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A Study for Improved Sinter Quality and Productivity with Optimum Use of Mill Scale and Coke Breeze

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Abstract— To improve the sinter quality and productivity of sinter plants of an integrated steel plant, elaborate laboratory studies of various input raw materials were conducted with preparation of green mix with optimum dosage of mill scale and coke breeze. A series of pot sintering tests, using mill scale and coke breeze in various proportion along with the conventional raw materials, were carried out to determine the suitability and optimum blending ratio of raw materials. It was observed that productivity of the sinter machine can be increased by high dosage of mill scale commensurate with use of coke breeze in the green mix. The results of the laboratory experiments indicate that for production of good quality sinter from iron ore fines received from Bolani and Gua mines, in particular, use of mill scale along with high coke rate is very effective. By use of 4.4% of coke breeze and mill scale at the rate of 0.8% of green mix, the specific productivity could be increased by 28% (from base of 1.21 to 1.55 t/m^2/hr). The yield and strength (Tumbler Index, TI) of product sinter was also found to be significantly improved from the base experimental figure. The productivity of sinter plant could be achieved to the designed figure by increasing the proportion of mill scale and optimizing the use of solid fuel.

Keywords— Sinter Machine, productivity, Goethite ore

1. INTRODUCTION

A state of the art sinter plant complex comprising of two sinter machines with 204 m^2 area each along with associated facilities have been commissioned in an integrated steel plant to produce 3.88 Mt/yr gross sinter. Both sinter machines are designed for 1.4t/m^2/hr productivity but the productivity of the sinter machines were hovering around 1.15t/m^2/hr mainly due to goethite nature of iron ore. Sinter plants of the above mentioned steel plant get iron ore fines from the Bolani and Gua mines which are having mainly hematite with significant amount of goethite mineral. The iron ore fines have about 5-6% chemically bonded water which reflects in its higher loss on ignition (LOI) value. This water gets evolved out during sintering process at temperature from 250^{0}C to 450^{0}C and increases moisture level of sinter charge mix and because of that the micro pellets charged over sinter machine for sintering gets disintegrated resulting in reduction of vertical sintering speed (VSS) and productivity [1].

In sintering process, iron ore fines are converted into a product suitable for blast furnace feed causing benefits such as improved furnace control, homogenized chemical composition of the product, increase in specific furnace throughput performance, reduce energy consumption, concentrating on essential components of the burden by expulsion of water and loss on ignition. The sinter plants have been designed for a total output of 3.88 Mt/yr iron ore sinter considering an operating time of 7920 h/a. The plant availability was considered to be 90% on an annual average [2].

Technological improvements along with stable supply of high quality iron ores and sinter can lead to improvement in blast furnace process. But the sources of good quality iron ores are getting depleted day by day due to increase in production of hot metal in world wide. Therefore, it is the need of the hour to continue improving our sintering technology in order to use lower quality iron ores in raw mix along with the waste materials generated from steel industry in day to day operation. In order to operate in consistent manner, blast furnace requires optimum quality of sinter with good physical strength measured in TI, high reducibility index (RI), low Reduction degradation index (RDI), calibrated size with little variation in its chemical composition. Therefore, with adequate sintering and quality control, blast furnaces can be operated with operational stability with low fuel rate [3].

At sintering plant of the aforesaid steel plant, there are two sintering machines namely SP1 and SP2 of identical shape and design having sintering area of 204 m^2. This paper will discuss the several trials which were carried out at the plant as well as in the laboratory. Physical and chemical analysis of raw materials received from various sources will also be discussed. Pot test data keeping similar condition as at plant with sintering of goethite ore, using optimization of coke breeze and mill scale and its effect on VSS, yield, productivity as well as TI will also be discussed. The test result is important as the iron ore received at the aforesaid plant is mainly goethitic in nature and it was hindering the productivity of sinter machines. Goethitic ore have low bulk density and high porosity which is the main constraint in increasing productivity. Productivity of sinter plant at the aforesaid plant could be achieved to the designed figure by increase in proportion of mill scale and optimizing the use of solid fuel.

2. EXPERIMENTAL

2.1 Description of the laboratory sintering unit

The schematic diagram of sintering process and pot sintering unit present in the laboratory is given in *Figures 1 and 2* respectively.

