Study of Reduction Behaviour Of Iron Ore Lumps

A

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CERTIFICATE

This is to certify that the thesis entitled, “STUDY OF REDUCTION KINETICS OF HEMATITE IRON ORE BY COAL” submitted by **Mr. Dharanidhar Patra** in partial fulfillment of the requirements for the award of Bachelor inTechnology 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 him under my supervision and guidance. To the best of my knowledge, the matter embodied in 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 chemical and physical properties, and reduction behaviour (in coal) of hematite iron ores, procured from ten different mines of Orissa, were undertaken to provide information to the iron and steel industries (sponge iron plants in particular). Majority of the iron ores were found to have high iron and low alumina and silica contents. All these iron ores were free from the deleterious elements (S, P, As, Pb, alkalies, etc.). The results indicated lower values of shatter and abrasion indices, and higher values of tumbler index in all the iron ore lumps except Serazuddin (previous) and Khanda Bandha OMC Ltd.. For all the fired iron ore pellets, the degree of reduction in coal was more intense in the first 30 minutes after which it became small. Slow heating led to higher degree of reduction in fired pellets than rapid heating. All the iron ores exhibited more than 90% reduction in their fired pellets in 2 hrs. time interval at a temperature of 9000C. Iron ore lumps showed lower degree of reduction than the corresponding fired pellets.

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CHAPTER 1

1.1 INTRODUCTION

DRI or Sponge Iron is a porous solid-state product of direct reduction process, which is produced either in lump or pellet form. DRI is a good substitute for steel scrap for producing steel in EAF, BOF etc, which resulted a rapid growth of the sponge Iron Industry. In view of increasing demand of sponge Iron in the manufacturing of different verities of steel, a good deal of emphasis is being given to promote the study of direct reduction process.

The growth of DRI industry took place in it's nascent form the later half of the 20th century, until then steel scrap constituted the major part of our import, next to petroleum product. Then Indian government imposed some curtailment measure and search for the alternatives began, and direct reduced iron was resulted as an alternative to the steel scrap, which is produced by the direct reduction of iron ore in the form of lump or pellet. In direct reduction (DRI) process ,there a good flexibility of using different kind of reductants like lower grade non coking coal, char coal, natural gas etc. The fast depletion of high grade cooking coal, reserves restricts the use of coke in conventional blast furnace-oxygen steel making route , in India.

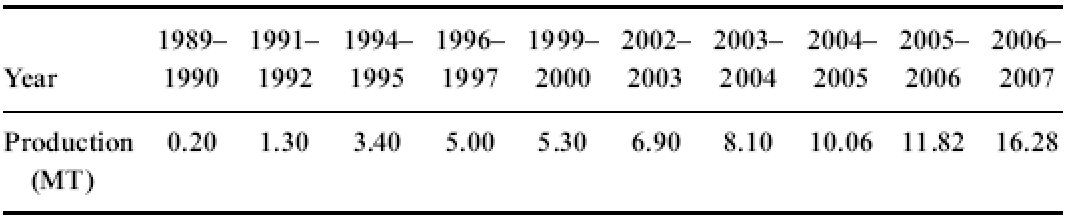
Being enriched with good quality Iron ore along with vast reserves of non coking Coal, which likely last for another 200 years or so India is in an adventitious for coal based Sponge Iron plants. The total gross reserves of coking and non coking coal in India are approximately 11,602 and 71,400 million tons respectively. From this prospective, the rotary kiln (coal based) DR process have developed well and vigorously in the country instead of natural gas based Shaft furnace or Retort furnace.

In order to accept the potential of the fact, it is rather imperative to understand the basic mechanism involved in DR process using non coking coal as reductant.

The reduction of iron ore by carbon is one of the most important reactions in iron making in blast furnace, rotary kiln and electric smelting furnace. Extensive studies has been carried out on the reduction behavior of iron ore mixed with carbon/char/graphite/coke etc , which reveals that the reduction reaction take place via gaseous intermediate like Carbon monoxide and Carbon dioxide. As such it is evident that, the actual direct reduction doesn’t need any gaseous medium to be carried out. But of late it has been rather well accepted that, the reduction of Iron oxide by carbon in blast furnace and direct reduction process of sponge Iron production is mostly the result of indirect reduction.

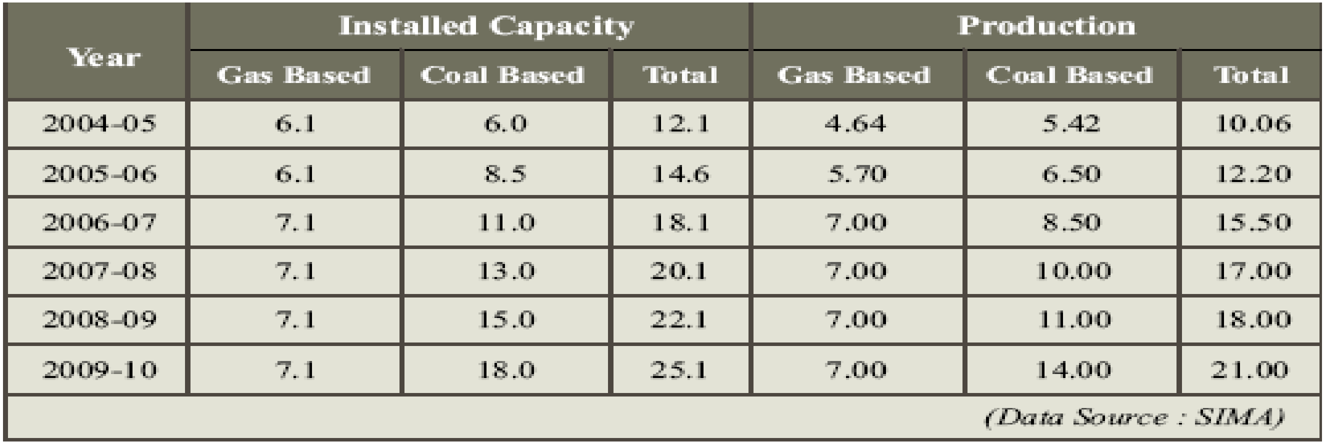
Currently a lot of emphasis is being given to direct reduction process because use of pre-reduced pellets or sponge iron as feed for blast furnace, induction furnaces and basic oxygen furnaces, despite some associated drawbacks, offers much scope for improving both productivity and economy in coke consumption.

