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MODIFIED COKE BREEZE DISTRIBUTION IN IRON ORE SINTERING - A NOVEL TECHNIQUE OF REDUCING ENERGY CONSUMPTION AND IMPROVING QUALITY

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Abstract

In normal sintering of iron ore, there is a wide difference in temperature of the sinter bed between top and bottom; i.e. the flame front temperature of the sinter bed gradually increases towards the bottom because the lower part gets longer time for drying and preheating by exit gas. Therefore, the top part may have insufficient fusion and the bottom is excessively fused. Thus, sinter quality may become inhomogeneous and the coke breeze requirement becomes higher than the actual thermal requirement. If it is charged in multiple layers; e.g. higher amount of coke at the top and a lower amount of coke at the bottom, heat will be homogeneously distributed and the actual coke requirement would be lower than the existing. However, no study has been done so far on this. Therefore, the current study explores the possibility of reducing energy consumption in iron ore sintering by reducing the coke ratio from top to bottom without deteriorating the sinter property. 12% reduction in coke breeze rate has been found and the sinter quality has been improved by the use of a triple layer of sinter mix with a lower coke rate towards the bottom. Further, when 5-vol% of oxygen has been enriched in suction gas along with using a triple layer of sinter mix, up to an 18-wt% reduction in coke breeze has been found.

Keywords: *Coke breeze; Multiple layers; Energy consumption; Oxygen enrichment*

1. Introduction

Conventionally coke breeze is used as the primary solid fuel in iron ore sintering. Reduction in consumption of primary fuel (coke breeze) without compromising on plant productivity and sinter quality would help in the operational cost reduction as well as in achieving the compliance of regulation related to hazardous emissions from sinter plants. Due to the poor availability of coke breeze in plant and environmental issues, coke breeze reduction in sinter plants is imperative.

To reduce the coke breeze (primary fuel) consumption in a sinter plant, many investigators [1-3] have tried to use alternative solid fuels viz. olive residue, sunflower husk, pellets, almond shells, etc. However, these materials have very low calorific value and may create operational difficulties. Gan et al. [2] found how to decrease the tumbler index of sinter for replacing coke breeze with biomass. However, the replacement of coke with char significantly decreases the sintering time and improves productivity [4]. There is some evidence of using high volatile raw petroleum coke and anthracite in commercial plants [5]. JFE Steel Corporation has developed the hydrogen-based gas fuel injection technology for sintering machines to improve sinter quality without increasing the coke breeze rate [6]. It has been possible to extend the temperature zone between 1200 °C and 1400 °C by injecting the gaseous fuel from the top surface of the sintering machine as a partial substitute for coke breeze.

Flue gas recirculation technology [7] was applied at Tobata No. 3 sinter plant of Nippon Steel Corporation in 1992. The technology succeeded in recirculating 25% of the sinter bed exhaust gas and reducing stack emission by the same degree without appreciable effects on sinter productivity and quality. The energy required to fire the raw sinter mix was successfully reduced from about 1500 to 1400 MJ/t-sinter.

The above studies were concentrated on the

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reduction of primary fuel consumption by the use of alternative solid fuels or injection of gaseous fuel. However, to reduce the overall energy consumption, the optimum use of coke breeze with optimum size range and its distribution in bed is required. Coke particle sizes 0.25 to 3mm were to be optimum for combustion efficiency and productivity [8]. However, Karabasov et al. [9] reported that the combustion rate of 1-2 mm coke particles was the highest, and Mikhalevich et al. [10] reported it as 1.6-2.5 mm coke particles. Tahanpesaranedezfuly et al. [11] proposed that eliminating particles smaller than 0.212 mm and larger than 3.35 mm creates an optimal condition for bed diffusivity and coke reactivity.

From the above, it is clear that earlier investigators have tried to reduce primary fuel consumption by the use of alternative solid fuels, such as olive residue, sunflower husk, raw petroleum coke and anthracite, and gas recirculation technique. Overall, fuel consumption has also been optimized by controlling the coke breeze size. However, the studies on the reduction of energy consumption in sintering are very rare. It is found that in the sintering bed the ignition happens from the top and moves towards the bottom, wherein, wind and gas also flow from the upper part to the lower part of the bed. Therefore, the heat generated from the ignition is carried by the gas and the convective transfer happens from the gas to the sinter mix at the lower bed. We know that the sinter mix is a homogeneous mixture with coke breeze, but the energy available is much higher at the lower portion of the bed, which is utilized for drying and preheating. On the other hand, when cold air enters the bed, it first passes through the hot sinter at the upper part wherein, heat exchange happens to preheat the cold air. The extent of preheating may gradually increase with the movement of the flame front. This preheated air helps improving the temperature of the flame front. Thus, the sinter bed may be inhomogeneously heated from top to bottom. The uppermost part may have insufficient fusion and the lowermost part may have excess fusion. This may result in inhomogeneity in bonding and poor quality of sinter. If the bed can be homogeneously heated, the sinter quality may be improved and energy consumption may be reduced.