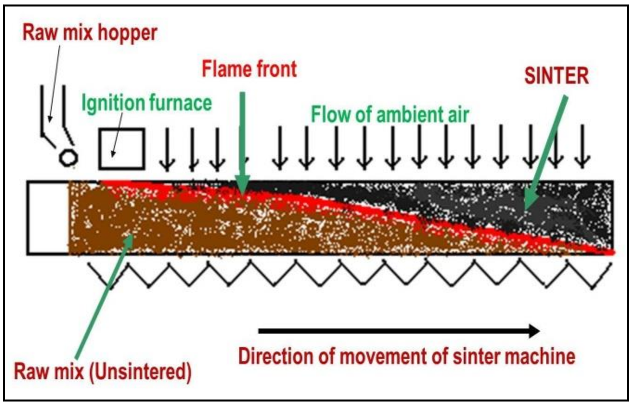

Figure 1: Schematic diagram of sintering process

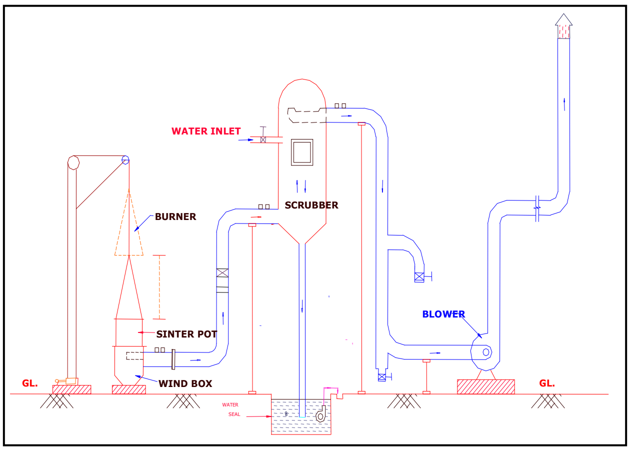

Figure 2: Schematic representation of pot sintering unit

The unit present at laboratory consists of a replaceable sinter pot of internal diameter 310 mm and the pot is installed on a vacuum chamber. Necessary suction for this unit is provided by an exhauster and it can be controlled by means of a butterfly valve. The waste gas generated during sintering is cleaned in a scrubber, where water is continuously sprayed as cooling and de-dusting agent. The under grate suction is measured with the help of a digital pressure meter. *Table 1* shows the fixed parameters of the experimental set up installed at laboratory used in several trials. All the raw materials such as iron ore fines, lime stone fines, dolomite fines, coke breeze, mill scale, lime dust, return sinter fines were proportioned as per the charge calculation and thoroughly mixed in the mixing cum balling drum. Thereafter, required amount of water is added into the mixture and again fed into the drum for green mix ball formation. Two (2) kg of sinter size bearing +10mm to -25mm was charged on grate bars as hearth layer. Then, the green mix is charged into the sinter pot over hearth layer.

Table 1: Fixed parameters of the experimental set up

Sl. No.	Parameters	value
1	Bed height	600mm
2	Hearth layer	2.0kg
3	Ignition time	2min 30s
4	Suction during ignition	200mmwc
5	Suction during sintering	1300mmwc
6	Return sinter	20%
7	Bulk density	1.95t/m^3

After charging the green mix in the sintering pot, the exhauster/blower is switched on to create vacuum. Air filtration velocity at required suction is measured. The top layer of green mix is ignited by burning LPG through ignition hood above the top layer. Suction is maintained at the required level (200mmwc) during ignition and after ignition the valve of blower is closed to create required value of suction for the experiment. When top layer combustion starts, the ignition is stopped. Sintering process travels downward up to hearth layer as shown in *Figure 1*. When exhaust gas temperature reaches maximum the sintering process is complete. This pot sintering unit was used to carry out this study.

2.2 Raw Materials

Bolani and Gua iron ore fines, flux fines, mill scale, calcined lime dust, coke breeze etc. were used as raw materials. Chemical analyses of the raw materials were conducted in the laboratory and the corresponding results are presented in *Table 2*.