1.2 Sponge iron production scenario in India



Year	1989–1990	1991–1992	1994–1995	1996–1997	1999–2000	2002–2003	2003–2004	2004–2005	2005–2006	2006–2007
Production (MT)	0.20	1.30	3.40	5.00	5.30	6.90	8.10	10.06	11.82	16.28

Trend of growth of production in India

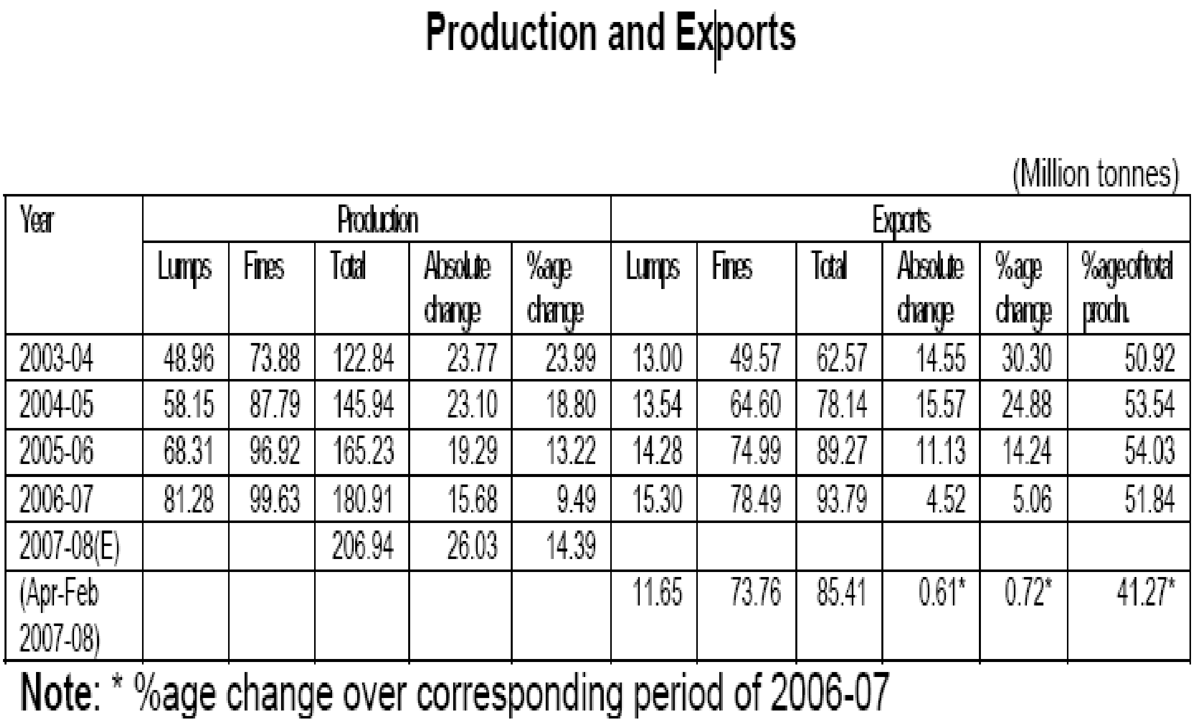


Year	Installed Capacity			Production		
	Gas Based	Coal Based	Total	Gas Based	Coal Based	Total
2004-05	6.1	6.0	12.1	4.64	5.42	10.06
2005-06	6.1	8.5	14.6	5.70	6.50	12.20
2006-07	7.1	11.0	18.1	7.00	8.50	15.50
2007-08	7.1	13.0	20.1	7.00	10.00	17.00
2008-09	7.1	15.0	22.1	7.00	11.00	18.00
2009-10	7.1	18.0	25.1	7.00	14.00	21.00

(Data Source : SIMA)

Installed capacity & production sponge iron in India up to 2009-10 : SIMA Projection (Million Tonnes)

1.3 iron ore and coal reserves in India

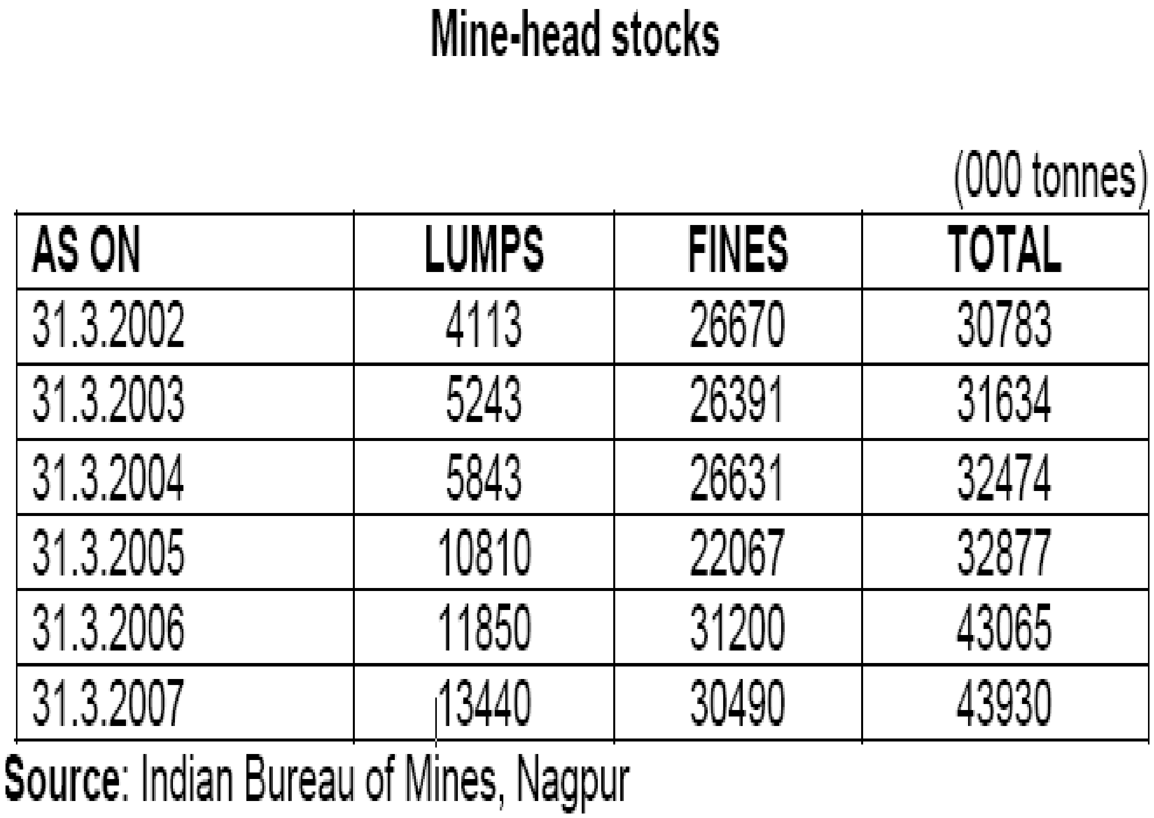


Production and Exports

(Million tonnes)

