floor. This allows the safer and easier use of mobile vehicles in the cast-house area. The use of radio controlled equipment and other devices have helped to reform cast house work, and these, along with effective emission control systems, have improved working conditions beyond recognition. As the blast furnace hearth diameter increases there is a consequential need to increase the size of the cast-house. Large blast furnaces should be designed with four tap holes with consideration to the provision of a fifth. With a four top-hole configuration, the cast-house arrangement needs to provide sufficient space for movement around the floor itself [22]. There is no design issues associated with this requirement as long as there is the necessary space provided in the site plan. Increasing the size of the cast-house in terms of floor plan does not represent a radical change in design philosophy that will challenge the furnace designer. An efficient and strictly controlled tapping is necessary for guaranteeing a stable operation and high productivity of the Blast Furnace [23, 24].

One taphole operation was very old practice from where slag and metal were simultaneously come out and separated by skimmer plate. Due to low density of liquid slag almost 2/3 volume of hearth is being occupied by slag itself and 1/3 by metal. When this layer is being increased certain extend furnace irregularities like slow burden descent, fluctuating in burden chemistry etc. problems are being raised. To overcome the problem slag notch is being introduced in furnace, from where after a regular interval of time; slag is being drained to minimize the irregularities.

Due to increasing demand of steel production, hot metal production is being also increased simultaneously. To drain the huge hot metal through a single tap hole, many problems raised such as greater erosion of tap-hole as well as sidewall portion of the hearth near tap hole and lesser runner maintenance time etc. To overcome the above problems double or multi tap hole system introduced (Fig. 6) .It is successfully adopted in many large furnaces in India like TATA Steel, Jindal Steel etc. Use of alternate tape-hole resulting enough time for cooling the top-hole so lesser erosion of refractory observed and maintenance time of the cast house runner increased. Use of alternate opposite side top-hole gives better permeable hearth for flow of hot metal because of lesser erosion of hearth side wall .To avoid delay in maintenance work of cast house runner, some developments occurred. Non drainable runner practice is being adopted where a certain level of metal pool is maintained continuously between two casting intervals from tap hole to skimmer plate. Tilting runner, Removable precast runner assembly is being used in place of conventional fixed runner which is made outside and fixed with temporary fastener for easy joining and removal for maintenance work [25]. Use of overhead crane, mobile vehicles etc, for easier maintenance work is now a common practice in many Indian furnaces [26].

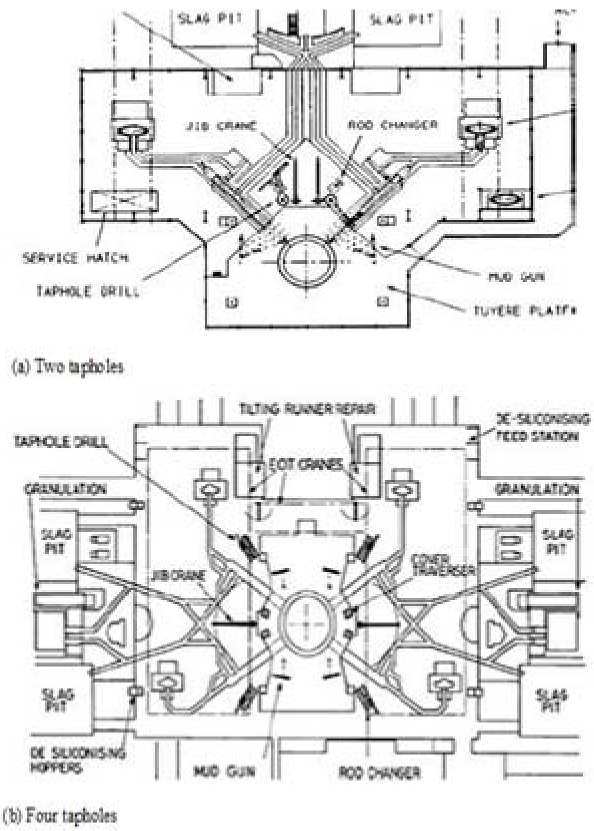


Figure 6: Double and multi tap-hole design

2.5 Furnace Cooling Systems

The traditional method of cooling the furnace shell with cooling plates has now been largely superseded by the use of staves [27]. These allow the furnace profile to be maintained throughout the campaign and hold the overall weight of refractory in the furnace shaft. Also, for the same internal furnace dimensions, the shell diameter is smaller for stave cooled furnaces. In the high heat flux areas around the bosh, belly and lower stack, copper staves are used which provide a greater level of shell protection in these critical areas due to high thermal conductivity of copper [28]. Other less critical areas are cooled by cast iron staves. Water systems are now designed to operate in closed loops rather than open circuits. This allows the chemistry of the cooling water is to be properly maintained so the cooling water inside the closed circuit remains clean and demineralized, ensuring that the heat transfer should be maintained uniform all times. As the furnace size increases the size of the water cooling system also increases proportionally, with the number of staves around the shell being proportional to diameter. (Fig. 7)