Table 2: Chemical analysis of raw materials (in %)

Sl. No.	Raw materials	Fe(T)	SiO_2	Al_2O_3	CaO	MgO	LOI
1	Bolani iron ore	61.7	3.16	3.16	0.057	0.039	4.97
2	Gua iron ore	60.0	3.84	3.39	0.037	0.041	6.49
3	Flux	0.71	1.18	0.062	44.15	8.68	44.14
4	Mill scale	67.84	1.08	0.32	0.32	0.10	-
5	Calcined lime dust	0.35	0.64	0.28	83.68	0.81	13.77
6	Coke breeze (Ash)	5.93	51.79	28.96	2.83	1.04	-

From the chemical analysis of iron ore fines, high LOI values can be clearly seen. This is due to chemically bonded water, a particular nature of goethitic mineral in iron ore fines. Physical analysis of these raw materials was conducted through screening and the data obtained are presented in *Table 3*. Coke breeze analysis clearly shows the higher -0.5mm percentage in as received sample.

Table 3: Physical analysis of raw materials (in %)

Sl. No.	Raw materials	+10mm	10mm to 5mm	5mm to 3mm	3mm to 1mm	1mm to 0.5 mm	-0.5mm
1	Bolani iron ore	7.48	21.09	9.07	22.22	8.16	31.97
2	Gua iron ore	0.39	17.70	10.51	28.60	9.53	33.27
3	Flux	0.00	2.37	9.23	51.72	11.61	25.07
4	Mill scale	0.00	8.00	7.00	50.00	18.00	17.0
5	Coke breeze	1.0	11.0	10.0	25.0	9.0	44.0

2.3 Experiments with optimum use of coke breeze size for iron ore fines sintering

Four sets of pot sintering studies were conducted to understand the effect of coke breeze micro-fines. Based on the pot sinter studies, the optimum coke breeze size for achieving better sinter quality was identified. In this experiment, +3mm size fraction of coke breeze was fixed as 15% and the other two size fractions +0.5 to -3mm% and -0.5mm% were varied as given in *Table 4*. These two size fractions were generated by crushing the +3mm size fraction. Coke rate was also fixed for these experiments at the rate of 71kg/t of sinter for maintaining the uniformity of experiments for all four sets. Moisture percentage was measured after green mix formation and the same is presented in *Table 4*. Accordingly, VSS, yield, productivity, TI and +10mm% of sinter was calculated for these four sets of experiments.

Table 4: Effect of micro-fines in coke breeze on performance of sintering

Parameters, unit	Set 1	Set 2	Set 3	Set 4
Coke rate, kg/t	71.0	71.0	71.0	71.0
Size, + 3mm %	15	15	15	15
+0.5 –3mm, %	70	55	45	35
-0.5mm %	15	30	40	50
Moisture, %	8.4	8.35	8.37	8.28
VSS, mm/min.	13.06	13.09	13.9	12.88
Yield (+5mm), %	76.37	73.26	72.8	71.09
Productivity (+5mm), t/m^2/hr	0.967	0.965	0.98	0.883
TI, %	69.3	68.9	68.6	68.1
+10mm in sinter, %	62.67	58.65	58.5	58.1

The main energy input to sintering is solid fuel i.e. coke breeze [4]. Coke breeze size and quantity influence sinter quality and productivity. Coke breeze crushing generates micro-fines i.e; -0.5mm percentage size fraction. Micro-fines burn out very fast and create void, which results in inferior sinter quality [5]. Results of the experiments are shown in *Figures 3 and 4*, and *Table 4*.

2.4 Experiments with several proportion of mill scale and coke breeze

Laboratory pot sintering studies were conducted with Gua and Bolani ore in 2:3 ratios as per plant condition. Coke breeze (CB) and mill scale (MS) were varied as shown in *Table 5*. Remaining parameters were kept fixed as given in *Table 1*. A total of thirteen sets of pot sintering studies were conducted to understand the effect of coke breeze and mill scale on sintering. Base study was carried out with coke breeze and without addition of mill scale at 3.85% and 4.4% respectively. Mill scale was added to these two base experiments. Four and five set of study was carried out with increasing mill scale addition with the base of 3.85% and 4.4% coke breeze respectively. After getting the optimum mill scale quantity from the laboratory study, experiments were repeated with varying coke breeze quantity of 4.3% and 4.2% respectively.