Year	Production					Exports					
	Lumps	Fines	Total	Absolute change	%age change	Lumps	Fines	Total	Absolute change	%age change	%age of total prodn.
2003-04	48.96	73.88	122.84	23.77	23.99	13.00	49.57	62.57	14.55	30.30	50.92
2004-05	58.15	87.79	145.94	23.10	18.80	13.54	64.60	78.14	15.57	24.88	53.54
2005-06	68.31	96.92	165.23	19.29	13.22	14.28	74.99	89.27	11.13	14.24	54.03
2006-07	81.28	99.63	180.91	15.68	9.49	15.30	78.49	93.79	4.52	5.06	51.84
2007-08(E)			206.94	26.03	14.39						
(Apr-Feb 2007-08)						11.65	73.76	85.41	0.61*	0.72*	41.27*

Note: * %age change over corresponding period of 2006-07



Mine-head stocks

(000 tonnes)

AS ON	LUMPS	FINES	TOTAL
31.3.2002	4113	26670	30783
31.3.2003	5243	26391	31634
31.3.2004	5843	26631	32474
31.3.2005	10810	22067	32877
31.3.2006	11850	31200	43065
31.3.2007	13440	30490	43930

Source: Indian Bureau of Mines, Nagpur

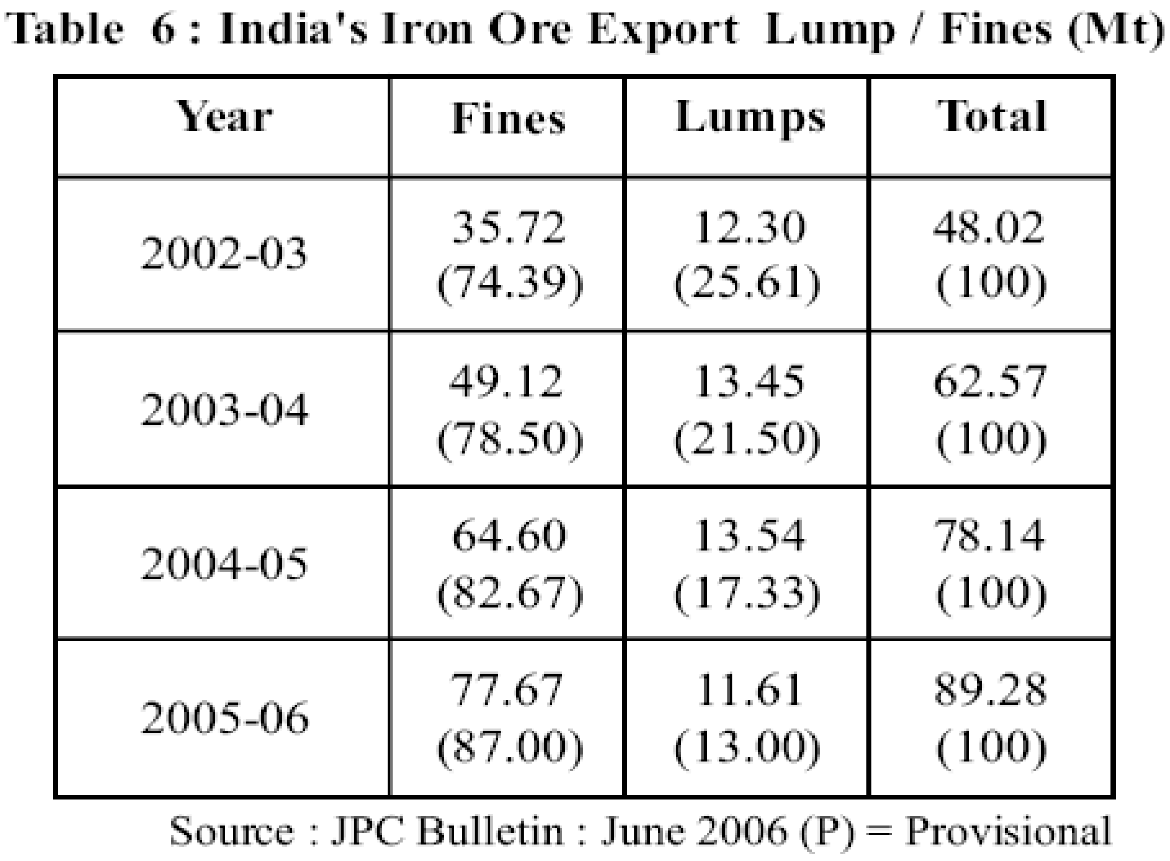
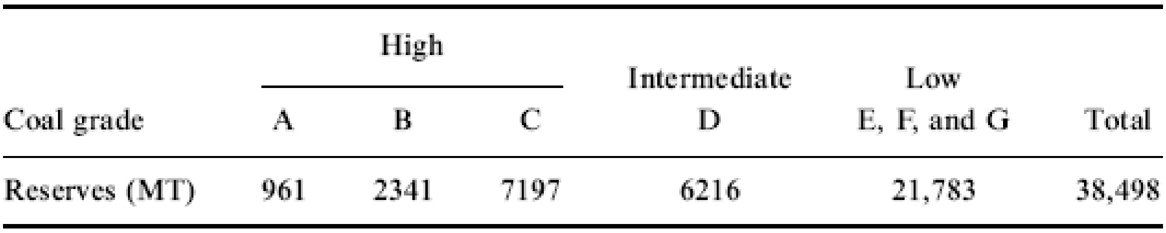


Table 6 : India's Iron Ore Export Lump / Fines (Mt)

Year	Fines	Lumps	Total
2002-03	35.72 (74.39)	12.30 (25.61)	48.02 (100)
2003-04	49.12 (78.50)	13.45 (21.50)	62.57 (100)
2004-05	64.60 (82.67)	13.54 (17.33)	78.14 (100)
2005-06	77.67 (87.00)	11.61 (13.00)	89.28 (100)

