

STUDY OF REDUCTION BEHAVIOUR OF IRON ORE LUMPS BY COAL

A

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By

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CERTIFICATE

This is to certify that the thesis entitled “STUDY OF REDUCTION BEHAVIOUR OF HEMATITE IRON ORE LUMPS BY COAL” submitted by Mr. krishen kabijeet and Mr. Abhishek Kumar in partial fulfillment of the requirement for the award of Bachelor of technology degree in metallurgical and materials engineering with specialization in “metallurgical and materials engineering” at the national institute of technology, Rourkela (deemed university) is an authentic work carried out by them under my supervision and guidance. To the best of my knowledge, the matter of the thesis has not been submitted to any other university/institute for the award of any degree or diploma.

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ABSTRACT

Studies on the reduction behavior of hematite iron ore (OMC Ltd.) lumps with coal at different temperatures with varying time were undertaken to understand the effect of time and temperature on degree of reduction. The experiment were carried out at three different temperatures 850 c,900 c,950 c. The holding time was also varied to 30 mins,60 mins,90 mins. Majority of iron ore lumps were found to have high iron and low alumina and silica contents. All these ores were free from impurities such as Sulphur , Phosphorous, Arsenic, Lead, Alkali elements etc. the lumps have low values of shatter , abrasion and swelling index. Proximate analysis of coal was done to determine the percentages of fixed carbon, ash, volatile matter, moisture. The reduction of iron ores were carried out in muffle furnace and were carefully monitored to avoid oxidation after being taken out of the furnace after completion of assigned time interval. The degree of reduction of iron ores were plotted against temperature and time . The results have indicated that with increase in temperature the overall percentage of reduction for the same time interval also increases. But for increased time interval the rate of reduction shows a slow decrease for holding at the same temperature.

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1.1 INTRODUCTION

DRI (directly reduced iron) or sponge iron is a porous solid-state production of direct reduction process. This is produced in lump or pellet form. DRI is being used in steel making through various routes such as EAF (electric arc furnace) BOF (basic oxygen furnace), as it is very economical and readily available material to substitute steel scrap, it has been used in extensive amount. In view of this increased demand for sponge iron, studies are being carried out to observe the reduction behavior of iron ores by direct reduction method.

The reduction of iron ore by carbon is the most important reactions in iron making by blast furnace or any other routes of iron making. Various studies have been carried out on the reduction behavior of iron ore mixed with coal/char/graphite/coke etc. which showed that the reduction takes place via gaseous intermediates like carbon monoxide and carbon dioxide. The actual reduction reaction does not need any gaseous medium to be carried out. Now it is a well-accepted fact that the direct reduction is mostly result of indirect reduction.

Some of the various advantages of DR process over blast furnace iron making are elimination of dependence on coking coal, small module size, optimal size DR units require lower capital investment, superior environmental friendliness and it provides improved process control and maneuverability. It is one of the preferred raw materials for the production of low carbon steels. It has limitations owing to its low productivity per unit volume of the reactor. Hence this process also poses some problems where economical productivity is the main concern.

This calls for some method of innovation to make this process economically viable. These studies are thus aimed at getting a better understanding of reaction kinetics at various temperatures with varying time. So that the data can be used for finding better process making method.

1.2 IRON ORE AND COAL RESERVES IN INDIA

Coal deposits in India are mainly confined to eastern and south central parts . The states of Jharkhand, Odisha, Chhattisgarh, West Bengal, Andhra Pradesh, Maharashtra and Madhya Pradesh account for more than 99% of the total coal reserves in India. As on 31.03.12 the estimated reserves of coal was around 293.5 billion tonnes, an addition of 7.64 billion over the last year (Table 1.1). The total estimated reserve of coal in India as on 31.03.11 was around 285.86 billion tonnes.

Table 1.1 : State wise Estimated Reserves of Coal in India as on 31.03.2011 and 31.03.2012

States/ UTs	(In billion tonnes)									
	Proved		Indicated		Inferred		Total		Distribution (%)	
	31.03.2011	31.03.2012	31.03.2011	31.03.2012	31.03.2011	31.03.2012	31.03.2011	31.03.2012	31.03.2011	31.03.2012
Andhra Pradesh	9.30	9.57	9.73	9.55	3.03	3.03	22.05	22.16	7.71	7.55
Arunachal Pradesh	0.03	0.03	0.04	0.04	0.02	0.02	0.09	0.09	0.03	0.03
Assam	0.47	0.47	0.05	0.05	0.00	0.00	0.51	0.51	0.18	0.17
Bihar	0.00	0.00	0.00	0.00	0.16	0.16	0.16	0.16	0.06	0.05
Chhattisgarh	12.88	13.99	32.39	33.45	4.01	3.41	49.28	50.85	17.24	17.32
Jharkhand	39.76	40.16	32.59	33.61	6.58	6.58	78.94	80.36	27.61	27.38
Madhya Pradesh	8.87	9.31	12.19	12.29	2.06	2.78	23.13	24.38	8.09	8.31
Maharashtra	5.49	5.67	3.09	3.11	1.95	2.11	10.53	10.88	3.68	3.71
Meghalaya	0.09	0.09	0.02	0.02	0.47	0.47	0.58	0.58	0.20	0.20
Nagaland	0.01	0.01	0.00	0.00	0.31	0.31	0.32	0.32	0.11	0.11
Odisha	24.49	25.55	33.99	36.47	10.68	9.43	69.16	71.45	24.19	24.34
Sikkim	0.00	0.00	0.06	0.06	0.04	0.04	0.10	0.10	0.04	0.03
Uttar Pradesh	0.87	0.88	0.20	0.18	0.00	0.00	1.06	1.06	0.37	0.36
West Bengal	11.75	12.43	13.13	13.36	5.07	4.83	29.96	30.62	10.48	10.43
All India Total	114.00	118.15	137.47	142.17	34.39	33.18	285.86	293.50	100.00	100.00
Distribution (%)	39.88	40.25	48.09	48.44	12.03	11.31	100.00	100.00		