Kang et al. [12] and Cheng et al. [13] observed the uneven distribution of heat pattern at different height of sinter bed. This uneven distribution can be controlled either by modifying the charging pattern to provide more coke at the upper part than the lower or by the control of gaseous fuel. Cheng et al. [13-15] proposed gaseous fuel segregation to optimize the heat distribution in a sintering bed and improve energy efficiency. First, the theoretical analysis was done for the selection of parameters to get the benefits of gaseous fuel [15], next the experiments were conducted by installing a gaseous fuel segregation control device in a normal sintering strand. They observed improved sinter quality and reduced energy consumption by 4% [13]. Solid fuel charging control was done by optimum coke segregation. Machida et al. [16] performed it by controlling the charging chute angle and magnetic flux density of the magnetic braking feeder to achieve the optimum segregation degree for coke. Zhao et al. [17] theoretically investigated minimizing the imbalanced heat distribution in iron ore sintering and determined the optimum segregation level of fuel. Modeling of two-layer iron ore sintering by charging raw materials with a normal coke content in the upper layer and a reduced coke content in the lower layer was carried out by Nath et al. [18] and the optimum conditions were obtained for the fuel efficiency and sintering performance by using a genetic algorithm.It is envisaged that the above investigators tried to homogenize heat distribution either by optimum gaseous fuel segregation or by optimum coke segregation. Most of the studies are theoretical and based on mathematical modeling. An experimental study is very rare, especially for solid fuel segregation. Therefore, the current study objects towards homogeneous heat distribution with multiple layers of sinter mix charging with a decreasing coke from top to bottom (i.e. lowest at the bottom and highest at the top) by which energy consumption and CO and CO_2 emission can be minimized and quality can be improved. Some investigators [19, 20] carried out oxygen injection to make up the insufficient heat in the upper part of the sinter bed. The air used in normal sintering contains 20% oxygen. However, 80% is atmospheric nitrogen, which does not take part in combustion. Although it helps in carrying heat from the flame front to dry and preheat the mix at the lower portion, a considerable sensible heat goes outside by exit gas. The amount of unreacted gas can be proportionally diluted to the optimum value by injecting a little bit of oxygen in the suction gas. Injected oxygen may also help faster combustion of coke breeze resulting narrow heating zone and a higher flame front speed [21]. Thus, oxygen injection may be one more option to reduce energy consumption in the sinter bed. Therefore, the objective of this study is to explore the possibility of reducing energy consumption in iron ore sintering by reducing the coke ratio from top to bottom and oxygen enrichment without deteriorating the sinter property.

2. Experimental

Raw materials were received from Tata Steel Jamshedpur whose chemical analyses are shown in Table 1. Joda iron ore of -10 mm was used for this study. The size distribution of all raw materials is also shown in Tables 2 and 3. Although the limestone was used for maintaining the basicity, 2% of hydrated lime was used which helped in granulation during mixing.

Table 1. *Chemical composition of raw materials used, wt%*

	Fe_{total}	SiO_2	Al_2O_3	CaO	MgO	P	C
Joda iron ore	65.6	3.98	2.35	0.4	0.24	0.063	
Limestone		0.3	0.11	55.18	0.35	0.03	
Dolomite		0.57	0.25	29.7	21.33	0.05	
Pyroxenite		41	2.5	7.46	32		
Coke		11.26	4.81	0.64		0.101	79.1

After the preparation of the mix, the mixture was mixed manually in dry conditions. Then the mixture was mixed in a disc pelletizer applying 7-8% of water. During rolling in the disc, it becomes homogeneous and micro balling was possible wherein large particles were surrounded by micro fines. The calcined lime helps in bond formation in the presence of water. After making the green mix, the granulated mixture was charged in a sinter pot for its sintering.

The photograph of the laboratory scale pot sintering assembly (8-9 kg capacity) is presented in Figure 1. The unit, a sinter pot made of a 190 mm diameter (I.D. 150 mm) and 480 mm long mild steel shell, which has a 20 mm thick refractory lining. The shell has six numbers of openings at six different heights of its sidewall wherein thermocouples are fitted to measure the bed temperature. TC1 through TC3 measures the temperature at the vertical centerline and TS1 through TS3 measures the inside wall temperature of the pot. There is an airtight-hinged door 350 mm long in front of the pot for removing the mass after sintering. The top is open for entering air and the green sinter mix is charged through. Ignition is also done from the top. At the bottom, there is a perforated magnesite refractory plate (grid), supported by a cast-iron grid to hold the burden and provide passage for sucked outgoing gas. Below this grid there is a separate chamber of the same diameter connected through a flange for arresting the dust carried by the outlet gas. The suction pipe is attached to the bottom of this chamber. The suction blower of a maximum capacity of 1200 lpm flow rate and maximum suction pressure of -5884Pa (-0.06 kg.cm^{-2}) is connected with the bottom pipe of the pot. Suction pressure is measured by a water gauge.