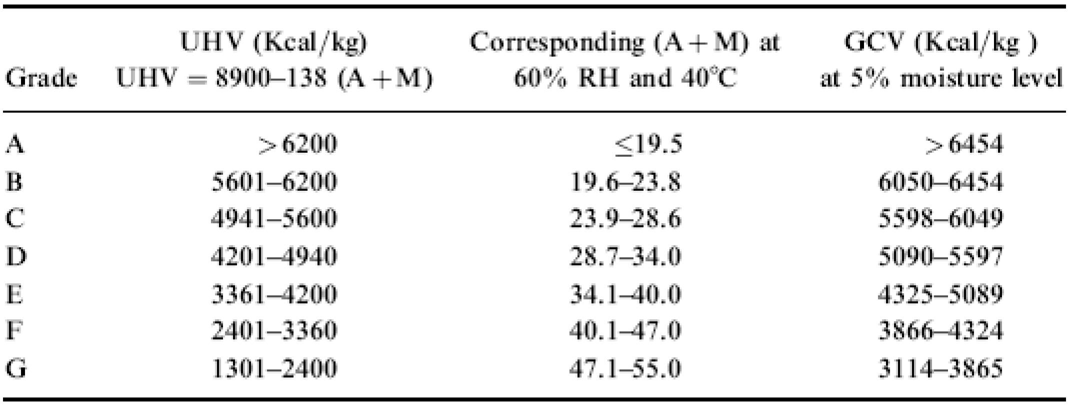
Source : JPC Bulletin : June 2006 (P) = Provisional

Grade wise coal reserves in india



	High			Intermediate	Low	
Coal grade	A	B	C	D	E, F, and G	Total
Reserves (MT)	961	2341	7197	6216	21,783	38,498

Gradation of Indian non-coaking ccoal



Grade	UHV (Kcal/kg) UHV = 8900–138 (A + M)	Corresponding (A + M) at 60% RH and 40°C	GCV (Kcal/kg) at 5% moisture level
A	> 6200	≤19.5	> 6454
B	5601–6200	19.6–23.8	6050–6454
C	4941–5600	23.9–28.6	5598–6049
D	4201–4940	28.7–34.0	5090–5597
E	3361–4200	34.1–40.0	4325–5089
F	2401–3360	40.1–47.0	3866–4324
G	1301–2400	47.1–55.0	3114–3865

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.

1.4.1 Rotary Kiln Processes

Rotary Kiln Processes are very useful for Sponge Iron Production using non-coking coal as reductant. The Iron Ore in the form of lump or pellet is charged from one end with non-coking coal and heated from the other end, thus keeping counter current movement of raw materials and gases. The reduced ore comes out as product from opposite end .The Rotary movement of the Kiln requires good strength of raw materials during reduction. Generation of fines from poor raw material promote ring formation leading to poor performance and decreased productivity.

1.4.2 Retort Process

In Retort process the reactor vessel is a retort where the charge is fed from top end remains stationary till discharged after reduction, thus it works in batches .a mixture of hot gases containing about 89% of reducing gases (75% H2 +14%CO) moves through 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 redution by means of automatic valve manupulation during which bulk of reduction takes place. When most of the reduction is overed ,the reactor is changed to cooling mode and during all stages pellets remains statonary.the total process needs along time of about 23/24 hrs.

1.4.3 Rotary hearth process

In this process iron oxide fines, coal fines and binder are mxed together and palletized .The green pellets are placed on a rotating hearth. As the hearth rotates around the circular furnace, the pellets are heated to 1250^oC-1350^oC and the iron oxide is reduced to metallic iron. Reduction of iron oxide is accomplished by the carbon contained in the pellets. 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.

The DRI produced from the RHF is fed to an electric melter called Electric Iron making Furnace (EIF) to produced a high quality liquid iron known as FASTIRON.

1.4.4 Shaft furnace

The shaft furnace can be considered as upper part of the blast furnace , working on a counter current principle. Raw materials (iron ore pellet) charged from the top, undergoes abrasion and burden load moves downward towards discharge end through various thermal zones. Good pellet strength is necessary to withstand wear and tear during the course of reduction.

1.5 SELECTION OF RAW MATERIALS FOR DRI PRODUCTION

The efficiency and cost effectiveness of DRI production are very sensitive to their raw material characteristics. In a coal based process , these are governed by nature of coal

1.5.1 Iron Ore

The following parameters are consider for selection of iron ore for DR process.

Chemical Composition

Reducibility

Physical Characteristics

CHEMICAL COMPOSITION :

a. Fe Content :

b . Gangue Content (SiO_2+Al_2O_3):

c. Sulpher, phosphorus and alkali content:

d. Oxide of Calcium and magnesium (CaO & MgO)

REDUCIIBILTY:

The reducibility determines the ease with which oxygen can be removed from the iron oxide in the ore by reducing gases. This influences the productivity and quality of the product. The reducibility is inversely proportional to the time required reach some arbitrarily chosen degree of reduction.

The standard norm is represented by ,

dR/dT = 0.5% per minute ,minimum, which can be verified experimentally.

Reducibility of the iore depends on size, shape and distribution of the ore. Hematite ore is chosen for DRI production, because it has better reducibility than magnetite ore.

PHYSCAL CHARACTERSTCS :

a. Size :

Size of the ore is very important for DRI producton. The particle size, shape and it's distribution affect the reducibility of the ore. The rate of reduction of iron oxide increases with decrease of size of the iron ore. The size is determined by it's reducibility . It has been observed that best results are obtained with size ranging from +6 to + 18 mm, wth particle diameter of 10.5 mm to 11.5 mm.

b. Strength :

The strength and resistance of the iron ore to degradation is represented by Tumbler Index, Abrasion Index, Shatter Index and Thermal Degradation Index.

(i) Tumbler Index

The Tumbler Index is a relative measure of the resistance of the material to breakage or degradation by impact.

(ii) Abrasion Index:

It is a relative measure the degradation of iron ore by abrasion. The Tumbler Index and Aibrasion Index are determined in a tumbler test apparatus as per the Bureau of Indian Standard No. IS:6495 .

(iii) Shatter Index

It is a measure of resistance to free fall of the material . it is determined by the quantity of material which after being tested , retains a size over specified dimension. This test can be carried out as per Bureau Of Indian Standard No.IS:9963.

(iv) Thermal Degradation Index:

It is a measure of the tendency of the iron ore bearing materials to undergo size degradation as a result of either thermal shock or reduction or both .The term decrepitation or law temperature breakdown (LTB) are also used in place of degradation in technical literature.