Table 5: Result of pot test with varied conditions

Variable	VSS (mm/min)	Yield (+5mm) %	Productivity (T/m^2/hr)	TI (%)	+10mm sinter %
Base with CB-3.85%	19.7	66.5	1.21	60.8	50.9
CB-3.85%, MS-.8%	21.7	55.3	1.09	55.0	37.0
CB-3.85%, MS 1.3%	19.7	65.1	1.22	60.3	48.7
CB-3.85%, MS-3.85%	23.2	63.8	1.28	60.4	48.1
CB-3.85%, MS-3.9%	21.3	64.8	1.23	61.3	49.2
Base with CB 4.4%	20.3	69.5	1.31	63.0	52.8
CB-4.4%, MS-.5%	22.7	73.1	1.48	65.0	55.8
CB-4.4%, MS-.8%	**22.8**	**75.3**	**1.55**	**64.8**	**59.4**
CB-4.4%, MS-1%	22.4	74.6	1.38	63.8	57.1
CB-4.4%, MS-3.85%	21.3	70.8	1.38	68.7	51.6
CB-4.4%, MS-3.9%	**22.0**	**77.2**	**1.51**	**66.0**	**62.9**
CB-4.3%, MS-.8%	23.2	67.9	1.43	65.0	52.9
CB-4.2%, MS-.8%	18.8	69.4	1.17	66.0	55.1

Accordingly, VSS, yield, productivity, TI and +10mm% of sinter was calculated for these thirteen sets of pot sintering studies. Coke breeze and mill scale quantity was optimized to get the best result in sintering of goethite ore.

2.5 Vertical Sintering speed

The time taken to reach the maximum waste gas temperature during sintering process is called sintering

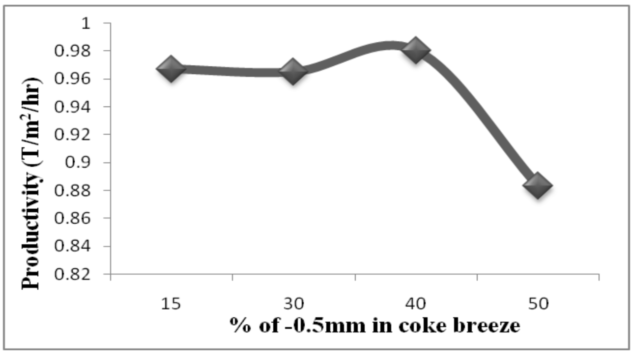

Figure 3: Effect of coke breeze micro-fines on productivity of sinter

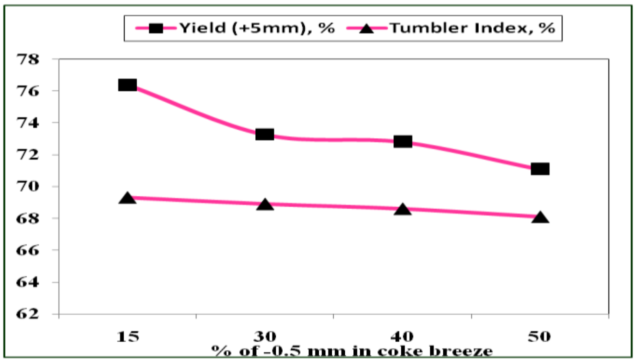

Figure 4: Effect of coke breeze micro-fines on yield & TI of sinter

time. The ratio of total height of charge mix on sintering pot/machine (in mm) to sintering time (in minutes) is called as vertical sintering speed and it is represented as VSS (mm/min).

2.6 Yield of finished sinter

After completion of sintering process the product sinter was air cooled for one hour and then the cooled sinter was dropped five times from a height of 2 meter on a steel plate for stabilization of sinter. Thereafter, it was screened for different size fractions such as -5mm, +5mm, +10mm, +25mm, and +40mm. The percentage of +5mm sinter size is considered as yield.

2.7 Strength of sinter

15 kg of +10mm to –40mm sinter is fed into a tumbler drum and rotated for 200 revolutions as per I.S. Standard No. 6495-1984 for 8 min. Sinter is then taken out from the drum and then screened for 6.35mm and 0.5mm screens. The percentage of + 6.35mm is taken as Tumbler Index.

3. Results and Discussions

3.1 Effect of micro-fines in coke breeze on performance of sinter plant

In the sintering process coke breeze is used as a primary fuel. This also acts as a reducing agent in sintering process. Studies have demonstrated that the rate of fuel combustion will depend upon the reactivity of the fuel and the oxygen content of the gas [6]. More reactive fuels produce a higher carbon monoxide concentration in the waste gas, and that a significant portion of the carbon monoxide may be lost through oxidation with air or gasified by carbon dioxide in the preheat zone.