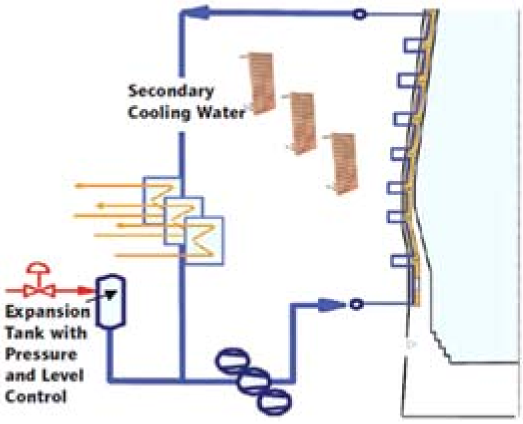


Figure 7: Modern water cooling system in Blast Furnace

The water cooling system demands in terms of circulation. The flow rate is a function of the number of staves and the stave water demand per pipe in the stave. Water flow rates per circuit of the order of 3000 to 5000 m^3/h can be achieved on modern blast furnaces [29].

From a technical point of view, it is being considered that for a large blast furnace, the demand of monitoring performance and operation; require the water system is to split into multiple circuits for different zones of cooling. The instrumentation applied to these circuits will permit adequate heat flux monitoring of different zones of the furnaces. A blast furnace cooling system is not simply a number of pumps and pieces of pipe work. The key of the furnace cooling is the actual element that facilitates the heat exchange within the furnace i.e. the stave or plates. The cooling element design is not sensitive to the size of the furnace. The furnace designer acknowledges that the cooling element size is limited and simply increases the number of elements to adapt to the revised furnace sizing.

2.6 Refractory Material

Extend the life of an important part of blast furnace is to improve the wear resistance of blast furnace refractory bricks. In the 20th century, the early 70's, Spray cooling system was widely adopted for furnace shell cooling. Installation costs were lower but when shell got corroded and damaged, it creates problem. In this cooling method, the life of firebrick system was expected to be around 6 years. 80's of the 20th century, the lining of the blast furnace due to replacement or repair, of damage caused by the bosh region. Therefore, many designers have worked on the development of main geometry of bosh refractory and cooling systems. The mature experience by using copper cooling at the bosh region, closed loop cooling water softener etc. which enhanced the furnace life more than 15 years [30].

The advantages of good thermal conductivity of copper staves accelerate the formation of protective layer of slag skin. Use of thin copper stave (80 ~ 120mm), enhances the furnace capacity by decreasing the thickness layer of the refractory materials. Lower furnace body parts, both ancient and modern remedies have to be carried out with the repair, or replacement of damaged components to increase the cooling capacity, or lining grouting or gunning to extend the effective life of blast furnace. Improve the lower furnace body refractory material is to reduce the wear, thereby reducing the work load of its key patch. [31]

The wear of hearth refractory caused mainly for the iron cycle. The impact of these iron cycle is very bad on the refractory because it caused erosion by the flow of metal through the tap-hole, resulting in molten iron circulating in the furnace on the cylinder wall at a result the furnace cylinder wall and bottom cushion combined with erosion of the Ministry of mushroom there. Repeatedly found that, with more than 60% of the tar-soaked high alumina bricks have a good anti-wear effect. The results show that the lower furnace refractory wear body mainly by the thermal fluctuations, heat load, thermal chemical aspects of wear and mechanical wear caused by the combined effects.

Blast furnace bottom refractories, and specifically the hearth refractory, are the most critical element in a successful long campaign life. Use of carbon blocks at the bottom of the hearth is a common phenomenon for its hot metal and slag corrosion resistance, high temperature strength, thus greatly extending the service life of blast furnace linings. To get the proper life of the carbon bricks hearth under cooling system is necessary to protect from damage [32]. Carbon hearths, with water under- cooling and with or without a ceramic cup, remain the main solution for this area of the furnace. The philosophy is to maintain the iron freeze line in a reasonable position within the refractory. This is where a solid layer of iron forms and therefore protects the refractory from wear damage. As the hearth size increases then it is simply considered that the number of hearth bricks will need to be increased. There should be no limitation applied to the hearth size by the refractory design. Carbon hearth linning is a compound linning methodology, [33] which consists of compound linning of graphite blocks, carbon blocks, and ceramic bricks. By utilizing different refractory materials gives the advantages of the best properties of each material. Most of the Indian blast furnace (around 1000 m^3 working volume) carbon hearth design is as (Fig. 8).