The standard values of tumbler index, shatter index, abrasion index, thermal degradation index of iron ores are given in the table.

1.5.2 COAL

The properties to be considered for selection of coal for DRI production are as follows.

1.Proximate Analysis

- Fixed Carbon
- Volatile matter
- Ash
- Moisture

2.sulpher

3.Ash fusion temperature

4.Ash chemistry

5.Coal char reactivity

6.Coal char strength

7.Particle size

8.Caking Index

9.Bulk density

2. SULPHER CONTENT

Sulpher remains in the coal in two forms; Organic sulpher and Pyretic sulpher. The pyretic sulpher may be present as sulphde or sulphate .The amount of sulpher as sulphate is usually very law. However this should be checked or determined, because it lowers the ash fusion temperature .The pyretic sulpher is partially roasted in the pre heat zone and the organic sulpher is gradually .Sulpher balance shows that around 80-84% of sulpher leaves the kiln in the off gas and in the char, under Indian condition .

3. ASH FUSION TEMPERATURE

Ash Fusion temperature is an important parameter for smooth operation of the kiln. This is the temperature at which the coal ash start to fuse. But for selection of coal, the initial deformation temperature should also taken 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 hamper the furnace operation. Therefore, the Initial Deformation Temperature (IDT) of coal ash should 200^0C more than the operating temperatur**e.**

4. ASH CHEMISTRY

The coal ash chemistry is good tool to evaluate coal for DR process. The silica ratio of the ash should be high and preferably above 80% . It s found that , the ash fusion temperature has a linear relationship with the constituent of the ash.

Silica Ratio= % SiO_2/(%SiO_2+%Fe_2O_3+%CaO=%MgO)

$$\text{Ash Fusion Temperature in } ^{o}\text{C} = \frac{2344\ 2SiO_2/\ Al_2O_3}{FeO+CaO+MgO+K_2O+Na_2O}$$

$$\text{Alkali Ratio} = \frac{(\%\ \text{Ash in coal}) \times (K_2O + Na_2O)\ \text{in ash}}{100}$$

The alkali ratio of the coal should be less than 0.3. High alkali ratio, indicates low ash fusion temperature.

5. COAL CHAR REACT IVITY

The availability of coal char to react to form carbon monoxide is called reactivity of coal . The reactivity of coal should preferably more than 1.8 cc/ gm of C/ sec . Reactivity influences the operating temperature of the kiln . Coal char with low reactivity will require higher operating temperature, where as coal char with high reactivity require low operating temperature.

6. COAL CHAR STRENGTH

The degradation of char in the kiln depends on coal char strength. The carbon loss in the flue dust will be high if char strength is low. Therefore, the char strength should be high .

7. PARTICLE SIZE

The size of the coal should be such that it mixes well with charges as the charge move along the kiln. Size of the coal should not be very fine, otherwise it causes carbon loss. The size of the coal should not be very large as it will float on the top of the charge bed. The lower size is determined from the fluidizing velocity of coal, the coal fines are not desirable . However a small amount may remain in the charge. The proportion of the -5 mm size in the coal feed should not exceed 5-10%.

The coal from the discharge end is blown to meet the reduction reaction and heat requirement .The size of the particle depends on the throw required to reach a particular distance in the kiln . In general the blown coal size ranges between 3mm to 25 mm .

8. CAKING INDEX

High caking index coal causes agglomeration and reduces the char reactivity of the coal, it also causes accretion formation in the kiln and hinder operation of the kiln. Therefore caking index of the coal should be less than three , preferably less than on

9. BULK DENSITY

The bulk density of coal plays an important role in the productivity performance of the kiln. In general the coal with higher volatile matter have smaller bulk density, and occupy larger space in the kiln., there by reducing available kiln volume for production. Experience in DRI production indicates that the bulk density of the coal (sized) should be 800kg/m^3

Some recommended physical and chemical properties of coal are given in the table.

1.6 MECHANISM OF DR PROCESS

_ The reduction of iron oxide in a direct reduction system is known to occur by both solid and gaseous reductant, e.g. solid carbon, CO gas, H_2 gas, in various stages as given below.

Fe_2O_3 → Fe_3O_4 → FeO → Fe (Hematite) (Magnetite) (Wustite) (Metallic iron)

The reaction which are involved in the reduction of iron ore is as follows,

1.6.1 Stages of iron oxide reduction by solid carbon :

$3Fe_2O_3 + C \rightarrow 2\ Fe_3O_4 + CO\ ;\ \Delta H_1 = 28.38$ Kcal. --- (1)

$Fe_3O_4 + C \rightarrow 3\ Fe + CO\ ;\ \Delta H_2 = 49.98$ Kcal. --- (2)

$Fe + C \rightarrow Fe + CO\ ;\ \Delta H_3 = 37.38$ Kcal --- (3)

The reduction of iron oxides initiated by solid carbon as per the above mention reaction, and the CO gas evolved again participate n the further reduction of iron oxides.

1.6.2 Stages of iron oxide reduction by CO :

$Fe_2O_3 + CO \rightarrow Fe_3O_4 + CO_2$; $\Delta H_4 = -12.85$ Kcal --- (4)

$Fe_3O_4 + CO \rightarrow FeO + CO_2$; $\Delta H_5 = 8.76$ Kcal. ----- (5)

$FeO + CO \rightarrow Fe + CO_2$; $\Delta H_6 = -6.85$ Kcal ----- (6)

$C + CO_2 \rightarrow 2CO$; $\Delta H_7 = 41.22$ K cal ---- (7)

The CO gas produced by, carbon gasification reaction, reduction of oxides by solid carbon , and by oxidation of carbon, reduces the iron oxides to their lower oxidation states, and the CO_2 gas produced again react with solid carbon to form carbon monoxide gas and that carbon monoxide gas again participate in the reduction of iron oxides

1.6.3 Stages of iron oxide reduction by H_2 :

$Fe_2O_3 + H_2 \rightarrow 2Fe_3O_4 + H_2O$; $\Delta H_8 = - 3.08$ Kcal ----- (8)

$Fe_3O_4 + H_2 \rightarrow 3 FeO + H_2O$; $\Delta H_9 = 18.52$ Kcal ----- (9)

$FeO + H_2 \rightarrow Fe + H_2O$; $\Delta H_{10} = 59.20$ Kcal --- (10)

$C + H_2O \rightarrow CO + H_2$; $\Delta H_{11} = 21.71$ Kcal --- (11)

The H_2 gas reduces the iron oxide to their lower oxidation state and produce water vapour as per the reaction (8), (9), (10). The water vapour thus produced react with solid carbon to form H_2 and CO gas as per reaction (11) and the H_2 and CO gas again participate in the reduction of iron oxides.