Table 3. *Size distribution of fluxes and coke breeze used in sintering*

Materials	+ 2 mm	+1 mm to -2 mm	+ 0.5 mm to - 1mm	-0.5 mm
Limestone	31.6	14.9	7.7	45.8
Dolomite	30.4	7.1	5.4	57.1
Pyroxenite	33	13.3	6.3	47.4
coke	57.1	26.3	16.6	

12-13 kg (dry weight) of the green granulated mix was charged into the sinter pot from the top hole. The suction pump was switched on and the ignition was initiated at the top by burning jute and coke oven gas flame with a mild suction of air. After the ignition, the air suction was increased by opening the valve to its maximum suction capacity in all experiments. The flame front propagated from the top towards the bottom, which was monitored through temperature measurement. Skin temperature and the flame front propagation were observed from the readings of the thermocouples. The maximum temperature of the flame front was recorded to be in the range of 1200-1350 °C for different experiments. The trend of temperature rise of the top middle and bottom thermocouples were recorded. The operation was continued until the bottom thermocouple started to cool. After cooling, the sinter cake was removed from the pot through the front door. The cake was crushed to the desired size and the sinter was characterized physically and physicochemically to assess its usability.

To study the effect of oxygen enrichment, sintering experiments were done in the same set-up with minor modification as shown in Figure 2. A conical top was fitted at the top to connect the pot to the gas mixing facility. Commercially pure oxygen was supplied from the cylinder and air was supplied from the compressor. There were a pressure gauge and a flow meter at the inlet line of air with an oxygen purging facility. The specific ratio of the oxygen to air was maintained by a ratio controller. There was one opening at the conical top for ignition and another opening was fitted with blue glass for viewing. After the ignition, the ignition hole was closed by a socket. The ignition was initiated through the ignition hole at the conical top by burning jute with a little flow of oxygen under mild suction. After the ignition, the oxygen and air ratio was maintained as desired and

Table 2. *Size distribution of iron ore fines used in sintering*

Material Taken	Size distribution, wt%								
	+ 10 mm	+ 8 to -10 mm	+ 6.35 to -8 mm	+ 5 to -6.35 mm	+3.15 to -5 mm	+ 2 to -3.15 mm	+ 1 to – 2 mm	+ 0.5 to -1 mm	- 0.5 mm
1000 g	6.9	17.8	5.9	5.0	17.8	17.1	6.85	4.9	17.7

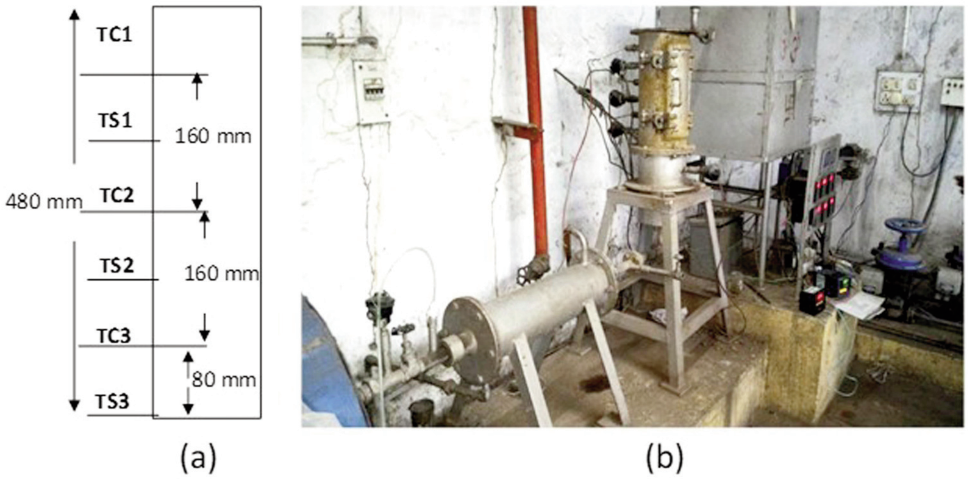

Figure 1. *Sintering set-up using air only (No oxygen enrichment): a) Schematic of thermocouple position in sinter pot; b) photograph of set-up*

sintering experiments were done as mentioned above. The maximum temperature of the bed was measured by R- type thermocouple, TC2.

