### **CHAPTER-11**

## FUNDAMENTALS OF IRON ORE SINTERING

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# INTRODUCTION

The process of sinter making originated from a need to make use of fines generated in mines and in ore beneficiation plants. With the development of sintering technology, a sintering plant has become a tremendous success for providing a phenomenal increase in productivity and saving in coke rate to the blast furnace. The technology of sinter making has undergone radical changes both in operation and process throughout the world. High competitiveness amongst the iron and steel industries has forced the operators to radically modify their operation in several fronts including the raw material preparation through sintering. In this regard It is essential to understand the sintering fundamentals.

# **EFFECT OF SINTER AND ITS QUALITY ON BLAST FURNACE (BF) PERFORMANCE**

Before we discuss the basic aspects of sintering, we must know the important parameters of sinter which do affect the blast furnace performance. This has got significance in view of the fact that while most of the burden materials are the product of nature with inherent variability in physical and chemical properties, sinter is produced in the plant whose quality can be regulated through control of sintering condition and requisite chemistry of sinter. Simultaneously, a requisite amount of available lime in sinter eliminates limestone from the burden: thus calcination, which is highly endothermic reaction, can be can be inside the furnace. Theoretical calculation shows that avoided to take place approximately 0.26 kg of carbon is saved for every kg of limestone removed [A.K.Biswas: 'Principles of blast furnace iron making': Theory and Practice (1981), Cootha Publ.House, Australia, Ch VI]. The statistical analysis of the performance data of the blast furnace 'X' at Bhilai (SAIL Plants) has shown that the parameters, specific consumption of sinter and weight of limestone in the burden were closely correlated: 20 kg. of carbon /THM can be saved by eliminating 100 kg raw limestone from the burden [R P Bhagat, H.S.Ray, S.K.Gupta: ISIJ International, Vol.31 (1991), p.669-676.]. In view of the fact that the capacity of sintering plants in India is limited, it requires to produce super-fluxed sinter in order to incorporate the lime required for fluxing the acid constituents during the smelting inside a blast furnace. Other parameters which has influence on the coke rate and blast furnace productivity are (a) reduction properties (RDI/RI) of sinter, (b) Fe content in the sinter, and (c) fines in the sinter.

It has been conclusively proved in relation to the blast furnaces (BF) of SAIL- Bhilai, TATA STEEL, Schwelgerm and Ruhort (No.6) that Coke rate and productivity are greatly influenced by RI and RDI values of sinter. Understandably, the fines generated inside the furnace during reduction affect the permeability of the stack zone, increase the pressure drop and disturb the gas distribution causing channelling of the furnace. All these

factors result in decrease in driving rate and adversely affect the CO utilisation with ultimate consequence of higher coke rate and lower productivity. A close relationship between RDI value of sinter and the permeability of Fukuyama BF have been reported [Nishio et al. (Loc. Cit. Anil Kumar et al. 2001)]. The permeability index decreases with increase in RDI value. A decrease in productivity with increase in sinter RDI has been reported in case of TISCO furnaces [Anil Kumar, S N Sinha & U S Yadav : Proc. Coras 2001, SAIL Ranchi 149-155]. In case of Vizag BF a definite relationship between the coke rate and RDI of sinter has been observed [. Tiwari, Y Venkateshwarlu, R. Mohanty & U. N. Behra: Proc. CORAS 2001, SAIL Ranchi, 191-201.].

## THEORETICAL DESCRIPTION OF THE SINTERING PROCESS

In sintering, a shallow bed of fine particles is agglomerated by heat exchange and partial fusion of the quiescent mass. Heat is generated by combustion of a solid fuel ad mixed with the bed of fines being agglomerated. The combustion is initiated by igniting the fuel exposed at the surface of the bed after which a narrow, high temperature zone is caused to more through the bed by an induced draft applied at the bottom of bed. The bonding is effected by a combination of fusion, grain growth and slag liquidation. The generation of volatiles from the fuel and flux stone creates a frothy condition and the incoming air quenches and solidifies the rear edge of the advancing fusion zone. The product 'sinter' consists of a cellular mass of ore bonded in a slag matrix. The sinter mix, besides the ore fines, usually contains other materials like flue dust, return fines, limestone and/or dolomite etc., in order to control the properties of the product as well as to utilize industrial waste. Return sinter fines having lower fusion temperature than the raw mix serve as seeds for initiation of the sintering process.

