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"A study on the accretion formation in DRI kilns and possible ways for its reduction"

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Abstract: *Direct reduction of iron ore with aid of either carbon or natural gas under controlled temperatures and pressures within a rotary kiln generates sponge iron as a product. However rotary kiln performance is adversely affected by the ring formation known as accretion. These accumulated sintered solid particles which gives formation of ring along the length of the kiln hinder material flow, lowers the life span of kiln and productivity. To improve the performance of rotary kiln and maintaining the quality of sponge iron, there is a need to reduce the accretion formation in the kiln. However it is difficult to control accretion formation in the kiln due to the erratic nature of the reduction process dynamics. This paper suggests the control of accretion formation in rotary kiln by increasing the fusion temperature of the complex compound which sticks to refractory wall by adding suitable additives.*
Key-words: *direct reduction, rotary kiln, accretion and fusion temperature*

I. Introduction

Primary iron production is still predominantly made by the blast furnace process. However, there are disadvantages inherent to the blast furnace process such as: 1) dependence on high-quality metallurgical-grade coke and iron oxide feed stocks (pellets, sinters, briquettes); 2) economic viability only at large capacities; 3) environmental constraints on the

coke ovens and sinter plants; 4) requirement of auxiliary plants (e.g., raw materials handling and preparation systems, sinter plants, coke ovens with strict environmental control systems, pellet hardening kilns); and 5) high capital and operational intensity, etc. [1]. These disadvantages led to the development of alternative iron-making processes such as the mini blast furnace process, smelting reduction processes, and direct reduction processes.

Mini blast furnace and smelting reduction processes include the reduction and smelting of iron oxide feed stocks utilizing charcoal (mini blast furnace process) or carbon-bearing materials (smelting reduction processes) producing slag-free pig iron.

On the other hand, direct reduction processes include reduction of iron oxides in the solid state, below the fusion temperature of pure iron (1535^{o} C), utilizing hydrocarbon gases and or carbon-bearing materials as reducing–carburizing agents. Direct reduced iron (DRI) is a highly metallized solid that still contains slag. Due to the fact that during direct reduction processes only oxygen inherent to the iron oxide feed stocks is removed from the system, the DRI produced has a similar but more porous physical form than the iron oxide feed materials utilized [2,3]. Thus, due to this porous structure, DRI is often called sponge iron.

Sponge iron is the metallic form of iron produced from reduction of iron oxide below the fusion temperature of iron ore (1535^{o}C) by utilizing hydrocarbon gases or carbonaceous fuels as coal. The reduced product having high degree of metallization exhibits a 'honeycomb structure', due to which it is named as sponge iron. As the iron ore is in direct contact with the reducing agent throughout the reduction process, it is often termed as direct reduced iron (DRI).

Sponge iron is produced primarily both by using non-coking coal and natural gas as reductant and therefore classified as coal based and gas based process respectively. Due to promising availability of coal of 264,535 million tonnes the coal based sponge iron plants share the major amount of its production [5]. At present, there are 118 large and small sponge iron plants operating in India, among them only 3 are natural gas based and the remaining 115 plants are coal based. Among all the available options, rotary kilns have been widely used as a reactor in coal based plants and the important processes applying this technology include: SL/RN, Codir, ACCAR, DRC, TDR, SIIL and Jindal [6–9]. In the present work SL/RN process based plant is selected for energy conservation as it is oldest and most widely applied process. Many investigators considered sponge iron manufacturing process and suggested improvement in that [8, 10, 11].

Directly reduced iron (DRI, or called sponge iron) has been found an excellent feed in electric arc furnace (EAF) steel making, which has low tramp element content and steady component as a substitute for scrap, it is generally preferred in the production of high quality steel [12-14]. Nearly 59.8 million tons of DRI were produced in 2006 over the world, some 80% of which were produced by gas-based processes, the left by coal-based processes. However, total DRI output continued to increase and reached 68.8 million tones even confronted with economical crisis in 2008; coal based DRI was increased up to 17.6 million tons amounting for 25.7% of total DRI production due to higher natural gas price [15].