To examine the cold handling property of the produced sinter, the shatter and tumbler tests were conducted. The shatter test was done (as per standard: IS9963-1981-2003) by dropping 2 kg of a dry sample of the size range +10 to -40 mm from the height of 2.0 m for four times over a 10 mm thick mild steel (MS) plate. The different size fraction of broken material after the shatter was quantified. The percentage of +5 mm size was termed as Shatter Index (SI).

Tumbler test was done (as per standard: IS6495-1984-2003) taking 500 g of dry sinter of the size range +10 to -40 mm and allowing 1500 revolution (@25 rpm) in a 200 mm diameter and 150 mm long mild steel drum. After the revolution, the percentage of +6.3 mm was taken as a measure of the Tumbler Index (TI). Abrasion Index (AI) was measured as follows:

AI= {M-(M1+M2)} x 100/M

Where, M: Mass of the sample before the test, M1: Mass of sample retained in 6.3 mm screen after test, M2: Mass of sample passing through 6.3 mm screen and retained in 0.5 mm screen after the test.

The reducibility index (RI) of the sinter in this study was measured as per standard: JIS: M 8713-2000. The reduction degradation index (RDI) of the sinter was measured as per standard: JIS: M 8720-2001.

Acceptable properties [22] of sinter for blast furnace operation is shown in Table 4.

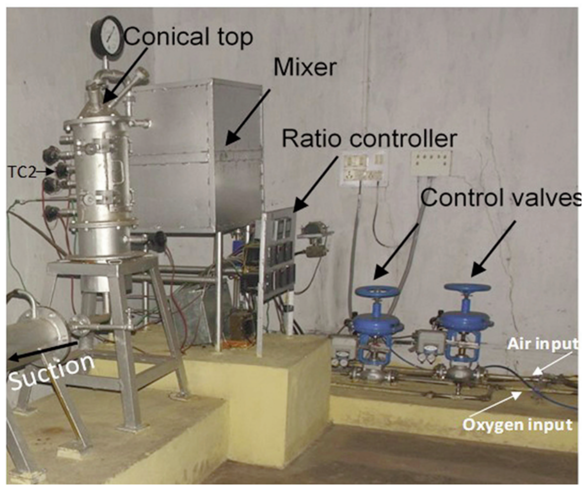

Figure 2. *Sintering set-up with oxygen enrichment*

3. Results and discussion

The results obtained in this study are discussed in four different sections as follows.

(i) Sintering of the sinter mix with uniform coke breeze content.

(ii) Sintering study with two different coke content at the top half (higher) and the bottom half (lower) of the sinter bed.

Table 4. *Acceptable properties of sinter for blast furnace*

	Minimum Shatter Index % of +5 mm	Minimum Tumbler Index, % of + 6.3 mm	Minimum RI, %	Maximum RDI, %
Acceptable limit [22]	85	69	65	27

(iii) Sintering study with three different coke content as the top (highest), middle, and the bottom half (lowest) of the sinter bed.
(iv) Sintering with oxygen enrichment.

In this study sinter basicity and MgO content were maintained as per typical plant (Tata Steel, Jamshedpur) practice; i.e. CaO/SiO_2 ratio was around 2.6 and MgO content was 1.9%.

3.1. Sintering study with uniform coke breeze distribution

For this study, the optimization of the coke breeze is required first. Therefore, sintering was conducted with varying coke breeze content with a uniform mix. The properties of the sinter with varying coke rates are shown in Table 5. With 6 and 6.5% coke breeze some over fusion was found. When coke content was 5%, the sinter yield was found to be decreased drastically because of improper fusion. 5.5% coke breeze can produce very good sinter yield with good properties like shatter index, tumbler index, and abrasion index. Therefore, a 5.5% coke breeze requirement was found to be optimum for uniform coke breeze distribution.

When the coke breeze was kept uniform (5.5%) throughout the bed, the sintering temperature at the centerline thermocouples was measured and plotted in Figure 3. The temperature of the thermocouple at the bottom is much higher than that at the top. This is because the top part is ignited first and the heat front moves from the top towards the bottom. During the burning of coke in the upper part, the air gets preheated and passes towards the bottom. Again, the hot sinter produced at the top is cooled by the air entered at the top; i.e. inlet air gets preheated. As the flame front propagated towards the bottom, the air has to pass through a longer path of the sintered bed resulting in higher extent of preheating. This preheated air takes part in the combustion of the sinter mix at the lower part, which helps increasing flame front temperature. Moreover, the materials at the lower portion become dry and preheated during the combustion at the upper part. Thus, the lower portion becomes more heated, which increases the temperature of the bed; i.e. a higher amount of energy is consumed at the lower part of the bed. This also may cause over-fusion.