#source- Energy statistics, by central statistics office, India

The majority of iron ore production also comes from southern and eastern parts of India .The contributing states are Andhra Pradesh, Chhatisgarh ,Goa ,Jharkhand ,Karnataka, Madhya Pradesh, Maharashtra, Orissa, Rajasthan. The total production of iron ore from all parts of India stand at 127719 thousand tonnes. It puts India in a unique position to give emphasis on the development of sponge iron industries. As the production rate of iron ores is high the ores can be subsequently used both for blast furnace and production of DRI.

STATE-WISE PRODUCTION OF IRON ORE DURING THE LAST THREE YEARS

(in Thousand Tonnes)

State	2008-09	2009-10	2010-11(P)	2011-12(P) (Apr-Dec)
India	212960	218553	207998	127719
Andhra Pradesh	10112	6246	1435	1297
Chhattisgarh	29997	26211	29146	23583
Goa	31195	38136	36723	23090
Jharkhand	21329	22547	23174	15639
Karnataka	46971	43163	37878	11247
Madhya Pradesh	412	1058	1745	941
Maharashtra	294	283	1520	1056
Orissa	72627	80896	76350	50842
Rajasthan	23	13	27	24

P: Provisional, Source : MCDR Returns

1.3 SPONGE IRON PRODUCTION SCENARIO IN INDIA

In the last decade the production of sponge iron has increased dramatically in India. Today India is the major producer of sponge iron in the world. Due to low availability of natural gas resources in India, large emphasis is given to production by the use of coal. The coal reserves in India are estimated to last for another 190 years hence it calls for modern innovations to shift the trend of production towards sponge iron. However the production is seriously constrained by the low availability of good grade ores which results in poor metallization, high volume of ash and fines that are generated. Rise of the sponge iron industry has helped the Indian steel industry – especially through the DR-EAF routes – to overcome a crippling shortage and rising price of scrap feed for steel making. The primary push for the growth of this sector has come from the rapid expansion of secondary steel making in India in the last decade and a half.

	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07
Total Sponge Iron	5.481	5.443	7.858	9.877	12.54	14.825	18.345
<i>CAGR (%)</i>							22.3%
Gas-based Sponge Iron	3.453	3.180	3.624	3.976	4.643	4.545	5.265
% Share in total	63%	58.4%	46.1%	40.3%	37.0%	30.7%	28.7%
<i>CAGR (%)</i>							7.3%
Electric Arc Furnace	5.418	4.377	5.297	6.324	7.994	8.569	10.033
<i>CAGR (%)</i>							10.8%
Coal-based Sponge Iron	2.028	2.263	4.234	5.901	7.897	10.280	13.080
% Share in total	37%	41.6%	53.9%	59.7%	63%	69.3%	71.3%
<i>CAGR (%)</i>							36.4%
Induction Furnace	8.043	8.253	9.014	10.477	13.193	13.493	15.390
<i>CAGR (%)</i>							11.4%

Source: Joint Plant Committee

1.4 DIFFERENT ROUTES OF SPONGE IRON PRODUCTION

The process of DRI or sponge Iron making can be classified into different categories, which are as follows.

a> Rotary Kiln Process.

Rotary Kiln Processes are highly useful for Sponge Iron Production using non-coking coal as reductant . The Iron Ore in the form of lump is charged from one end blended with non-coking coal and heated from the other end, thus keeping counter movement of air current and raw materials . The DRI comes out as product from opposite end .The Rotary movement of the Kiln requires good strength of raw materials during reduction such as tumbler index ,abrasion index and thermal degradation strength etc.. Generation of fines from poor raw material promote ring formation leading to poor performance and decreased productivity.

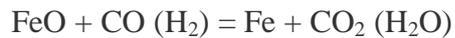
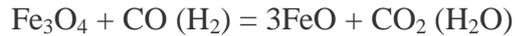
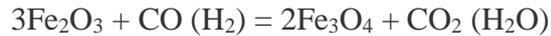
b>Retort Process.

In Retort process the reactor vessel is a retort where the charge is fed from top end remains stationary till reduction, thus it works in batches .a mixture of hot gases contains about 89% of reducing gases (75% H₂ +14% CO) moves between ore bed held in three retort. The three retort works in cycle covering three stages, each approximately 3hrs duration. The first stage consist of heating and preliminary reduction of pellet charged. Once preliminary reduction is completed the reactor is switched onto second stage of reduction by means of automatic valve manipulation during which bulk of reduction takes place. The total process needs along time of about 23/24 hrs.

c> Rotary hearth process. This process iron oxide fines, coal fines and binder are mixed together and palletized . As the hearth rotates around the circular furnace, the pellets are heated to 1250oC-1350oC and the iron oxide is reduced to metallic iron. Residence time in hearth is around 15-25 mins. during which 90-95% of iron oxide is converted in to metallic iron. Burner fuel for RHF can be in the form of pulverized coal , natural gas, and coke oven gas , coal oil mixture. Volatiles and CO gas evolved from the pellets are combusted within the RHF thus providing a significant portion of total heat requirement.