Optimisation of energy through solid fuel i.e. coke breeze granulometry plays a critical phenomenon in sintering process. Coke breeze particle size to be used in sinter making must be -3mm to +1mm. In particular, coke breeze -3mm size fraction should be 100% with a minimum amount of micro-fines for maximum economy and efficiency of utilization. This also helps in improvement of RDI and RI properties of sinter [7]. From *Figure 3* and *Table IV*, it is very much clear that productivity starts decreasing after increasing the micro-fines above 40%. *Figure 4* shows that yield and TI also decreased very fast after input micro-fines increased from 15%. +10mm percentage in sinter also decreased with increase in coke breeze micro-fines. The moisture content of the solid fuel (coke) should ideally be constant to enable proper control of the amount of carbon added to the mix to be maintained [8].

If micro-fines percentage in coke breeze is high then the sinter will be weak and coke consumption will go up, because micro-fines of coke breeze will burn very fast and the required heat will not be available for sintering. Also more fines in fuel decreases efficiency through decreased bed permeability and by premature combustion. If +5mm percentage in coke breeze is high then also the sinter process will be slow and productivity will decrease. The main reason behind this is too coarse coke breeze will create segregation problem, form localized hot spots and broadening of combustion zone which in turn will lower the minimum temperature attainable as well as increasing fuel consumption.

As there is diversity in mineralogical components, it is understandable that there is complexity in sinter structure. *Figure 5* shows sinter structure produced in pilot scale. The shrinkage of geothitic ore particles due to presence of inherent moisture causes a gap to develop between them as confirmed by *Figure 5*. Also, presence of higher micro-fines leads to many pores of varying shapes and sizes as confirmed by black/void space in the microstructure of sinter. From macro pores of sinter structure sinter strength is determined while from micro pores reducing properties can be controlled. Thus, to improve sinter reducibility it is necessary to optimize the pore structure in sinter without affecting sinter strength [9].

3.2 Optimization of mill scale and coke breeze

As discussed earlier, goethite ores are porous in nature and thus granulometric efficiency is deteriorated by this. This deterioration in granulometric efficiency could be recovered by adding more water during preparation of green mix ball formation [10]. Owing high porosity, goethite ore have low density which in turn creates high reaction surface areas. Therefore, during sintering increased melt volume can be seen which are highly mobile which in turn decreases the permeability of sinter bed affecting sintering speed and productivity. For improving productivity at an integrated steel plant sinter machine speed or yield needs to be increased [11].

From these studies, it was envisaged that green mix granulation efficiency is very important in sintering process. The sinter microstructure with optimum mill scale and coke breeze is presented at *Figure 6*.

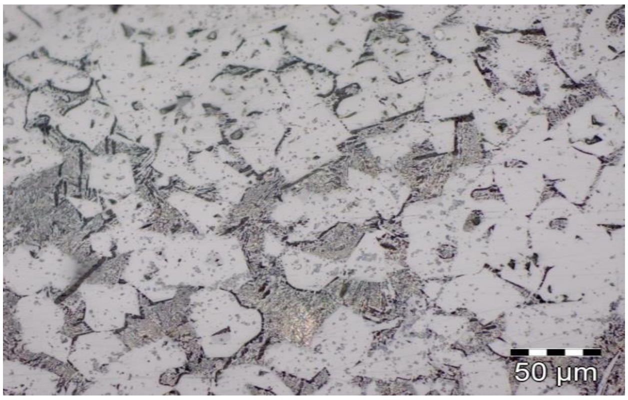

Figure 6: Microstructure of sinter after optimization of mill scale and coke breeze
(black = pore, white and grey = magnetite and wustite embedded in silicate matrix)

Addition of mill scale in green mix promotes the reaction of magnetite with CaO above 1150^{0}C and formation of di-calcium ferrite. The reduction in number of pores confirms the formation of more melt generation. Carbon content in the green mix affects the sinter TI with goethite ore. As the amount of coke breeze increases, the heat available for sintering also increases and it results in broadening of thermal profile after ignition. The peak temperature also rises from this improved thermal profile improving slag bonding in the melt [12].

Variation of TI, yield, +10mm sinter, VSS and productivity with change in coke breeze and mill scale quantity is shown in *Figure 7*. Addition of higher amount of mill scale decreases sinter bed permeability and hence a decrease in vertical sintering speed can be seen with CB-4.4% from *Table 5*. TI also increased after addition of mill scale in base experiments. Best results in terms of yield, productivity and TI are obtained with 4.4% coke breeze, mill scale 0.8% and 3.9% respectively but availability of mill scale in the tune of 3.9% may be difficult in the present situation. Hence, it is recommended to run the sinter plant with coke breeze 4.4% and mill scale 0.8% along with other raw material as above.