1.6.4 Oxidation of solid carbon

$C + ½ O_2 \rightarrow CO$; ΔH_{13} = -94.05 Kcal ------ (12)

$C + O_2 \rightarrow CO_2$; ΔH_{14} = 25.42 Kcal ------- (13)

The solid carbon present in the charge material is oxidized by the little air present in the kiln to produce carbon monoxide and carbon dioxide .The carbon monoxide formed, reduces the iron oxides, and the carbon dioxide react with solid carbon to form carbon monoxide through carbon gasification reaction.

1.7 LITERATURE REVIEW:

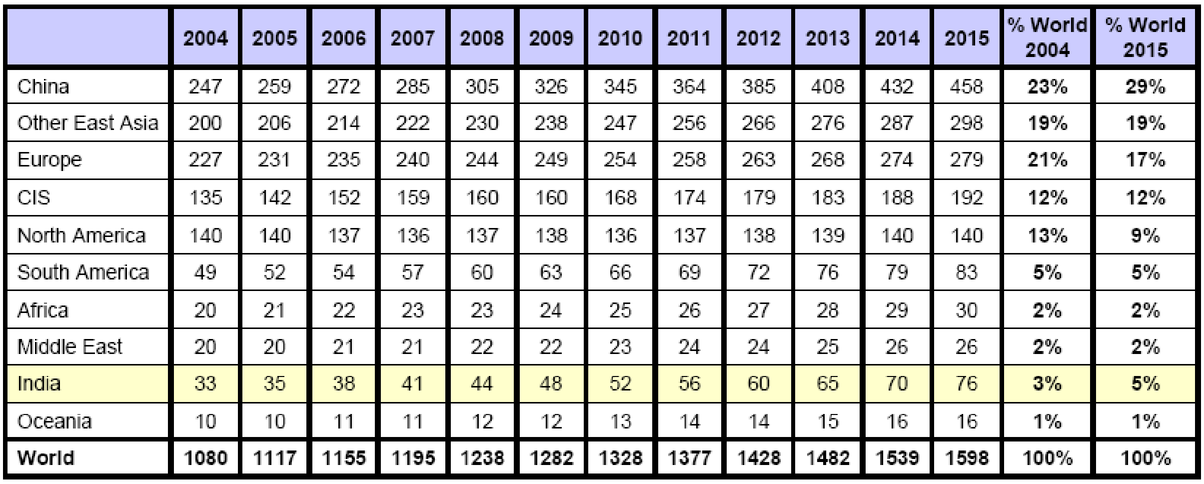
The investigation on the reduction of iron ore pellets (mixed or composite) with coal fines has been made by a number of workers .The reduction behavior of hematite and magnetite pellets containing coal char has been studied by Seaton et al where they have observed higher reduction rate during the initial stage of reduction. This stage comprises the pyrolysis of the remaining volatile matter in char, the reduction of hematite and magnetite to wustite and part if wustite to iron. They have indicated that the steps $Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO$ and $Fe_3O_4 \rightarrow FeO$ took place rapidly during early stages of reduction.

Seaton et al also studied the effect of heat transfer on the reduction behavior of the lumps and proposed that reduction of iron ore : cal char mixed pellet is controlled by the heat transfer rate in the samples. They observed temperature difference between the centre and surface of the pellet and this gape decreased with increase in degree of reduction. In their observations,15 and 27 minutes are needed for lumps to reach thermal equilibrium at 1000^0C and 1100^0C respectively and 10 minutes was sufficient to reach at 1200^0C. The reduction was not found to be 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

The value of activation energy obtained for zenith iron ore lumps varies from 79.81-140.51KJ/mole.

1.8 Iron and steel production scenario in india



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	% World 2004	% World 2015
China	247	259	272	285	305	326	345	364	385	408	432	458	**23%**	**29%**
Other East Asia	200	206	214	222	230	238	247	256	266	276	287	298	**19%**	**19%**
Europe	227	231	235	240	244	249	254	258	263	268	274	279	**21%**	**17%**
CIS	135	142	152	159	160	160	168	174	179	183	188	192	**12%**	**12%**
North America	140	140	137	136	137	138	136	137	138	139	140	140	**13%**	**9%**
South America	49	52	54	57	60	63	66	69	72	76	79	83	**5%**	**5%**
Africa	20	21	22	23	23	24	25	26	27	28	29	30	**2%**	**2%**
Middle East	20	20	21	21	22	22	23	24	24	25	26	26	**2%**	**2%**
India	33	35	38	41	44	48	52	56	60	65	70	76	**3%**	**5%**
Oceania	10	10	11	11	12	12	13	14	14	15	16	16	**1%**	**1%**
World	**1080**	**1117**	**1155**	**1195**	**1238**	**1282**	**1328**	**1377**	**1428**	**1482**	**1539**	**1598**	**100%**	**100%**

Composition of zenith iron ore

Constituents	**Percentage**
Fe (total)	**64.51%**
Fe_20_3	92.25%
Al_20_3	2.34%
$Si0_2$	1.55%
$Ti0_2$	0.14%
MnO	.03%
LOS	3.68

Chemical Composition of Lingaraj coal mines

Volatile matter	39.12%
Ash content	15.93
Fixed carbon	44.95
Caking index	nil
'S' content	0.40
Ash fusion temp.(idt)	1105^{o}C
ST	1410^{0}C
HT	1513^{0}C

1.9 Aim and objective of the project

- Study of the effect of time on the degree of reduction of iron ore pellets.
- Study of the effect of temperature on the degree of reduction of iron ore pellets.
- Reduction studies of iron ore lumps in coal- For comparison with the pellet reduction result.
- Study of the effect of coal type on the reduction characteristics of iron ores

CHAPTER -2

EXPERIMENTAL DETAILS

2.1 PROCEDURE FOR REDUCTION STUDIES

- Zenith iron ore lumps and Lingaraj coal were taken.
- Crushing the iron ore lumps to 20-25mm in size.
- Crushing the coal to -6+16# size.
- Air drying of lumps followed by oven drying at 110^0C to remove moisture.
- The lumps that were formed were taken inside a stain less steel container (size: 77mm height × 40 mm inside diameter) with a mouth tightly closed by an air tight cover having an out let for exit gas. Then the lumps were surrounded by coal and then reduced.