To assess the difference of sinter quality between the top and bottom, the samples have been collected separately from the top and bottom portion and tested. The properties of the sinter collected from the top and bottom portion were measured and shown in Table 6. Sinter at the bottom part has better SI and TI than the top part because of better fusion at the higher temperature. However, slightly lower RI was found in the sinter of the bottom part. This may be because of a proportional loss of permeability due to the greater extent of fusion. Thus, from the above findings it is

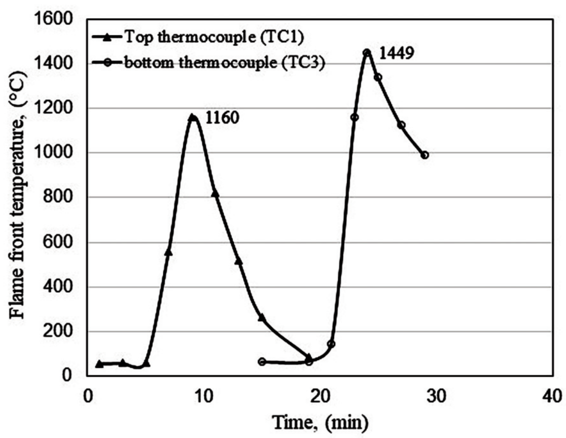

Figure 3. Temperature of sinter bed at along the center line at top and bottom thermocouples

Table 5. Sinter properties with varying amount of coke breeze in sinter mix with uniform coke distribution

Sl. No.	Coke breeze, %	Avg. max. temp, °C	Yield +10 mm, wt%	Yield +5 mm, wt%	Mm SI +10 mm, wt%	SI +5mm, wt%	TI, wt%
1	6.5	1304	67.8	85.7	65.1	89.5	87.9
2	6	1372	70.7	86	67.3	90.2	87.3
3	5.5	1258	64.6	79.5	68.2	90.6	88.0
4	5	1186	39.2	61.3	63.7	90.6	84.9

Table 6. Properties of the sinter collected from the top and bottom for uniform charge mix

Sinter collected from	SI , %		TI, % (+5 mm)		RDI, %	RI, %
	(+10 mm)	+5 mm		AI, %		
Top	65.4	88.8	87.1	3.1	17.9	84.1
Bottom	70.7	91.5	89.0	4.3	21.7	78.1

envisaged that in spite of the homogeneous mixture in sintering, the inhomogeneous temperature distribution in the sinter bed happened which caused inhomogeneous fusion resulting in inhomogeneous sinter properties.

3.2. Sintering study with two layers with reduced content of coke breeze at the bottom

To reduce this temperature difference at the top and bottom of the sinter bed, correct coke distribution is required. First, the study was conducted in two different coke ratios. Higher coke at the top half and lower coke at the bottom half. In these experiments, coke content at the top and bottom were varied and the average percentage was gradually reduced. The properties of sinters obtained from the different coke percentages at the top and bottom are shown in Table 7. All the sinter properties were satisfactory. The coke rate could be reduced down to an average of 5% with 5.5% at the top and 4.5% at the bottom. At this percentage of coke, the average flame front temperature was found to be 1246 °C, which is reasonable and the sinter properties are good. It should be noted that when the average coke breeze percentage was reduced below 5% (say 4.75%); the sinter yield was drastically reduced to below 50%. Hence, an average of 5% coke was found to be the minimum requirement for two-layer charging. Thus, up to 9%, coke breeze reduction is possible if coke in the sinter mix is charged in two different ratios at the top and bottom of the bed.

At 5.5%, coke at the top, and 4.5% coke at the bottom the temperature of centerline thermocouples are shown in Figure 4. The figure shows that by using two different coke ratios the difference in temperature between the top and the bottom thermocouples could be reduced in comparison to the uniform charge mix (Figure 3). It is also observed from the figure that the heat front takes only 18 min time to reach the TC3 thermocouple position. However, for uniform charging (Figure 3) it takes much more time (24 min). This is mainly because in two-layer charging with lower coke at the bottom, the over-fusion of sinter in the lower portion of bed could be reduced, which facilitates passing the air through the combustion zone. This results in an improvement in the permeability of the sinter bed.

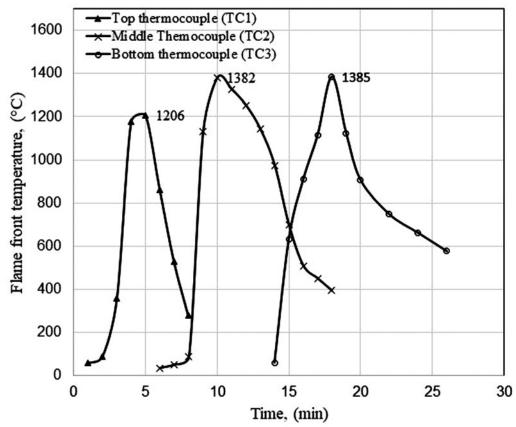

Figure 4. Temperature of sinter bed at along the center line at top, middle and bottom thermocouples with two different coke ratios at top and bottom