Rapid growth in technology has resulted in increased demand for high quality products. This has called for high performance control systems for industrial applications to produce high-tech products. The complexity of a processing plant determines the type of control strategy to be implemented. Sponge iron production process requires accurate monitoring and control of the process parameters. The performance of rotary kiln sponge iron based processes is normally affected by accretion build up along the kiln linings. Accretion build up is the accumulation of semi-molten material which form rings along kiln lining. These rings narrow the kiln diameter thereby hindering efficient material flow and effect lowering production rate and performance of the kiln.

A study on the accretion formation in DRI kilns and possible ways for its reduction.

The formation of a ring or an accretion is caused by the deposition of low melting complex compounds on the refractory wall of the kiln, which progressively increases in thickness and ultimately takes the shape of a circular ring. This occurs preferentially at a particular position in the reduction zone of the kiln, where the stability of the wustite phase is high.

Reasons for accretion/ring formation:

The principle reason for build-up in rotary kilns is the formation of low melting complex compounds in the **FeO-SiO_2-Al_2O_3** system, such as wustite, fayalite, iron cordierite, hercynite, and in the **CaO-MgO-FeO-SiO_2-Al_2O_3** system, such as melilite or anorthite, akermanite, iron-magnesium cordierite, spinel, and iron-magnesium silicate [16]. The coexistence of these complex compounds decreases the fusion temperature of the kiln charge, which in turn adheres to the refractory walls. Some accretions also forms because of agglomeration of fines nearer to the charge end or because of sintering of sponge iron owing to excessive temperature and/or lower carbon/iron ratio at the discharge end of a rotary kiln.

Major equipments:

The details and the purpose of the various kiln components installed for attainment of a better final product i.e. DRI are as follows:

Rotary kiln:

Kilns are thermally insulated chambers in which a controlled temperature regimes are produced used for the direct reduction (solid state reduction) of iron ore to obtain DRI as a final product. For the efficient operation of the kiln; the retention time of the charge is of significant .

The Dimensions of the Rotary Kiln used in Direct Reduction Plant of JSPL, DRI#II are as follows:

Kiln length	82 m
Internal diameter from shell to shell	4.8 m
Thickness of the refractory lining	230 mm
Slope or inclination of the kiln	2.5% of total length of the kiln
Kiln shell thickness	25mm
The **Capacity** of the kiln	500 tonnes of DRI /day

Analysis Of Accretion:

Chemical analysis of accretion:

It is seen from the analysis report that the chemical composition of accretion is not the same. So, we have taken two extreme accretion samples whose typical chemical compositions are:

Composition	Accretion 1 (%)	Excluding Fe (M) (%)	Accretion 2 (%)	Excluding Fe (M) (%)
Fe (T)	36.86		56.97	
Fe (M)	27.73		9.73	
FeO	11.78	16.34	48.69	55.38
SiO_2	31.0	42.98	12.36	14.06
Al_2O_3	24.45	33.90	23.63	26.88
CaO	4.5	6.24	3.04	3.45
MgO	0.16	0.22	0.20	0.23

Sources of these compounds:

- **Iron Ore** : Source of FeO
- **Dolomite** : Source of CaO and MgO
- **Coal** : Source of SiO_2 and Al_2O_3

XRD analysis of accretion: XRD analysis has been done to find out the phases presented in the accretion and which phase is mainly responsible to reduce the fusion temperature of the charge materials.

This is the as synthesized powder sample along with 2θ, value miller plane, component and phase. The XRD pattern shows 16 distinct peaks for different phases. The 2θ values corresponding to the "d" values are given in the table below.

S.No.	2θ		D values	Miller's Plain (h k l)	Component	Phase
	Obs.	Stdr.				
1	16.08	5.37	5.37	2 2 0	SiO_2	Orthorhombic + Triclinic
2	21.56	4.02	4.04	3 1 1	Fe_2SiO_4	
3	26.1	3.33	3.36	1 1 4	$CaAl_2Si_2O_8$	
4	27.8	3.13	3.15	2 2 1	$(Mg,Fe)SiO_4$	
5	30.7	2.84	2.88	3 5 2	SiO_2	
6	31.46	2.77	2.72	4 3 0	$(Mg,Fe)SiO_4$	
7	34.8	2.51	2.50	6 1 0	Fe_2SiO_4	
8	35.7	2.45	2.48	4 3 0	$(Mg,Fe)SiO_4$	
9	36.23	2.42	2.44	0 4 2	SiO_2	
10	44.4	1.99	1.99	4 8 1	SiO_2	
11	51.1	1.744	1.74	8 3 2	Fe_2SiO_4	
12	56.5	1.58	1.58	7 1 0	Fe_2SiO_4	
13	58.6	1.53	1.53	3 1 9	$CaAl_2Si_2O_8$	
14	60.8	1.48	1.48	2 8 5	Fe_2SiO_4	
15	64.3	1.41	1.40	1 1 8	$CaAl_2Si_2O_8$	
16	82.2	1.14	1.14	2 2 0	$CaAl_2Si_2O_8$	