### THE SINTERING MECHANISM

The total reaction involved in the process of sintering is the sum of a number of reactions which involve reactions in heating zone, reactions in sintering zone and reactions in cooling zone. These reactions are illustrated schematically for typical sintering of a lime-fluxed haematite ore in Fig. 11.





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The reaction mechanism followed and subsequently the sinter minerals formed are, however, depend on the mix composition. While magnetite, fayalite and glass containing iron oxides are the major mineral phases for siliceous sinter, the ferrites, magnetite and mixed calcium iron silicates are the major mineral phases for fluxed sinter. Sintering is a fast process and it is unlikely that equilibrium will be reached during sintering.

The reaction mechanism proposed for self fluxing sinter is summarized below :

### At 800-1000°C

Crystallisation of iron oxide – hematite Dissociation of  $CaCO_3$ Sintering of hematite with quartz and lime.

### At 1050-1200°C

Part of hematite + CaO = CaO.  $Fe_2O_3$ + 2CaO = 2CaO.  $Fe_2O_3$ SiO<sub>2</sub> + CaO = CaO SiO<sub>2</sub> (Minor quantity)

At 1250-1350° C

Mono calcium ferrite – decomposes Magnetite + Lime + Silica = Calcium olivines.

#### Various Zones of Sintering

The sintering process consists of the passage of a heat and reaction front through a packed bed of solids. In general, the objective is to attain a temperature wave passing through the bed in such a way that a zone of incipient or partial fusion passes through the bed in order to agglomerate (sinter) the fines in the bed to a porous lumpy material suitable for feed to a blast furnace.

A vertical section of the sinter bed is shown schematically in Fig. 11.2.. The sintering process consists of the following five different zones :



Fig. 11.2 Temperature prevailing in a sinter bed 3 minutes after ignition and various zones during the process of sintering.

- (a) Zone of Sinter : The gross physical character of this zone is established upon the solidification of the fluid slag matrix, but the physical and chemical cheques occur just after solidification such as oxidation of magnetite to hematite, grain growth of iron oxide crystal.
- (b) Zone of Combustion and Fusion : The oxidation of carbon to carbon monoxide and carbon dioxide provides large quantity of heat for slag formation and the fusion of ore particles. The burning of coke breeze by the preheated air proceeds successively vertically downwards. The calcined limestone reacts with the gangue constituents to form the semi-liquid slag phase. Reduction of hematite to magnetite by Cq, initiated in the calcination zone continues and a substantial portion of the original hematite may be reduced to wusstite (FeO) in the fuel content is too high.
- (c) Zone of Calcination: At this level in the bed, the gas stream is suff. jently hot as to calcine carbonates and sufficient Co is present to initiate reduction of hematite to magnetite.
- (d) Dry and Preheat Zone: The hot gaseous combustion products preheat. this zone. The preheating results in the evaporation of moisture and hydrated water.

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(e) Wet Zone: This lowest portion of the bed has essentially the same characteristics as the original mix. The gas stream has transferred essentially all its sensible heat to upper part of the zone and the lower part of the zone is at the temperature of original mix.

The process continues in successive layers up to last one when due to the absence of any cold mix the waste gas temperature shoots unto  $300-350^{\circ}$ C. The rate of sintering is very fast and depending upon the permeability and thickness of the bed it takes 15-20 minutes for completion.

## **Thermal Characteristics**

he gases following through the bed continuously carry the heat from the flame front further along the bed. The velocity of the heat transfer front has been described by the following equation :

Velocity of heat transfer front =  $h_g V/h_s (1-\varepsilon)$ 

Where,

 $h_g$  = the volumetric heat capacities of the gases (Kcal/m<sup>3</sup>)  $h_s$  = the volumetric heat capacity of hundred percent dense solids (Kcal/m<sup>3</sup>)

V = the volumetric flow of the gases  $(m^3/m^2-min.)$ ,  $\xi = void$  fraction of the bed.

This relationship shows that the velocity of the heat transfer front is directly proportional to the gas velocity.

The reaction front results from the combustion of fuel in the bed and other reactions. The progress of the reaction front is largely determined by the oxygen content of the incoming gas and the reactivity of the fuel. Since the reactions are strongly exothermic, it is difficult to differentiate the heat transfer front from the reaction front in the sintering process. So the combination of heat transfer front and reaction front is called the 'flame front'.