3.3. Sintering study with three-layer with reduced content of coke breeze at the bottom

For the further improvement of coke breeze consumption as well as sinter quality, three different sinter mixes with reducing coke content towards the bottom were studied. Sinter mass was equally divided into three parts, but the coke content was kept different in three. Since 5.5% coke in uniform (single layer) and 5% in double-layer coke charging was found to be optimum, the coke content at the top layer is kept fixed at 5.5% and that of the middle is kept fixed at 5%. The coke content of the bottom layer is gradually decreased. The character of the sinter produced is shown in Table 8. It is envisaged from the table that the average coke breeze consumption could be reduced down to 4.83 wt%; i.e. 5.5, 5.0, and 4.0% at the top, middle, and bottom, respectively. At this coke breeze level, the yield was found to be very high, and the shatter index was improved. However, when the coke content of the bottom layer was decreased below 4% keeping the top and middle layer unchanged, the sinter yield was drastically reduced to below 52%. Therefore, 4.83% coke breeze with 5.5, 5.0, and 4.0 ratios for the top, middle, and bottom may be considered as optimum. Thus, a 12-wt% lowering in coke breeze is possible if the sinter mix is divided into three equal mass but also with reducing coke ratio towards the bottom.

Table 7. *Sinter properties with sinter mix of two different coke rate (higher at the top and lower at the bottom)*

Coke breeze, %			Avg. Flame front temp °C	Yield +10 mm, %	Yield +5 mm, %	SI, +10 mm, %	SI, +5 mm, %	TI, %
Top	Bottom	Avg.						
6.5	5	5.5	1300	60.0	77.6	72.3	91.1	
5.5	5	5.25	1254	63.8	78.1	73.1	91.5	86.4
5.5	4.5	5	1246	60.4	77.2	67.3	90.7	88.1

Table 8. Sinter properties with varying coke ratio in three layers, reducing towards bottom

Coke breeze, %				% Yield +10 mm	%Yield +5 mm	SI +10 mm, %	SI +5 mm, %	TI, %
Top	Middle	Bottom	Avg.					
5.5	5.0	4.5	5.00	45.4	65.1	65.9	90.1	91.3
5.5	5.0	4.25	4.92	63.8	80.3	72.4	90.3	90.5
5.5	5.0	4.0	4.83	65.3	82.8	72.6	91.3	87.2

The flame front temperature along the centerline was measured at top middle and bottom by R type thermocouples. The temperature versus time is shown in Figure 5. The maximum temperature of the three different zones is more or less the same. This is because of the lower coke at the bottom of the sinter bed. Thus, the temperature difference between the top and the bottom could be eliminated. This homogeneous temperature distribution in the sinter bed helps to improve the sinter quality, homogeneity and can reduce energy consumption. In the conventional uniform sinter mix, the bottom part becomes over fused and the topmost part remains unfused. However, due to the lowering coke ratio from top to bottom, this inhomogeneity problem could be alleviated and coke breeze consumption could be reduced by 12%.

Moreover, the time required to reach the flame front at TC3 position is around 18 min, which is similar to 2 layer charging and much less than uniform charging. The reason for the faster movement of the flame front is mentioned in sec 3.2. From this, it is envisaged that due to multi-layer charging with lower coke at the bottom, sintering process becomes faster and hence the productivity of a strand can be improved.

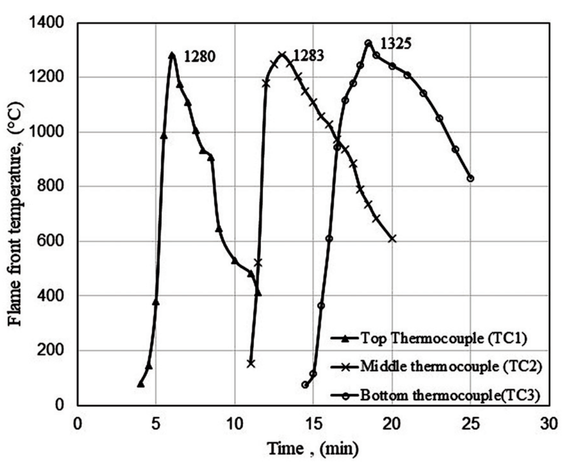

Figure 5. *Temperature of sinter bed at along the center line at top, middle and bottom thermocouples with three different coke ratios at top, middle and bottom*

3.4. Comparison of physicochemical properties

For the metallurgical application of the sinter, the physicochemical properties viz. reducibility index and reduction degradation index are very important. In Table 9, the physicochemical properties of sinter made with conventional uniform sinter mix and three-layered sinter mix are compared. It is depicted that RI is much higher and RDI is much lower in sinter made by the modified coke breeze distribution. This is because relatively more homogeneous heating of the sintered mass and homogeneous fusion, which causes uniform bonding in modified coke breeze distribution. However, in the conventional uniform coke breeze distribution in the sinter mix, the produced sinter shows less fusion and poor bonding at the top and over fusion at the bottom, which results in lower RI and higher RDI.