- The position of the iron ore lumps in the packed bed of solid reductant was approximately at the center. This ensures complete surrounding of lumps by solid reductant.

- The reduction experiments were carried out by heating the samples in a muffle furnace from room temperature to the required reduction temperatures of 850, 900, 950, 1000^0C at a rate of about 7^0C per minute and were soaked at these temperature for varying time periods in the range 15 - 120 minutes.

- During the reduction at a particular temperature each container was taken out at an interval of 15 minutes up to 30 minutes of residence , then at an interval of 30 minutes up to 120 minutes of residence in the furnace. Then the containers were cooled to the room temperature in air and the weight losses of the lumps were recorded.

The degrees of reduction of pellets were calculated by using the following formula.

$$\text{Degree of Reduction} = \frac{\text{Weight loss}}{\text{Total weight of removable oxygen in iron oxide}} \times 100$$

Graphical Analysis

The graphical analysis was done by plotting a graph of degree of reduction VS time(in min) which shows degree of reduction increases with time with increase in temperature.

Temperature	Time (in min)	Degree of Reduction (%ge)	Degree of Swelling
850^{0}C	15	31.09	0.50
	30	41.07	1.36
	45	41.14	3.49
	60	48.53	5.02
	90	56.12	5.20
	120	59.81	8.89
	15	36.86	2.04

900^{0}C	30	42.89	4.46
	45	50.13	10.63
	60	58.05	15.23
	90	62.33	18.11
	120	70.11	20.03
Temperature	Time (in min)	Degree of Reduction	Degree of Swelling
950^{0}C	15	37.73	2.45
	30	55.72	3.24
	45	64.46	6.69
	60	70.05	15.22
	90	72.28	17.6
	120	75.86	21.3
1000^{0}C	15	56.13	2.83
	30	64.25	4.87
	45	70.69	8.87
	60	76.59	9.05
	90	82.26	19.5
	120	88.13	22.4

Zenith iron ore lumps with lingaraj coal -6+16#

Figure 1: percentage reduction Versus time(in min)

Zenith iron ore lumps with lingaraj coal -6+16#

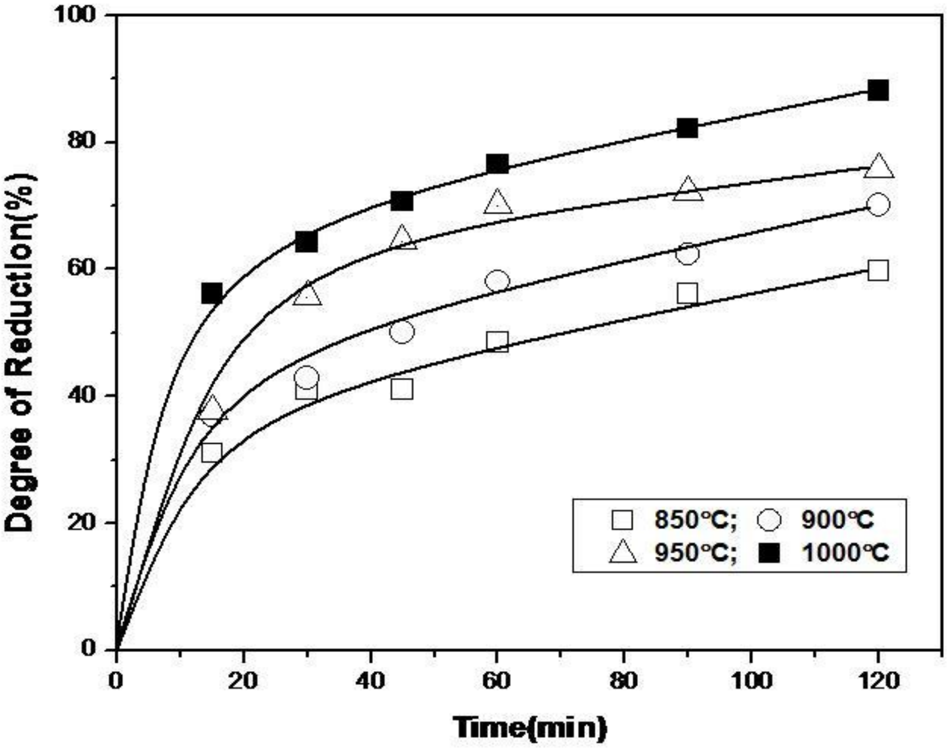
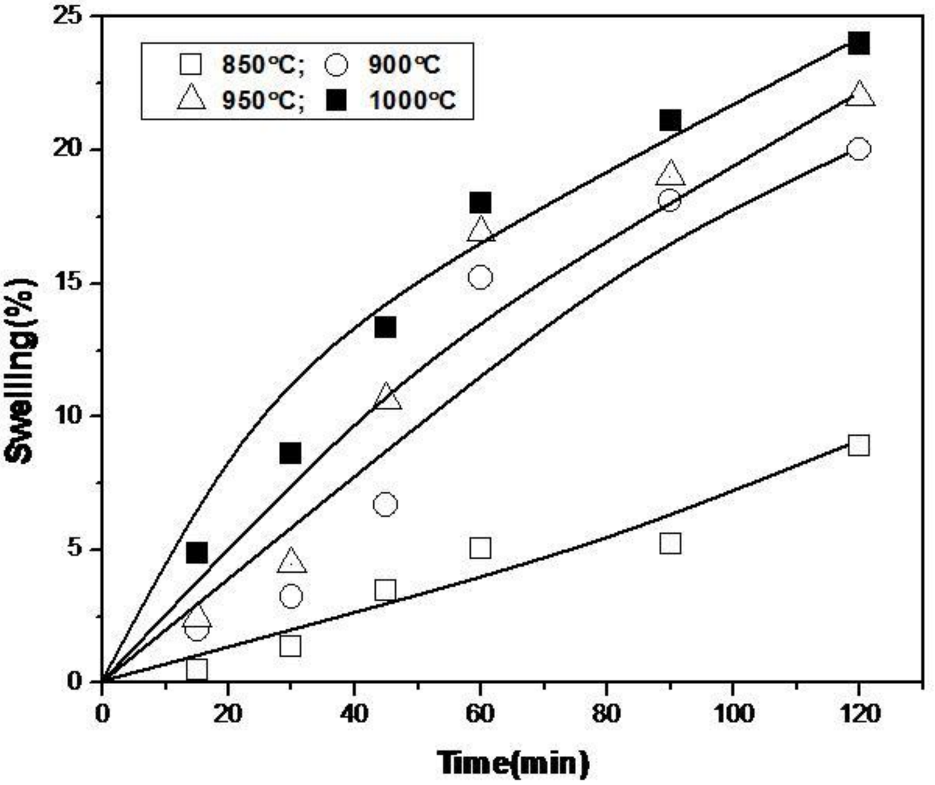