#### Permeability

The specific volume of air for sintering is almost constant, so the sintering rate will depend on how fast the air is blowing in. This dependent on the permeability of the bed, bed area, bed height and suction. The following relationship has been developed:

$$F = P.A. (W/h)^n$$

where

 $F = \text{air flow (ft^3/min. at NTP)}$  P = permeability in BPU  $A = \text{bed area (ft^2)}$ h = bed height (in)

 $W = wind box suction (in of H_2O)$ 

n = an empirical factor – varies from 0.55 to 0.65.

Therefore, high permeability allows faster air flow through the bed and faster sintering.

Bed permeability varies in a complex manner during the sintering as different zones have different permeability. Nevertheless for Bhilai ores, close relationship have been found amongst sintering time, the permeability of the green mix and the minimum permeability. The permeability is greatly affected by the two factors, namely, the moisture content and the proportion of return fines in the sinter mix.

# **GRANULATION OF SINTER MIX INGREDIENTS**

A sinter feed with good permeability from ignition until burn-through is required for efficient operation of a sinter plant. In this regard it is necessary to consider the widely held and simplistic view that sinter feeds containing iron ores with high ultra-fines content have low-pre-ignition permeability. A number of factors influence the granulation characteristics and permeability of sinter feeds. Attempts to improve granule characteristics of sinter mix have to date concentrated on the operational conditions shown in Fig 11.3.



Fig. 11.3 : Factors involved in the granulation and sintering of iron cres

The following factors play major roles in controlling the granulation characteristics of sinter mix.

- Internal perosity of the sinter feed which determine the amount of moisture available for the granulation.
- The size of *i* dhering particles reporting to the coarse granules
- The rate of granule growth with increasing feed moisture content.

### **Combustion Efficiency in Sintering**

In spite of the fact that an excess of oxygen is always present in the sintering atmosphere, the combustion never proceeds to completion, i.e. there is always some carbon di-oxide present in the waste gases. The gas analysis during the sintering of a typical ore mix (containing higher amount of carbonates) is shown in the Figure 4. Here the carbon dioxide content is rather high because of decomposition of carbonates in the mix.



Fig. 11.4: Analysis of combustion products in sintering

The presence of CO in the exhaust gas can be explained by the fact that the rapid air flow down the bed carries the carbon monoxide produced at the surface of the burning fuel into the cold zone of the bed so rapidly that oxidation by atmospheric oxygen cannot proceed to completion. The explanation is supported by the fact that increased suction, giving an increased linear flow rate down the bed, results in an increase in the ratio of CO/ (CO<sub>2</sub>+CO) in waste gas. An increasing fuel reactivity, whether it is caused by the nature of fuel or by finer grinding of the same fuel, increases the CO/ (CO<sub>2</sub>+CO) ratio in waste gas. An appreciable quantity of carbon monoxide may also be due to the direct reduction of iron oxides by solid carbon.

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# SINTER MINERALOGY

A sinter is regarded as consisting of essentially three types of materials namely,

- (a) original primary material,
- (b) original secondary material which is the result of alteration of the structure and shape through recrystallisation in the solid state, and
- (c) secondary constituents.

Two types of bonding are theoretically possible depending on the mineralogical changes:

(a) Slag or Fusion Bond :

Partial or complete embedding of crystalline constituents in the matrix of a fused glassy melt, the extent depending upon the volume and wettability of the liquid phase. The bond strength depends upon the amount of glass and the amounts and types of the constituents. These depend upon the fuel rate and impurities  $SiO_2$ ,  $CaO_2$ ,  $CaO_3$ , MgO and  $Al_2O_3$ , added or present.

## (b) Diffusion Bond :

Recrystallisation and crystal growth of hematite (magnetite). Hematite diffusion plays an important role, especially above 1250-1300°C, because of its relatively high surface mobility of this temperature. Such bonds are, however, obtained in Fe-rich low silica ores, since the impurities in lean ores form low-melting liquids before the 'diffusion' temperatures are reached. In addition, very close packing and good contact of particles is necessary for diffusion to operate effectively. The limits of surface mobility are such that a loosely packed aggregate could not be expected to acquire a high strength by diffusion bonding alone. Diffusion bonded sinters are more porous, accessible to reducing gases and hence easily reducible.