Table 9. *Physicochemical properties of sinter made*

Sinter description	RI, %	RDI, %
Sinter obtained from uniform coke breeze	78.1	21.76
Modified coke distribution (3 layered sinter mix lowering coke breeze towards the bottom)	84.1	17.96

Thus, the modified coke breeze technique can homogenize the fusion in the sinter bed from top to bottom, decrease coke breeze, and improve sinter properties.

3.5. Sintering study by oxygen enrichment

Oxygen has a very important role in iron ore sintering. Air is sucked for the ignition and combustion of coke in the sinter bed. The oxygen present in the air reacts with the C in the coke breeze and produces sufficient heat to the sinter bed. The rate of combustion and temperature rise can depend on the amount of oxygen present in the inlet air/gas. To reduce the coke breeze consumption, the oxygen enrichment in the supplied air in the suction point was done. For these experiments, the modified coke breeze ratio in three layers of sinter mix with lower coke breeze at the bottom was used.

3.5.1. Varying coke-breeze ratio with constant oxygen injection

Oxygen enrichment experiments were started with three-layer charging in the coke ratio of 5.5: 5: 4.5 because it was found to be the optimum ratio as mentioned above. In these experiments, the volume percentage (vol %) of oxygen enrichment is kept constant at 10%. With 10-vol.% oxygen enrichment, it was found to increase the thermocouple temperature further and some over fusion in sintered mass was observed in spite of the same average coke breeze ratio as it was optimized (5.5: 5.0: 4.0 ratio for the top: middle: bottom) in three layers. This is because, with 10-vol% oxygen enrichment, a proportional amount of air required for the burning of the same amount of coke is reduced. This volume reduction of required air is so significant (lowering by ~25% of original volume) that the heat (sensible heat) carried by the gas after combustion may reduce substantially. This helps in improving the flame temperature of the sinter bed. The high flame temperature causes over-fusion of material. To avoid over-fusion, the coke breeze needs to be decreased. Therefore, the coke breeze ratio could be decreased gradually to an average of 4.5% (5%, 4.5%, and 4% at the top, middle, and bottom, respectively). At this level of coke breeze, the properties of the sinter are shown in Table 10. The yield, TI, and shatter index remain similar to a decrease in coke breeze; however, RDI decreased and RI increased further, which is desirable. Thus, the 10% oxygen enrichment improves sinter property and decreases coke breeze consumption to 4.5%. Hence, due to the combined effect of three varying layer coke ratio and 10-vol% oxygen injection, coke breeze consumption reduces up to 18-wt%.

3.5.2. Varying oxygen enrichment

It has to be investigated whether 10-vol% oxygen enrichment in the sinter bed is appropriate or not. Therefore, the effect of a lower amount of oxygen was examined. The results of 0, 5, and 10-vol% oxygen enrichment are shown in Table 11. It is envisaged from the table that with 5% oxygen enrichment, the maximum temperature of the sinter bed is achieved to 1257 °C. However, the shatter index and the tumbler index are improved, and RI and RDI are acceptable. Since the 5-vol% oxygen enrichment can also reduce the coke rate by 18-wt% and yields good quality sinter, 10-vol% oxygen enrichment is not required.

It is evident from the above that a reduction in coke-breeze consumption is possible by the gradual decrease of the coke breeze distribution in the sinter mix from top to bottom. Thus, the average coke consumption decreases by 12-wt% and sinter quality improves. Further decrease in coke breeze is possible by 5-vol% oxygen enrichment with suction air. The combined use of these two can reduce the coke breeze rate up to 18-wt%. Reduction in coke breeze rate means less amount of carbon burning and hence less amount of CO and CO_2 emission. Thus, this technique may help in controlling pollution.