1.5 KINETICS OF IRON ORE REDUCTION.

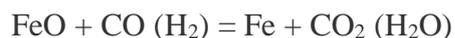
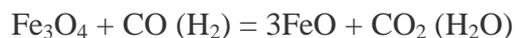
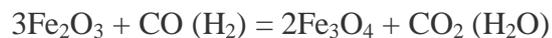
The reduction of iron ore by carbon and hydrogen gas is a very complicated process. For a better understanding of the factors swaying the reducibility of the ores, sinters and pellets, here is a very simple view of the rate-controlling reactions. In most cases, the iron ore is in the hematite form, and reduction starts from hematite and take place in the following order: hematite (Fe_2O_3) > magnetite (Fe_3O_4) > wustite(FeO) > metallic iron (Fe).



A sphere of hematite is initial reduced with CO or H₂ and produce a shell or layer of metallic iron in contact with wustite. Inward from the wustite there will be layer of magnetite nearby the core of hematite. Such a layered structure is typical gas – solid reactions where the reacting interface between the solid reactants and solid products moves parallel to the original solid surface.

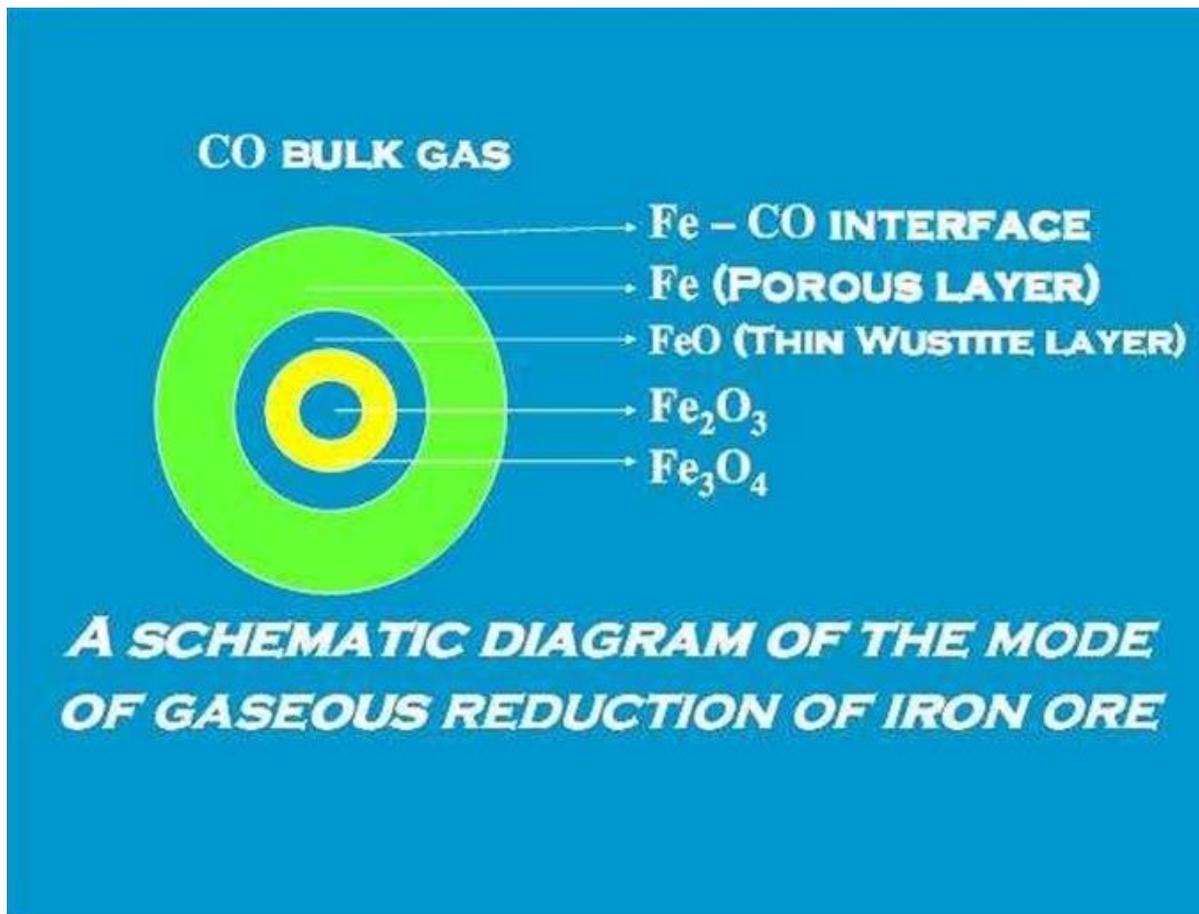
The reduction of iron oxide is a oxygen removal process from the iron ores. The gas–solid reduction of iron ore takes place in the 3 steps:

1. Diffusion of gaseous reductants through the gas - solid boundary layers inwards through porous layers of iron, wustite and magnetite,
2. Gaseous reductant is adsorbed on the solid surfaces and oxygen ions diffuse through the layers to react at the interface. Reduction of all oxides simultaneously at all interfaces according to above three reactions in a similar condition



3. Gaseous products (CO_2 or H_2O) diffuse out of the porous product layers.

If the product layer is dense, the reducibility of the ore will be poor and exhibit a rate minimum. The overall reduction rate is determined by the slowest step in a chain of these processes.