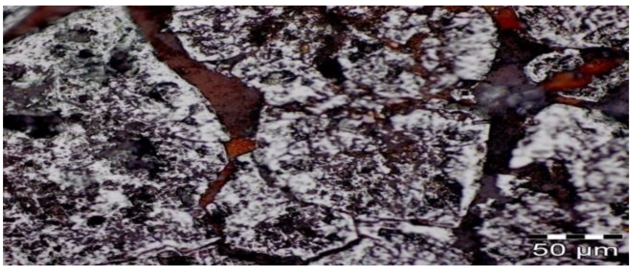

Figure 5: Microstructure of sinter with micro-fines of coke breeze

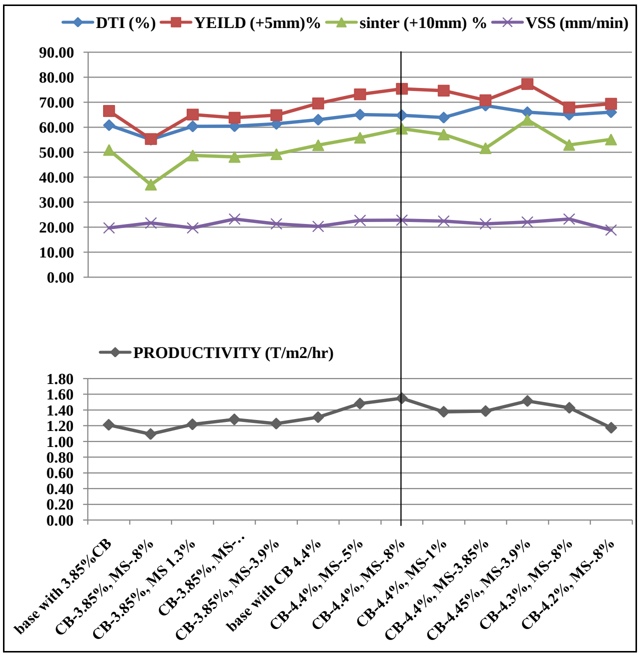

Figure 7: Variation of DTI, Yield, +10mm sinter, VSS & Productivity with change in coke breeze and mill scale quantity

Result obtained corresponding to each change is also shown in *Table 5*. Pot test data clearly shows that in case of sintering with high LOI ore i.e. goethitic ore, use of higher amount of coke breeze of optimum size with mill scale improves VSS, yield, productivity as well as TI.

4. CONCLUSION

Sinter; an agglomerate of iron ore fines, coke breeze and fluxes; is a tailor made blast furnace ferrous burden feed whose physical and chemical properties can be modified, to some extent, as per operational requirements. The following conclusions can be drawn from the present study:

1. Mill scale is a must for better sintering along with higher coke rate in goethite ore. Also, mill scale replaces equivalent amount of iron ore concentrate and increases the amount of iron percentage in sinter.
2. By optimizing the green mix blend, an increase in yield and strength (TI) of product sinter in the tune of ~11% each was achieved from the base with 3.8% coke breeze.
3. The required size (-40 to +10 mm) of sinter produced with optimum coke breeze and mill scale is much higher in the tune of 16% from the base with 3.8% coke breeze.
4. Best results in terms of yield, productivity and TI are obtained with coke breeze 4.4%, mill scale 0.8% and 3.9%, although, the availability of mill scale in the tune of 3.9% may be difficult. The specific productivity can be significantly increased by 18% from the base figure using mill scale 0.8% in the base mix on regular basis.
5. By improving the crushing index of coke breeze (-3 mm%) to 90% with <20% of micro-fines, the productivity and quality improves substantially with less specific coke breeze consumption leading to overall energy saving.
6. The permeability of green and sinter bed are very much dependent on each other. As goethite ore received at

above mentioned integrated steel plant have high LOI, green bed permeability must be given importance for improving productivity of sinter machines.

7. Besides cost savings, there is a need to address the environmental concern in sinter making, especially with emission of effluent gases like SO_x, NO_x, CO_x and generation of fine dust particles. Therefore, increasing sintering process efficiency is of paramount importance to reduce the environmental damages. The present work also aimed towards achieving that goal.

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