### **Relationship of Sinter Mineralogy with Basicity**

The basicity ratio is one of the most important factor affecting the mineralogy of sinter. The minerals that are present in the sinter of different basicity are hematite, magnetite, mono calcium ferrite and iron calcium olivines of composition  $Ca_xFe_{2-x}SiO_+$  with the value of x increasing from 0.25 to 1.75 as the basicity is increased. In general, the sinter mineral proportions depend on the CaO/ SiO2 ratio which is indicated in Figure 5.

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Fig. 11.5: Variation in Sinter Minerals Constituents with CaO/SiO2 ratio having 0.5 % Magnesia and 1.5% Alumina

### CaO/SiO<sub>2</sub> ratio 1.4-2.8 :

Specially this basicity zone is relevant to the Indian practice. As the basicity increases above 1.4, the glassy matrix is replaced by calcium silicate and ferrites. The ferrites increasingly takes over as bonding with simultaneous increase in sinter strength : the needle like ferrites precipitates hold the ore grain together. Reducibility also continues to increase. Because of formation of ferrites at comparatively lower temperature and strong bond created by them, a lower fuel basic sinters compared to acidic sinters.

The minerals present in the fluxed/ super fluxed sinter are given below:

*Magnetite* : The morphology of magnetite, Fe3O4, is best seen in sinters of low basicity (CaO/SiO2 = 1.0-1.2) which are composed of ex solution magnetite grains in glass. Here it exhibits a range of forms from euhedral skeletal to anhedral crystallites. The crystal shape is function of the rate of cooling of sinter bed. In addition to this ex-solution magnetite, magnetite may also be formed by the essentially solid state reduction of hematite.

<u>Hematite</u> : Fe<sub>2</sub>O<sub>3</sub> in iron ore sinters may be produced in sinters in different ways :

- Fragments of original hematite ore which are bonded by silico-ferrite of calcium and aluminium (SFCA). This is primary hematite and is typically quite pure Fe2O3 (Fig. 6)
- The natural slagging constituents of the ore may take into solution much of the finer ore hematite and ex solve these as crystallites of secondary hematite (Fig. 7).
- Hematite may also result from the high temperature re-oxidation of ex solution magnetite.



Fig. 11.6: Photomicrograph showing Primary Hematite (white) bonded by prismatic SFCA (grey). Interstitial Cavities and Di-Calcium Silicates are Black



Fig. 11.7: Photomicrograph showing Ex-solution Crystals of Secondary Hematite (white) c.id SFCA Crystals (Pale grey) in Glass (Dark Grey)

Silico- ferrite of Calcium and aluminium (SECA) : Fluxed iron ore si ters contain crystals composed of major calcium and iron oxides (Fig. 8). A number individual compositions have been recognised in relation to sinter mineralogy.

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۲	Mono-calcium Ferrite	: CaO-Fe2O3		CF
•	<b>Di-calcium</b> Ferrite	: 2CaO-Fe2O3		C2F
•	Tri-ca'cium Ferrite	: 3 CaO-Fe2O3		C3F
•	Calcium di-Ferrite	: CaO -2 Fe2O3		CF2
•	Calcium Alumino- Ferrite	: CaO- (Fe Al)2O3	•	CFA
•	Silico-Ferrite of Calcium & aluminium :		SCFA	



Fig. 11.8 : Photomicrograph showing typical Field of Prismatic SFCA (grey). Interstitial Cavities and Di-Calcium Silicates are Black

# **RELATIONSHIP OF SINTER MINERALOGY WITH REDUCTION PROPERTIES**

Theoretically, there should be relationship between the sinter quality parameters and sinter mineralogy & mico-texture. It is postulated that under suitable oxidising conditions during sintering multi- component magnetite is converted to multi-component hematite which has lost CaO and MgO, but retained  $Al_2O_3$  as precipitate. It is claimed that this form of hematite in sinter is responsible for reduction- degradation effect in the BF.

The mineralogy (also morphology) of a sinter and its role in bonding has a marked effect on the properties of the sinter. Table 11.1 shows the reducibility and compression resistance of sinter minerals. Some results of the reduction experiment are shown in Fig. 11.9.