From the above sample we can find that mixed phase is present.

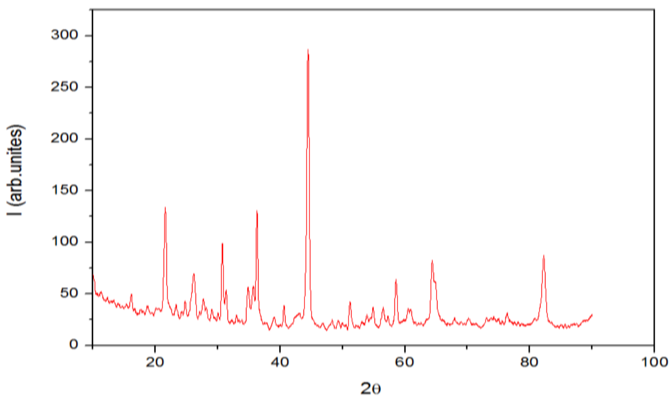


Figure: XRD graph of accretion 1.(from IUC, Indore)

Identified Phases

Phases	Chemical formula	Melting point °C	JCPDS file no.
Hortonolite or Fayalite	Fe_2SiO_4	1205	34-0178
Iron Magnesium Silicate	$(Mg,Fe).SiO_4$	---	26-0876
Cristoballite	SiO_2	1720	44-1394
Anorthite	$Ca.Al_2Si_2O_8$	1552	41-1486

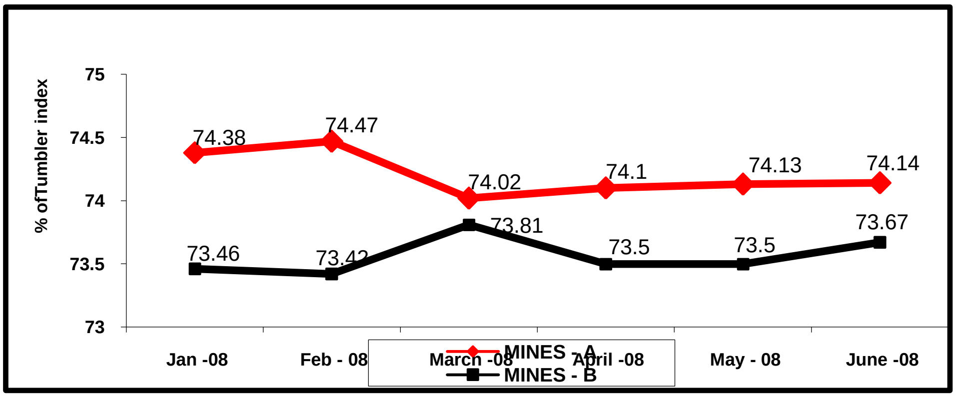
Some Parameters Which Are Responsible For Accretion Formation In Dri Kilns At Jspl:

A) Raw material quality at JSPL:

Some quality parameters which are responsible for accretion formation

1. Iron Ore:

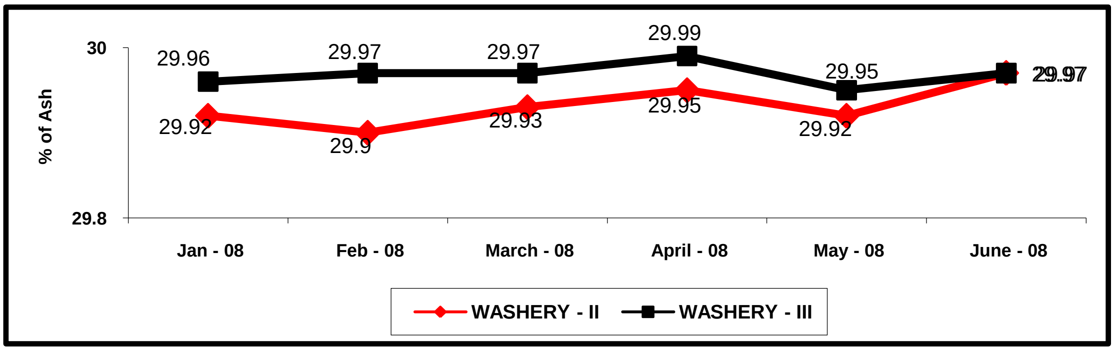
Trend of Tumbler index in Iron ore (DRI)



Tumbler index should be greater than 88. Here in the graph it has the value between 73.42 and 74.47 which is very low. And low tumbler index means fine generation is high which is more prone to accretion formation.

2. Coal:

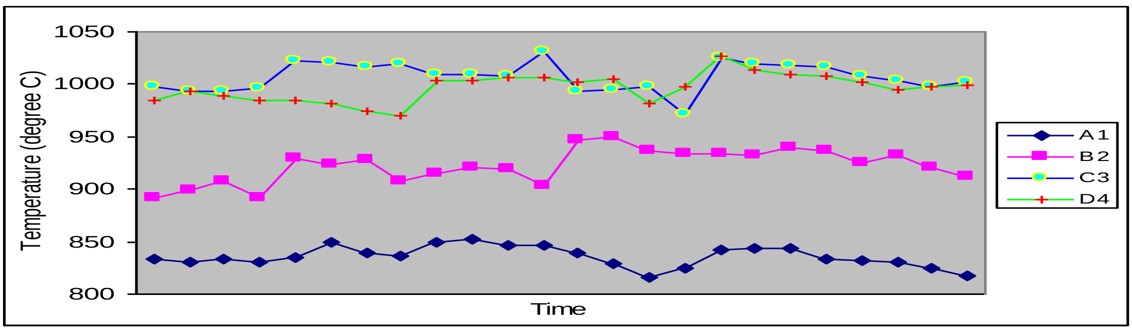
a) **Trend of Ash % in Incoming wash coal**



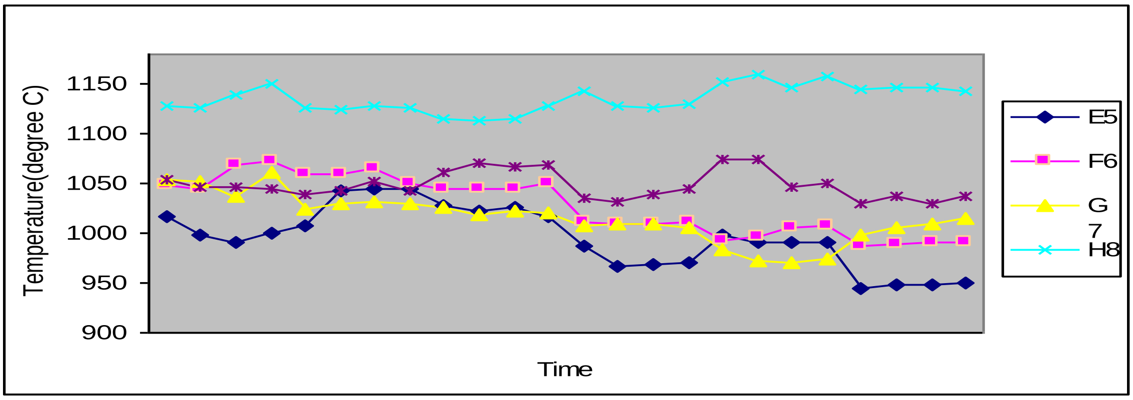
Ash content in the coals should be +23 to -25 but, in this graph it is more than 29 which is too high. As we have seen that ash plays an most important role in the accretion formation it value should be as low as possible.