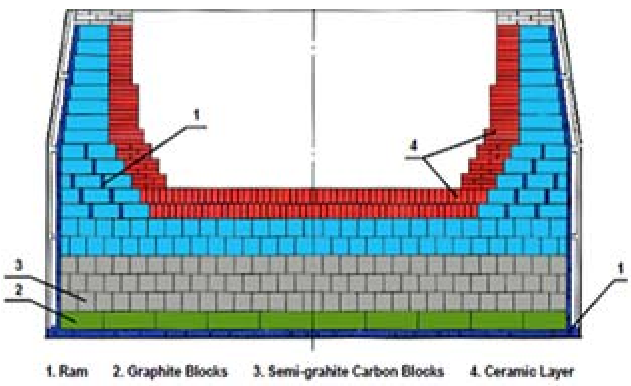


Figure 8: Modern carbon hearth lining design

This design offers various advantages such as:

1. Unique materials are utilized based on the needs of different areas of furnaces.
2. The use of ceramic brickwork in the inner surface increases the erosion resistance and effectively prevents thermal loss therefore increase the temperature of the liquid iron.
3. The carbon block layer provides good thermal conductivity and absorbs the thermal expansion properly
4. The graphite blocks are used in cooling the furnace bottom.

Overall the lining structure adopts graphite blocks, carbon blocks and corundum bricks have a very strong, long, productive campaign life. To get better top-hole length as well as less erosion of hearth side wall, taphole clay quality also improved. Use of anhydrous clay (pitch impingent clay) has replaced hydrous clay. Use of Duel thermocouple at the hearth sidewall and bottom to understand the remaining thickness [34]' and metal puddle formed at the bottom of hearth.

2.7 Water Cooling System

Tuyere is more sensible equipment in the blast furnace because it is made with low melting point copper and works at intense heat zone (>2773K).For protection of these a continuous water cooling system is needed. The failure of tuyeres resulting serious problem inside the furnace creates operational disturbance i.e. irregularities in furnace operation, inconsistency in metal composition, damage in refractory lining (modern trends to use carbon bricks inside the hearth side wall which became fragile when contacted with water), in extreme cases hearth chilling may be occurred [35] .This was the common problem faced in almost all furnaces. To overcome these problems an automatic tuyere monitoring system is being developed [36]. For cooling in Tuyere, hot blast stove valve, Stave cooler arrangement adequate water circulation necessary for better performance. But deposition of some insoluble salt such as calcium carbonate on inner portion causes chocking of the area less heat transfer causes serious problem, so suitable treated water is required, such as demineralization and pH control of the water [37].

2.8 Hot Blast Quality

Blast Furnace produced 1500-1700Nm^3 of gas per ton of liquid metal. Calorific value of this gas is as high as 3500-4000 kJ/Nm^3. It means one third of total energy input of the blast furnace is removed by off gas .In early age cold air was blown into furnace resulting high reductant rate in the blast furnace. About 8 tons of coal was required to produce coke sufficient to produce one ton of iron. Neilson in1829 introduced the concept of preheating the air blast [38].

Metallic Blast Preheater (MBP) was widely used for that purpose till last decades of past century in many Indian furnaces. Main drawback of MBP was limitation of Hot Blast Temperature(HBT) which was produced around 1073K and the maintenance cost during changing of coils when got burnt was very high. In 1857, Cowper patented fire checker bricks lined stove which is now widely and successfully used in all the furnace .The installation cost is very high, but it can give the HBT as high as 1673K. The modern internal combustion chamber stove is a proven high temperature unit, which has been developed from the older, more traditional design (Figure 9a). The high temperature internal combustion chamber stove provides an economic alternative to the more complex external combustion chamber designs. Stoves of this design are suitable for operation with dome temperatures up to 1673K and will produce a uniform blast temperature of 1523K. The successful Krupp Koppers design (Figure 9b) technology which allows a maximum operating dome temperature of 1823K and uniform blast temperatures up to 1623K.