Constituents	Percent	Compression Strength
	Reduction	Kg/mm <sub>2</sub>
Hematite (Ore)	49.90	26.70
Magnetite (Ore)	26.70	36.90
Mono caleium Ferrite	40.10	37.00
Dicalcium Ferrite	28.50	14.20
Olivine (Ca <sub>x</sub> Fe <sub>2-x</sub> SiO <sub>4</sub> ):		
X = 0 (Faylite)	1.00	20.00
X = 0.5	2.70	56.60
X = 1 (Crystalline)	6.60	23.30
X = 1 (Glassy)	3.10	4.60
X = 1.5	4.20	10.20
	8.1	

Table 11.1 : Reducibility and compression resistance of sinter minerals





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# **EFFECT OF PROCESS VARIABLES ON RDI AND RI VALUES OF SINTER**

Although the fundamental cause of degradation of sinter during the reduction is well understood, the mechanism (steps involved) that leads to breakdown of the sinter structure is only partially understood. Certain research findings, which are generally accepted are mentioned below:

- High basicity and lower coke consumption are helpful in improving sinter reducibility by way of favoured mineralogy.
- The calcination of limestone & its assimilation by hematite are crucial in the sintering, especially at high basicity. Poor accessibility of hot gas to the mix during the sintering could result in weak sinter. (*R&D- SAIL*) [R.P.Bhagat, S.K.Gupta and H.S.Ray: Heat transfer consideration for improvement in sintering indices: Proc.48th Iron Making Conf.ISS-AIME Chicago (1989), p.481-490 & Ram Pravesh Bhagat: Scan. Jour. of Metallurgy 21 (1992), p.246-250.24,25].
- The sinter reducibility increases when dolomite is replaced by dunite (TATA STEEL) [Amit Chatterjee, S S Gupta : Monographs on Sinter Making at Tata Steel].

In contrast to alumina, a higher proportion of silica in the ore fines/ mix appears to have beneficial effect on RDI value. Study of micro-structural of sinter samples by Dey et al. [Anjan Dey et al. : Structure of fluxed sinter in Sintering Technology, Iron & steel Division of IIM, Jamshedpur] reveals that high silica favours the formation of the optimum form of SFCA (silico- ferrites of calcium and aluminium) which is fine, fibrous and resistant to crack propagation with consequence of reducing RDI value.

• It may be noted that while higher percentage of  $CaO + SiO_2$  is advantageous for the precipitation of SFCA phase, a minimum level of alumina in sinter could also be essential in order to stabilise the phases. This means the presence of certain percentage of the minerals excluding the ferrous ones, gangue content (CaO + MgO + SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub>) is essential from the RDI point of view.

Pandey et al. [B D Pandey, U S Yadav, D N Jena & B K DAS : TATA SEARCH (2000) 17-22] have summarised the research Findings on the factors which influence the RI / RDI of Sinter as follows:

- □ The presence of controlled amount of impurities or additives in sinter can alter the intra-crystalline structure, lattice diffusion, porosity etc.. The degree of crystallisation of silica has a favourable effect on reduction kinetics. The porous morphology of precipitated iron also facilitates the reduction reaction.
- □ The types of phases present in sinter, their composition, amount/volume fraction. Morphologies have a very strong influence on sinter properties.

- Pores in sinter can either increase or decrease RI as well as RDI depending on whether they are open or close and on the phases that are present around the pores.
- The level of hematite phase in sinter and its distribution is important for improved sinter reducibility.
- Generally the RDI value of sinter increases as the ratio of Alumina/Silica in it increases or FeO decreases.

## Effect of the Process Parameters on the Sintering Indices

The output of the blast furnace sinter, Q, can be expressed by the following equation:

Q = I(Y-C), Where,

I = Input of raw mix to the strand per unit time

Y = Weight of sinter cake per unit weight of raw sinter feed

C = Circulating load per unit weight of raw sinter feed.

The output can be increased by increasing the input of raw mix and/or decreasing the circulating load. These are governed by the parameters which influence aerodynamics of the sintering bed, air utilization efficiency; heat transfer, the mineralogy of the sinter produced etc.

Besides the RDI and RI the strand productivity and cold strength of sinter are important parameters of the sintering plant. There are many process and operational parameters which influence the above mentioned factors and consequently the sintering indices. These are mentioned below.