B) Kiln operating temperature:

Temperature profile of preheating zone (Gas Temperature)



Temperature profile of reduction zone (Gas Temperature)



POSSIBLE WAYS FOR THE REDUCTION OF ACCRETION:

Accretion formation can never be eliminated but it can be reduced to some extent by the adoption of certain parameters given below:

1. Using good quality of raw materials:

A. Iron ore:

- **Low gangue content**
- **High tumbler index**
- **Low abrasion index**

B. Non-coking coal:

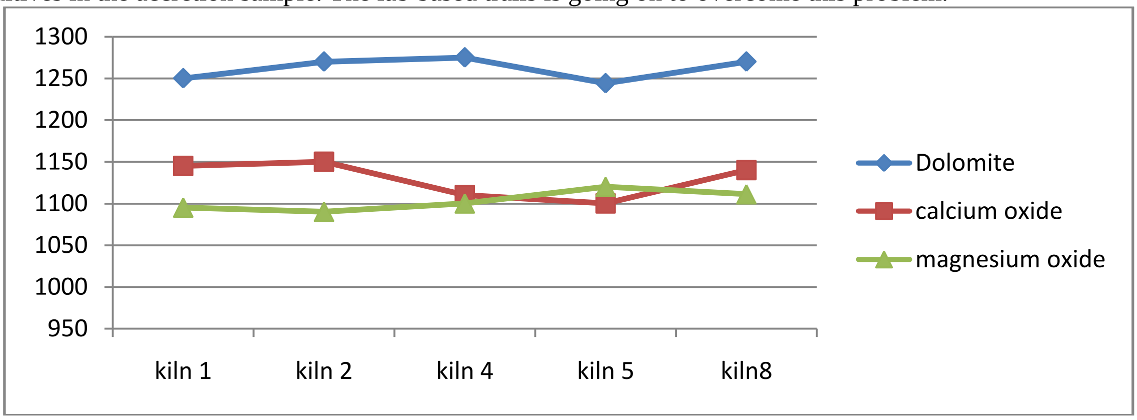
- **Low ash content**
- **High reactivity**
- **High ash fusion temperature**
- **Low swelling and caking index**

2. Maintaining kiln operation conditions:

Since the formation of accretion is high temperature phenomena, therefore a temperature profile should be maintained within the bed of solids such that the temperature level is moderated below the sintering temperature of the solid through out the kiln length and is maximized consistent with non-sintering through about the reduction zone.

3. By increasing the fusion temperature of the complex compound which sticks to refractory wall by adding suitable additives:

Some experiments have been done at JSPL to increase the fusion temperature by adding suitable additives in the accretion sample. The lab based trails is going on to overcome this problem.



4. Refractory Solution:

Presently LC 80 castable is being used as refractory lining on the shell throughout the kiln length. This castable has high Cold Crushing Strength (~1000 Kg/cm2 at 1100 C/ 3 hrs) and high B.D (~2.93 gm/cm3 at 110 C/24 hrs). High B.D. of the castable means it has high thermal conductivity values. Hence, thermal load of the kiln will be more and hence more fuel consumption. As a fuel coal is used in DRI Kilns so, more coal consumption. This indirectly will lead to more ash generation inside the kiln and hence more accretion. So, solution is to use comparatively low B.D LC castable having CCS comparable with LC 80.

5. By applying suitable coatings on the refractory wall which can withstand high temperature and abrasion.

II. Conclusion

1. Ring formation or accretion is a problem inherent to all coal based sponge iron rotary kilns to varying extents, and it can never be totally eliminated.
2. Chemical analysis of accretion indicates that it forms mainly from the raw materials which are fed inside the kiln. XRD analysis shows that in accretion mainly low melting complex compounds are present which at operating temperature under reducing conditions melts and stick to refractory wall.
3. Some accretions also forms because of agglomeration of fines nearer to the charge end or because of sintering of sponge iron owing to excessive temperature and/or lower carbon/iron ratio at the discharge end of a rotary kiln.
4. Accretion formation can be reduced by :

   a) Using good quality of raw materials.

   b) Maintaining kiln operation conditions

   c) By increasing the fusion temperature of the complex compound which sticks to refractory wall by adding suitable additives**.**

   d) By applying suitable coatings on the refractory wall which can withstand high temperature and abrasion.

   e) By using comparatively low bulk density LC castable having CCS comparable with LC 80.

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