Kinetics of direct reduction process

Reaction kinetics of iron ore reduction dealt with the rate at which iron oxide is transformed to metallic iron by removal of oxygen. The rate at which the ore is reduced affects the production rate, which ultimately determines the economic feasibility and keenness of the process technology involved. Thus the reaction rate in direct reduction process is of prime importance. The reduction of iron oxide to metallic iron proceeds through several kinetic steps and the slowest step controls the overall reaction rate. The different rate controlling factors which control the overall rate of reduction is given below:

Boundary Layer Control.

In boundary layer the overall reduction rate is controlled by the diffusion of gas and heat through the boundary layer of the gas which builds up around each particle. Firstly, the rate of diffusion of the gas through the boundary layer is directly proportional to the gas concentration gradient across the layer. Secondly, the rate of heat flow to the particles is directly proportional to the temperature gradient across the boundary layer. In most direct reduction process contact between gas and solids is achieved by counter current flow of preheated gas to the drive of the bed of solids.

Phase Boundary Reaction Control.

The chemical reaction at the wustite-iron interface is the rate governing factor. In this case the rate of reduction per unit area of the remaining iron oxide is found to be same with time. This mechanism is called "Phase Boundary Reaction Control". When counter diffusion of product gas and reducing gas on the reduced outer layer is sufficiently fast, the concentration of reducing gas at the reacting surface is Meritoriously the same as it's concentration at the particle surface. In such case the rate of reaction at the wustite-iron interface will control the overall reduction rate. This mechanism is unlikely at the exactly start of the reduction, when the iron layer is actual thin, or for very small porous grains of iron oxide.

Gaseous Diffusion Control

The rate of product gas outward and reducing gas inward through the reduced iron layer control's the rate of reduction of iron oxides. This phenomenon is generally associated with large ore particle and is known as "Gaseous Diffusion Control. When gaseous diffusion is the rate controlling step, the rate of diffusion of product gas outward and reducing gas inward through the porous layer of metallic iron neighboring the not reduced inner core particle, is slower than the rate of reaction. During such existence the concentration of the reducing gas will decline that of product gas will rise at the interface. The change in the gas composition will slow down the reduction rate until a pseudo steady state is established. This is the pre leading rate regulatory mechanism for high temperature reduction of large particle beyond 50% reduction, when iron layer thickness exceeds about 1mm.

Mixed Control

When both Gaseous Diffusion Control and Phase Boundary Reaction Control are combined and influence the rate of reduction, the mechanism is referred to as "Mixed Control". Mixed control has been proposed by several experiments to resolve the difficulties and incompatible results obtained from direct reduction of iron oxides with meeker mechanism. In mixed control, the gas boundary layer, the phase boundary reaction and gaseous diffusion act together under quasi steady state condition to decide the overall reaction rate. Different mathematical models equations are suggested to represent different rate controlling steps, which are given below

Equation for controlling steps

$$1 - (1-f)^{1/3} = kt \quad \text{Controlled chemically}$$

$$-\ln(1-f) = kt \quad \text{Controlled chemically}$$

$$[1 - (1-f)^{1/3}]^2 = kt \quad \text{Controlled by diffusion}$$

$$1 - 2/3f - (1-f)^{2/3} = kt \quad \text{Controlled by diffusion}$$

$$k' [1 - 2/3f - (1-f)^{2/3}] + D/r_0 [1 - (1-f)^{1/3}] = kt \quad \text{Mixed Controlled}$$

1.6 SELECTION OF IRON ORES FOR SPONGE IRON MAKING

During sponge iron manufacturing, iron ore is reduced in solid state. Unlike the conventional steel melting processes, the gangue in iron ore cannot be separated as slag. Hence, it becomes essential to select an ore with high iron content and a low gangue content, to optimize yield during steel making. The parameters that are kept in view while selecting iron ore for sponge iron making are

a> Chemical composition

- (i) Iron content:- This should be high (at least above 65%) . the more the iron content the better is the productivity and better is the economic output of the process.
- (ii) Gangue content:- The gangue content should be low , as this process poses problem of slag removal and disposal. The higher gangue content results in extra investment in the enrichment of ore and lower productivity. Hence the ores having a maximum gangue content of 10-20 percent are considered best for DR process
- (iii) Sulphur, Phosphorous, Alkali contents:- while Sulphur and Phosphorous cause removal problems , cause hot shortness and cold shortness respectively , alkaline elements attack on the refractory lining of blast furnace/reduction unit and decrease its service life.

b> Reducibility

It is desired that the ores should have a very high extent of reducibility for higher rate of reduction and higher productivity. It can be affected by various factors such as porosity and presence of catalytic impurities. The reducibility is inversely proportional to the time required to reach some arbitrarily chosen degree of reduction .

For best process control it is should be taken care that the reducibility i.e. $dR/dT=0.5\%$ per minute. Hematite ore is the most popular ore for use in DR process because of its better reducibility than magnetite.

c> Physical properties

Size:- particle size is a very important parameter to consider while selecting iron ores particles size should range from +6 to +18 mm with particle diameter ranging from 10.5 mm to 11.5 mm. Higher the size the lesser is the rate of reduction, lower productivity. The process is carried out by optimizing in the sampling of the raw materials

Tumbler index :- it is known as the resistance to degradation by impact. It is a very important factor since in the rotary kiln process the ores are constantly in impact with wall linings and other ores, hence it is imperative that they have high tumbler index to stop generating fines.

Abrasion index; - it is a measurement of the breakage or degradation due to abrasion. It is a standard test which is determined along with measurement of tumbler index.

Shatter index:- It is the resistance to breakdown upon free fall from a height . it is a indication of strength of the ore . Lower the shatter strength higher is the strength of coal.