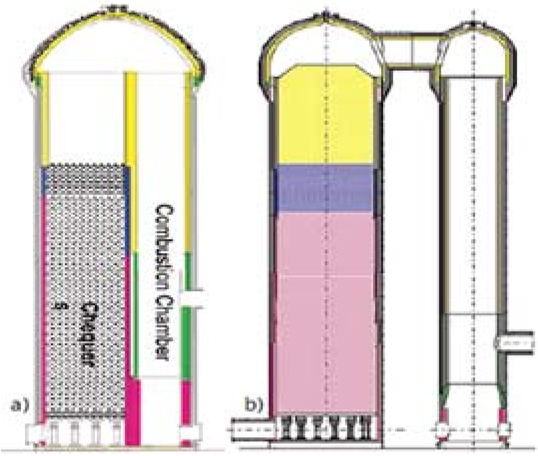


Figure 9: Modern 'Krupp Koppers' design hot blast stove

The external combustion chamber concept is particularly suited to ultra high temperature operation combined with large blast volumes, high combustion efficiency unit with low CO, SO_x and NO_x emissions. This burner has been in service in external combustion chamber design stoves for over thirty years and has now been developed for use in our internal combustion chamber stoves [39] . Stove size is clearly dependent upon the hot blast volume required for the blast furnace. In order to maintain acceptable levels of flue gas velocity, combustion density and the ratio of stove height to diameter, stove size must increase as the furnace size increases. It has been noted in the above comments that there are two options available for stove design one is internal and another external arrangement. There is a practical limit to the size of an internal combustion chamber stove that can comfortably enlarge. Maximum internal combustion stove size of 10m diameter can be achieved. Beyond this, the size of the dome becomes excessive and maintaining dome integrity is, therefore, somewhat suspect. As a result, the use of an external combustion chamber stove is recommended for large blast furnaces. Consideration must also be given to the number of stoves themselves. With the use of modern stove valve systems, particularly those utilizing hydraulic actuators, high levels of availability can be achieved. Therefore, it is recommended that a three stove system will be adequate even for large blast furnaces. Four stove systems are also popular for large Blast Furnaces for better thermal efficiency [40].

Improvement of blast quality means not only to increase the Hot Blast Temperature but also the enrichment of blast with oxygen, humidification, oil and gas injection through the tuyeres has been an available technology for a number of years. The coal injection is being currently preferred as a means to reduce the amount of coke consumption by the furnace and, therefore, raw material and processing costs. Initially, coal injection rates of 50kg/THM were used, however today, rates of up to 250kg/THM are considered world's best operation. But in India it is being reached up to 150 kg/THM (avg) [41].

The subject of debate is not at this time with regard to the level of coal injection but at what capacity of equipment that can be installed. With increasing furnace size for higher iron production and therefore for the same coal injection rate (kg/THM) was used. In similar way for such high Hot Blast Temperature, humidification of blast, oil and hydrocarbon injection with oxygen enrichment, cumulative effect of these reduce coke rate, increased productivity to a greater extend.

2.9 Gas Cleaning System

Blast furnace gas always contains solids, amounting to 40-50 kg/THM when it exit from Blast Furnace at a temperature of around 423-573K. Therefore cleaning of gas becomes mandatory before its use. For operating Hot Blast Stove (HBS) effectively and to enhance the life of the cowper stove, gas cleaning system is to be improved. In early stage dust catcher and wet scrubber use for cleaning purpose of off gas, but some problem arise in the case of wet type gas cleaning system where gas became cold and moist with decreasing Gas pressure remarkably due to use of ventury. For that reason it lost the sensible heat of gas and pressure which creates problem in use in power plant and hot blast stove [42]. To rectify these problem dry type gases cleaning system is being now popular, where bag filter and electro static precipitator introduce in the new GCP system [21]. It was introduced by Lodge and Cottrell in 1919, but in Indian blast furnace it is being used from last decades of past century.

2.10 Process Control

For increasing demand of better quality and least compositional variation in hot metal production, computer aided process control is necessary. Automatic feeding, weighing and charging system in Raw Material Handling Systems (RMHS) are necessary to feed the actual requirement of input material to maintain the final product quality (Fig. 10). In an automatic charging system activates in operation after determination of stock level burden descent rate automatically. Automatic temperature measuring system and hot metal analysis, during the pouring of hot metal is being done to understand the consistency of liquid metal [43]