For practical purposes, changing the coke breeze ratio in the different layers may not be possible in the existing sintering set-up because of the single line mixing and feeding provision to the sinter strand. If a multipoint mixing and feeding provision of raw materials mixture is installed, double layer and triple layer charging will be possible by a

Table 10. *Sinter properties and flame front temperature for varying coke breeze percentage with 10 vol% O_2 enrichment*

Average Coke Breeze, wt%	Coke ratio top : mid : bottom	Flame front Temp, °C (TC2)	O_2 Enrich-ment, vol%	Shatter Index, % +10 mm	Tumbler index, % +6.3 mm	Abrasion Index, % -0.5 mm	RDI, %	RI, %
5	5.5 : 5: 4.5	1326	10	72.2	91	3.3	18.3	73.80
4.7	5.5 : 4.5 : 4	1275	10	72.5	90	3.6	16.3	-
4.5	5 : 4.5 : 4	1260	10	72.3	90	3.9	15.1	78.13

Table 11. *Sinter properties and flame front temperature for varying oxygen percentage in three-layer sintering*

Average Coke Breeze, wt%	Coke ratio top : mid : bottom	O_2 Enrich-ment, vol%	Flame front Temp, °C (TC2)	Shatter Index, % +10 mm	Tumbler index, % +6.3 mm	Abrasion Index, % -0.5 mm	RDI, %	RI, %
5	5.5:5:4.5	0	1282	67	90	3.4	17.9	84.07
4.5	5:4.5:4	5	1257	73.5	90.5	3.9	18.9	79.83
4.5	5:4.5:4	10	1260	72.5	90.5	3.9	15.9	78.13

programmable logic controller (PLC) and up to 12% coke breeze reduction will be possible by coke breeze segregation. On the other hand, process oxygen is available in-house in all integrated steel plant. If a provision of 5-vol% oxygen enrichment to suction gas of the sinter strand is provided, further reduction of coke breeze is possible. Therefore, in both the approaches modification of existing sintering set-up and installation of additional facilities are required for their implementation

4. Conclusions

(i) A significant difference in maximum temperature between the top and the bottom of the sinter bed and inhomogeneous sinter properties was found with the use of coke breeze uniformly in the sinter mix. The temperature was found to be gradually increasing towards the bottom of the pot. This increases energy consumption and deteriorates sinter properties.

(ii) When the sinter mix containing two different coke breeze contents was used in two layers (lower one at the bottom), the temperature difference was reduced and coke breeze consumption was decreased by 9-wt%.

(iii) The temperature difference could be reduced further and made it thermally homogeneous by the use of three layers of sinter mix with a lower coke rate towards the bottom (5.5, 5.0, and 4.0 ratio for the top, middle,and bottom). Up to 12% lowering of coke breeze was possible by the use of three-layer charging and the sintering time could be reduced to a great extent (25%) which may result in the productivity improvement of the strand.

(iv) Sinter quality (RI, RDI, shatter Index, and tumbler index) could be improved by the use of the above three-layer of sinter mix with a lower coke rate towards the bottom

(v) Use of 5-vol.% oxygen enrichment with the suction gas improved the thermal efficiency of the sinter bed. The combined use of coke breeze in three layers as above and 5-vol% oxygen enrichment yields 18-wt% reduction in coke breeze consumption.

(vi) The triple layer sinter mix (lower coke at lower side) and oxygen enrichment in the sinter bed not only decrease coke consumption but also can reduce CO and CO_2 emission. However, its implementation in the plant requires a modification of the existing setup and the installation of additional facilities for charging and oxygen enrichment

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MODIFIKOVANA DISTRIBUCIJA KOKSNE PRAŠINE PRI SINTEROVANJU RUDE ŽELEZA – INOVATIVNA TEHNIKA SMANJENJA POTROŠNJE ENERGIJE I POBOLJŠANJA KVALITETA

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Apstrakt

Pri uobičajenom sinterovanju rude železa postoji velika razlika u temperaturi sintera između vrha i dna; temperatura vrha plamena sintera postepeno raste kako se kreće ka donjem delu zato što je potrebno više vremena za sušenje i predgrejavanje uz pomoć izlaznog gasa. Zato je moguće da fuzija u gornjem delu sintera bude nedovoljna, a u donjem delu prekomerna. Iz tog razloga kvalitet sintera može biti nehomogen, a zahtevi koksne prašine mogu postati veći od aktuelnih termičkih zahteva. Ako je punjenje sintera višeslojno, npr. veća količina koksa na vrhu a manja pri dnu, toplota će biti ravnomerno distribuirana i aktuelni zahtevi koksa će biti manji od postojećih. Pa ipak, do sada nijedna studija nije urađena o tome. Iz tog razloga, ova studija ispituje mogućnost smanjenja potrošnje energije pri sinterovanju rude železa uz pomoć smanjenja proporcije koksa od vrha do dna, a da se pri tome ne pogoršaju svojstva sintera. Otkriveno je da korišćenje trostrukog sloja mešavine sintera sa manjim udelom koksa prema dnu dovodi do smanjenja stope koksne prašine od 12% i do boljeg kvaliteta sintera. Osim toga, kada je uz korišćenje troslojne mešavine sintera usisni gas bio obogaćen kiseonikom 5-vol%, otkriveno je da dolazi do smanjenja koksne prašine od 18-wt%.

Ključne reči: *Koksna prašina; Višestruki slojevi; Potrošnja energije; Obogaćenje kiseonikom*