Thermal degradation index:- The exposure of iron ores to hot gases during stages of charging can cause them to expand and contract causing thermal decrepitation . This results in generation of fines. It is undesirable hence thermal degradation index should be measured to ensure better process control.

1.7 SELECTION OF COAL FOR SPONGE IRON MAKING.

The properties to be considered for selection of coal for direct reduced iron production are as follows.

- Proximate Analysis
 - # Fixed Carbon
 - #Volatile matter
 - #Ash
 - # Moisture
- Sulphur
- Ash fusion temperature
- Ash chemistry
- Particle size
- Caking Index
- Bulk density

SULPHUR CONTENT

Sulphur is present in the coal in two forms; Organic sulphur and pyretic sulphur. The pyretic sulphur can be present as sulphide or sulphate. The amount of sulphur present as sulphate is usually very low. However this should be determined, because it drops the ash fusion temperature. Sulphurs poise show that around 80-84% of sulphur leaves the kiln in the off gas and in the char, under Indian condition.

ASH FUSION TEMPERATURE

Ash Fusion temperature is a vital parameter for smooth operation of the kiln. In this temperature the coal ash starts to fuse. But for selection of coal, the initial distortion temperature should also take into account. The coal ash comes in intimate contact with other chemical compounds in the kiln forming low melting eutectic, promoting accretion formation in the kiln, and hampers the furnace operation. Consequently, the Initial Deformation Temperature (IDT) of coal ash should 2000C more than the operating temperature.

ASH CHEMISTRY

The coal ash chemistry is studied to evaluate coal for direct reduction process. The silica ratio of the ash should be above 80% . It is found that , the ash fusion temperature has linear relationship with constituent of the ash.

Silica Ratio= % SiO₂/(%CaO+%MgO)

Ash Fusion Temperature in Centigrade = $2344 - 2SiO_2 / Al_2O_3$

FeO+CaO+MgO+K₂O+Na₂O

Alkali Ratio = (% Ash in coal) . (K₂O +Na₂O) in ash.100

The alkali ratio in coal should be minus than 0.3. High alkali ratio, shows low ash fusion temperature.

PARTICLE SIZE:-The span of the coal ought to be such that it blends well with charges as the charge move along the oven. Size of the coal should not be fine, else it causes carbon misfortune. The span of the coal ought not be expansive as it will coast on the highest point of the charge cot. The more level size is dead set from the fluidizing speed of coal, the coal fines are not alluring . However a little sum may stay in the charge. The extent of the -5 mm measure in the coal food ought not surpass 5-10%.

The coal from the release end is blown to meet the diminishment response and high temperature prerequisite .The measure of the molecule relies on upon the toss needed to achieve a specific separation in the furnace. By and large the blown coal size extends between 3mm to 25 mm.

CAKING INDEX:-High caking index coal causes accumulation and reduces the char reactivity of the coal, it also causes accretion creation in the kiln and hinder operation of the kiln. Therefore caking index of the coal should be less than three, preferably less than one.

BULK DENSITY

The bulk density of coal plays an important role in the productivity performance of the kiln. In common the coal with higher volatile matter have smaller bulk density, and occupy larger space in the kiln., thereby decreasing available kiln volume for production. Experience in DRI production indicates that the bulk density of the coal (sized) should be 800kg/m.

1.7 LITERATURE REVIEW OF REDUCTION OF IRON ORE BY COAL.

The reduction behavior of hematite and magnetite lumps and pellets containing coal has been studied by Seaton et al where it was observed higher reduction rate during the initial stage of reduction. This stage does the pyrolysis of the volatile matter in coal, the reduction of hematite and magnetite is through wustite to magnetite to iron oxide and finally iron. They have shown that the steps $\text{Fe}_2\text{O}_3 \rightarrow \text{Fe}_3\text{O}_4 \rightarrow \text{FeO}$ and $\text{Fe}_3\text{O}_4 \rightarrow \text{FeO}$ took place at high rate during early stages of reduction.

Seaton et al also studied the effect of heat transfer on the reduction char mixed pellet or lump is controlled by the heat transfer rate in the specimen. They observed temperature difference between the center and surface of the pellet and this gap reduced with rise in the degree of reduction. In their observations, 15 and 27 minutes are needed for lumps to reach thermal equilibrium at 1000C and 1100C respectively and 10 minutes was sufficient to reach at 1200C. The reduction was stepwise throughout the lumps, where the the presence of magnetite, wustite and iron at the early stages was confirmed by metallographic observations. The used the following equations for data analysis.

$\ln t$ Vs $1/T$

1.8 AIMS AND OBJECTIVE OF THE PRESENT

- > To determine the effects of temperature on the degree of reduction and analyze in graphical format
- > To determine the effect of time on degree of reduction and analyze the rate of reduction.

CHAPTER 2

2.1 PROXIMATE ANALYSIS OF COAL.

Proximate analysis (Indian Standard : 1350 1969) was carried out on sample ground to pass through a 72 mesh B.S. test sieve. The analysis was done to determine the
Ash content.

Fixed carbon

Moisture percentage

Volatile matter percentage

2.2 PROCEDURE FOR REDUCTION STUDIES.

- > 100 mesh size coal powder was obtained through crushing operations. `
- > for reduction studies, three cylindrical steel containers (size: 7 cm * 10 cm)were procured from the market and hole was made on covers of each of them .
- > The iron ore lumps were first dried in an electric oven at 110 c for around 60 mins to remove any moisture content.
- > The lump iron ore samples were carefully weighed and observations were made.
- > All the containers were filled with coal powder up to half of the height and iron ore lumps of known weights were placed centrally in each of them.
- > The remaining portions of the containers were filled with coal powder.
- > Then the containers were marked by the numbers 1,2,3 respectively for proper recognition.
- > The furnace was switched on and the temperature was increased up to the required level. After this operation , all the steel containers were placed inside the heating zone of the muffle furnace with proper care.
- > The furnace was allowed to regain the holding temperature and a timer was set up to note time of holding.