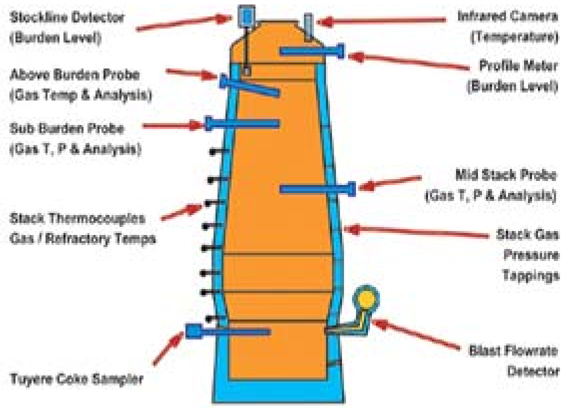


Figure 10: Process control parameters

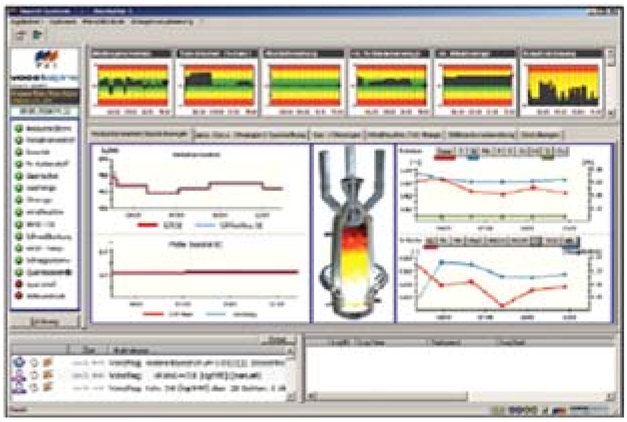


Figure 11: Computerized automatic process control system

Online tuyere monitoring system is being used to understand the rate of reaction and chemistry of liquid metal. Online BFG analyzer for analysis of top gas continuously for predicting the status of internal Physio-chemical reaction happened inside the Blast Furnace.

Automatic Raceway Adiabatic Flame Temperature (RAFT) calculation and adjustment by controlling input variables such as Oxygen, Humidity, HBT etc. Automatic stove changeover by showing HBT to get the maximum constant temperature and automatic top pressure control by controlling ventury gates (Fig.10) [44, 45]. All these are now using in almost all the modern large Indian blast furnaces through the Programmable Logical Control (PLC) system. More development in automation gives more productivity and accuracy in chemical composition. (Fig. 11)

2.11 Environmental Challenges

The steel industry recognizes that it has a role to play in sustainable development by raising the living standards of people in all parts of the world while not damaging the environment. Main issues are air pollution, sound pollution, soil pollution, water pollution. Steel production contributes largely to worlds green house gas emission since the process is highly energy intensive and releases about 2.3-3.0 tons of carbon dioxide,1.2-1.4 kg Sulphur dioxide,1.8-2 kg Nitrogen dioxide per ton of crude steel [46]. Ferrous metal production contributes 12% of total Green House Gas emission in India [47]. Typical Blast furnace gas contains around 22 % CO, which is very poisonous for human beings. It is being used for heating of stove, power plant, sinter plant as well as heating of ladle. Excess gas which is coming out from flare stack is continuously ignited to burn. During casting, pouring in Pig Casting Machine(PCM), Desulphurization treatment of liquid metal, huge fumes, dust, graphite flake and heat is generated which affects the human health of the people working in this area. Now a day's runner covering system fitted with dust collector is being used to overcome the problem and to keep cast house environment healthy [48]. Dust catcher waste/ sludge, iron ore tailings contain valuable particles such as iron oxide, carbon fines, which is being used to agglomerate to produce pellets/briquettes [49].These wastes are being also used to make bricks in many plants.[50] Pig Casting Machine (PCM) waste slurry (contain lime and graphite powder which is used for coating purpose of mould) is being recycled to use again to avoid soil and water pollution. It also saves money. Main sound prone areas are Raw Material Handling System (RMHS) area where feeding, screening of materials occurred and Blower House where air is being sucked to feed into Blast Furnace Stove. To minimize the sound pollution in RMHS, ceramic screen in place of metallic screen and covering of blower with silencer jackets are being used.

3. Conclusions

It is obvious that the technology and practice of iron making have made remarkable strides in terms of productivity, cost, quality and process efficiency in India since last few decades. Development and growth of metallurgical thermodynamics and kinetics, heat mass transfer, numerical and computer control have contributed significantly towards this achievement. Advance development in mineral agglomeration to produce sinter, pellets is added the advantage. As a result the productivity of Indian blast furnaces has grown up upto (2.5-2.6) level, with consequent reduction in the coke rate 260-270 kg/THM with PCI upto 250 kg/THM and Specific energy consumption up to 5.1-5.2 GJ/THM and working environment became safer and eco friendly to fulfill the norms level of GOI.

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