*Basicity*: An increase in basicity decreases the iron content of alag phase by replacing part or all of the FeO by CaO and MgO. As a result, the ferrite formation increases with consequent decrease in glass, fayalite and possibly iron silicates 15, 18. The ferrites crystallize as inter locking lathes and forms strong frame work to bind neighbouring grains of ore together. Formation of these mineralogical constituents starts at lower temperature, even at solid state and these have high reducibility. An increase in sinter basicity reduces the sintering time due to :

a) Reduction in the specific air requirement is due to increased air utilization efficiency
b) improvement in the pre-ignition as well as the average permeabilities.

*Return Fines*:\_Return fines in the sinter mix improves the permeability and a more even distribution and transfer of heat are attained so that the heat losses decreases, re-oxidation heat is liberated and the shrinkage of the mixture is lowered. On the other hand, the proportion of raw ore in the sinter mix decreases with increasing amount of return fines.

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So according to the preponderance of either of these factors, the sintering rate decreases or increases.

**Dolomite** The addition of dolomite in the sinter mix, in general, lowers the reducibility. This is attributed to the formation of magnesium ferrite and magnesowistite which have poor reducibility. The replacement of CaO by MgO leads to an increase in the liquidus temperature of the melt phase. Therefore, the coke (breeze) requirement increases with dolomite. It has been also observed that with the exception of acid sinters, as the limestone is progressively replaced by dolomite, both sintering period and cooling period increases.

*Lime*: Active CaO acts as a binder to improve the micro-pelletising and its stabilization of balls during the sintering process and also contact between the reactive charge components. An increase in the sintering rate with the addition of lime has been observed which is primarily due to improvement in permeability. A decrease in aerodynamic resistance of the sinter mix, however, leads to an increase in specific air consumption. Lime promotes an improvement in surface tension of water. Due to its binding properties, the strength of individual pellets increases.

*Moisture*: Insufficient moisture prevents proper agglomeration of fines, which then fill the voids in the dry and wet zones. Excessive moisture promotes condensation in the bottom of the bed which fills the voids with free water and may cause collapse of the bed structure in the wet zone. Since the evaporation of water acts as a large heat sink, the presence of water regulates the best and reaction fronts and consequently acts to sharpen the flame front.

Solid Fuel Content : Sinter strength is greatly affected by the carbon content of the mix. With increasing amount of coke breeze the peak temperature of the sinter bed rises considerably which in turn improves slag bonding. The presence of excessive coke in the sinter mix results in a broadened temperature profile and also increase in peak temperature. High peak temperature in the sintering bed can result in formation of lower oxides of iron.

*Particle Size*: When the percentage of very fine grains in the sinter mix is preponderant, the permeability of the mix and hence the sinter output decreases. On the other hand, if the proportion of coarse grains is high, the heat content of the waste gas can not be sufficiently absorbed by the solid. Besides the bonding by diffusion decreases. The grain size of the feed material, also, has a major role in deciding sinter mineralogy as it is easier for fine particles to be assimilated in the melt. By limiting the particle size of the feed materials the reaction between the lime and other constituents is greatly facilitated. The period of fusion need not be prolonged, therefore, less coke is required. This also increases the shatter indeed of the sinter.

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## **CONCLUDING REMARKS**

Sinter is a wonderful ferrous burden material - which could be tailor-made.. That is, its physical- chemical properties can be modified to an some extent which suits to the blast furnace operators. The practice of sinter making is more important under Indian context, since the characteristics of other raw materials in general and iron ore in particular are guided by the natural constraints. The operation of a sinter plant has been a tremendous success, since it provides an excellent way to utilize iron ore fines; besides, we could foresee that it could accept ultra-fines in future with the development in the technology of sinter making.

The objectives of an sintering plant operation are:

- To maximize production, and
- To produce sinter of best possible qualities with (a) Better reduction properties, (b) Close size range, (c) Better strength, cold as well during the reduction, and (d) High and uniform softening and melt-down temperature.

A successful sintering technology incorporates the possible ways to exploit both the goals simultaneously. In this regard, the fundamental aspects of sintering need to be explored keeping the present requirements of sinter qualities, which are becoming more stringent day by day, in view. We need to look into the sintering mechanisms as well as mineralogical and morphological characteristics of sinter when the characteristics of raw material changes, in particular with a higher proportion of ultra-fines in the mix. Besides the concern of environment has to be addressed, especially with reference to the generation of dust particles and and  $SO_x$ ,  $No_x$ ,  $CO_x$  effluent gases. In this regard it is of paramount importance to increase the efficiency of siniering.

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