- > The first sample was taken out after 30 minutes and was immediately covered to prevent any oxidation from air.
- > This process was repeated after taking out the samples at 60 mins and 90 mins respectively.
- > After the samples have been cooled they were separated carefully and they were blown to remove any additional coal powder on them.
- > The samples were carefully weighed and their weights were noted down.
- > Care was taken to not fracture the metallic lump.

FORMULA USED TO CALCULATE DEGREE OF REDUCTION

$\% \text{Degree of reduction} = (\text{wt. loss off iron lump} / \text{total weight of oxygen in the sample}) * 100$

OBSERVATIONS

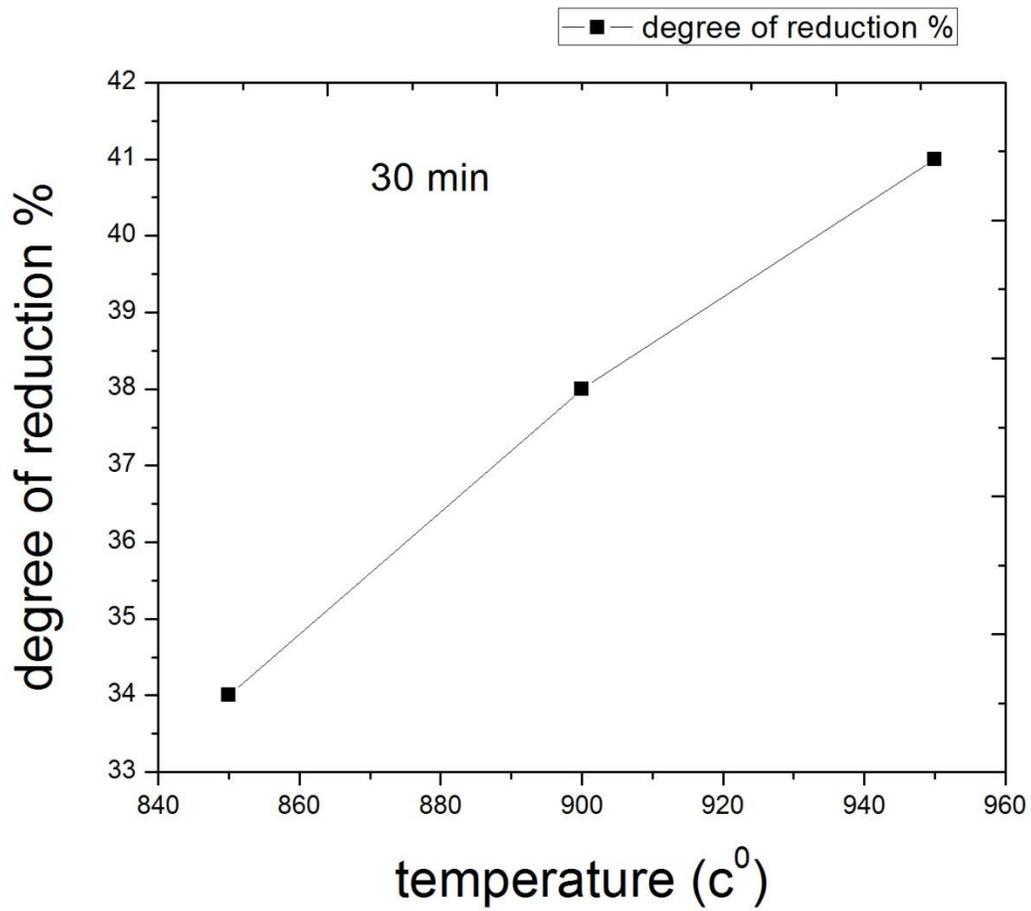
Sl. No.	temperature	Degree of reduction(%)	Time
1	850	34	30
2	850	49	60
3	850	61	90
4	900	38	30
5	900	56	60
6	900	65	90
7	950	41	30
8	950	58	60
9	950	68	90

OBSERVATION TABLE FOR PROXIMATE ANALYSIS OF COAL

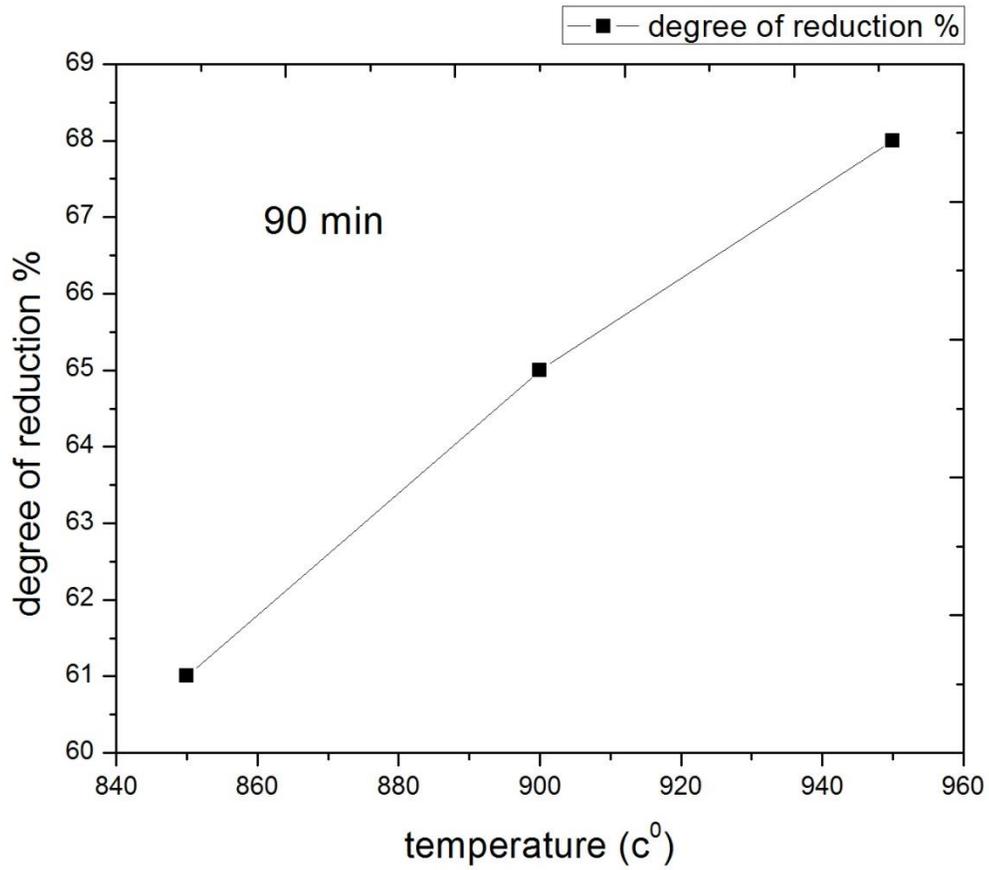
CONTENT	PERCENTAGE
ASH CONTENT	15.26
FIXED CARBON	46.67
MOISTURE	14.92
VOLATILE MATTER	46.25

GRAPHICAL ANALYSIS

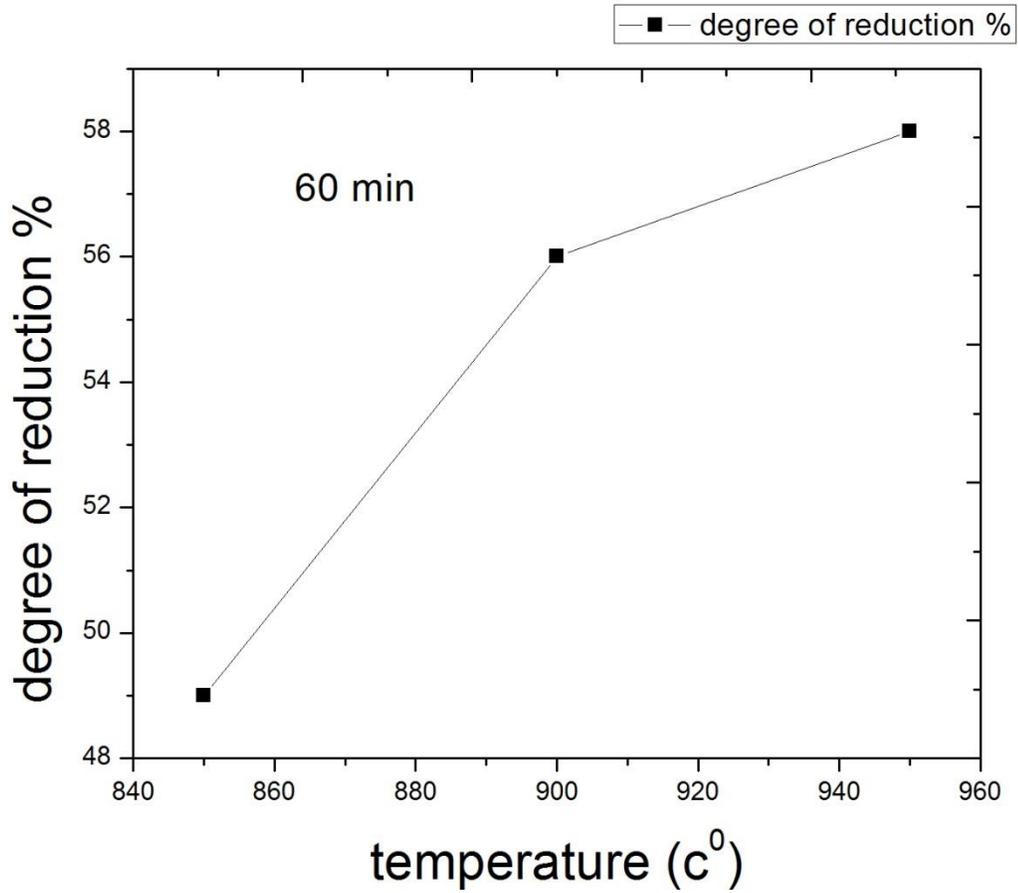
This plot shows the reduction behavior of three samples which were held at temperatures of 850C,900C and 950C for 30 minutes.



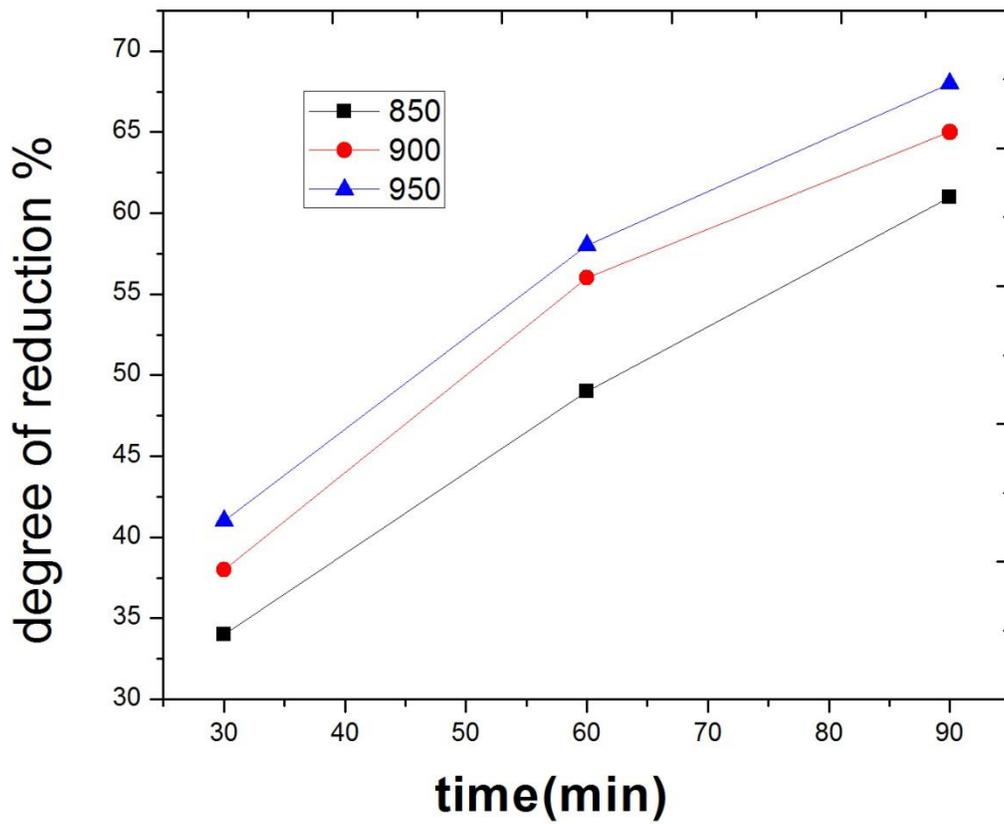
This figure shows the reduction behavior of 3 samples which were held for 90 minutes under the temperature of 850C,900C,950C.It can be observed that although the slope appears to be steep but the increase in percentage reduction is actually not that significant statistically.



This figure shows the degree of reduction vs time constant 60 minute . The data were taken for 3 samples, Which were kept at three different temperatures of 850C,900C,950C. here the data shows a significant rise in slope form 850C to 900C but the rise from 900C to 950C is not significant statistically.



This figure is obtained by superimposing three graphs of degree of reduction vs temperature. The temperatures are 850C,900C,950,C.The plot shows a high increase in the degree of reduction from 850C to 900C, as indicated by the gap between the two isothermal curves at 850C and 900C



RESULTS AND DISCUSSIONS

The results on the reduction studies were compiled at one place in the form of a table 1 and expressed in the form of plots in Figure presented in the figure above.

Effect of time on degree of reduction.

>The results obtained are indicating that the degree of reduction is highest in the first half an hour of the reduction experiment.

>After that, the percentage reduction has decreased with rise of reduction time up to the extent determined in the present study.

>This shows that the utilization of hematite iron ores in sponge iron making is likely to permit the rotary kiln operations to be performed at low temperatures (i.e. less than 1000 C) helping in greater savings of energy and kiln life. The excess high percentage reduction in the first 30 minutes is caused, with the release of volatile compounds from coal, their cleavage into H₂, CO, etc. and majority of these reducing gases participate in reduction reaction.

>At beginning of reduction, when the samples were kept in the furnace due to increase in temperature volatile matters are released into the crucible. These volatile matters take part in the reduction reaction and increases the rate of reduction. So for all the samples the rate of reduction was greatest during the first stage of the reduction process i.e. in the first half an hour

>There was decrease in extent of reduction after initial stage because of very small amount of release of Volatile matters and due to the formation of high thickness product layer which prevents the diffusion of carbon inside it.

Effect of temperature on degree of reduction

>It is known that in comparison to rapidly heating the sample the slow heating of sample to reduction temperature gives higher rates of reduction

>It is probable that rapid heating to 900 degree centigrade causes a higher rate of volatile matter escape from coal thereby producing less time for carbon monoxide and hydrogen to come in contact with iron ore lumps.

So the result is lower degree of reduction at rapid heating

>During slow heating of coal volatile matters are released at a very slower rates And hydrocarbons has sufficient time to undergo cracking process

The more the deposition of highly reactive pyrolic carbon and increased time of contact of lump ore to carbon and reducing gases are the reason for higher degree of reduction

CONCLUSION

>Reduction time and temperature extensively influence the percentage of reduction. The degree of reduction increased with increase in reduction temperature from 850-950C. In studied time period of 30-90 minutes the rate of reduction was higher up to 50-70% reduction and decreased in latter stages.

>The difference in the reduction behavior of iron ore lumps, in coal and, was apparent in initial stages of reduction at lower temperature

> The rate of reduction was found out to be not affected by amount of coal present. In each case the reduction rate is approaching some constant value of around 90% when it is extrapolated to higher time intervals at the same temperature.

> The difference in the reduction behaviors of iron ore lumps in presence of coal was evident at reduction carried out at low temperature .

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