Figure 2: percentage swelling Versus time(in min)

Zenith iron ore lumps with lingaraj coal -6+16#



Temperature	Degree of Reduction (α) (in %ge)	Time (t) (in min)	ln t
850^0C	20	9	2.2
	40	34	3.53
	60	120	4.79
	80		
900^0C	20	7	1.95
	40	21	3.09
	60	76	4.33
	80		
950^0C	20	5	1.87
	40	14	2.64
	60	35	3.56
	80		
1000^0C	20	3	1.10
	40	8.8	2.17
	60	22	3.09
	80	79	4.37

Figure 3: ln t Versus 1/T

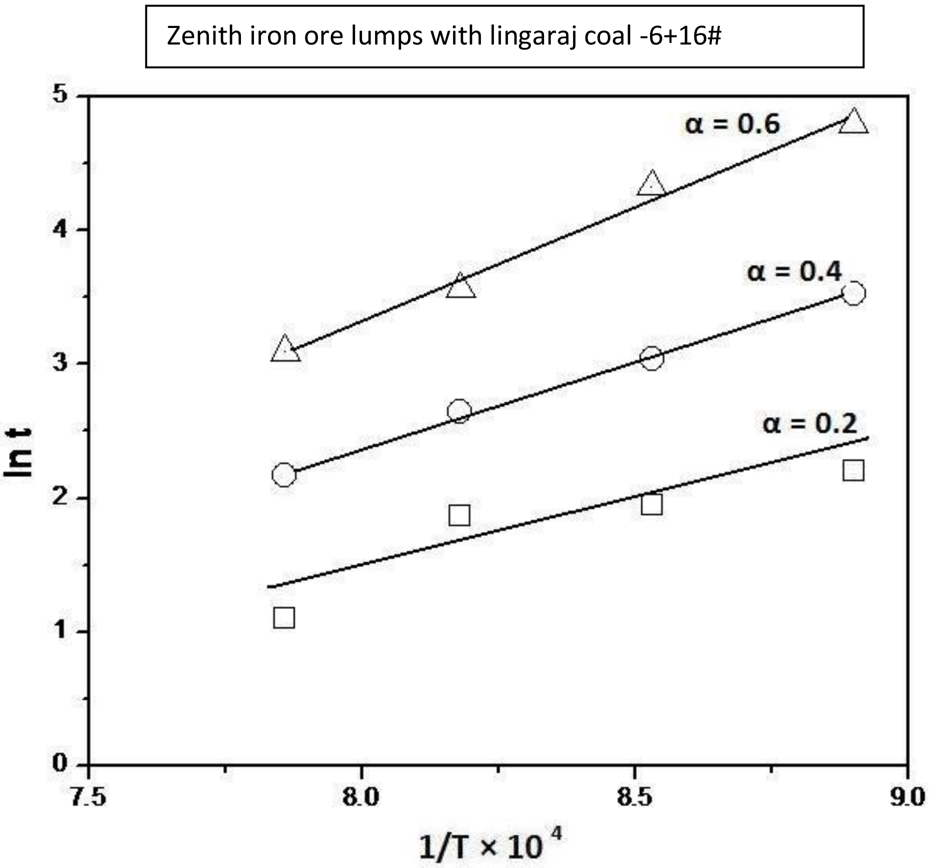
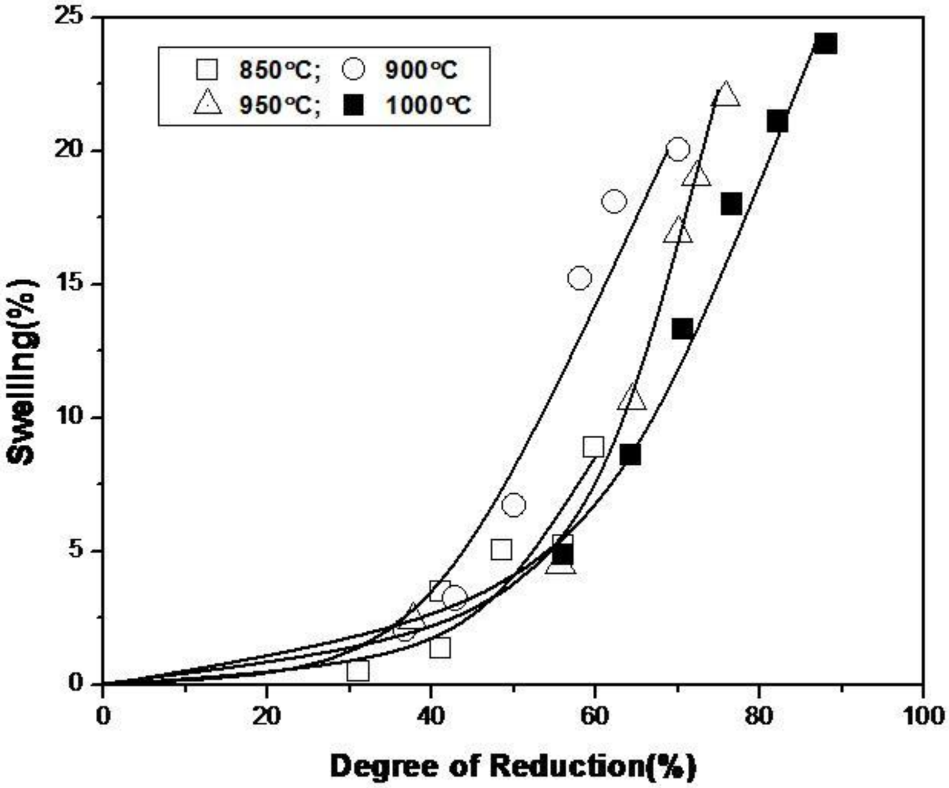


Figure 4: percentage swelling Versus degree of reduction



Degree of Reduction (percentage)	Slope	Activation Energy(kj/mole)
20	$0.96\text{x}\ 10^4$	79.81
40	$1.29\text{x}10^4$	107.25
60	$1.69\text{x}10^4$	140.51

Zenith iron ore lumps with lingaraj coal -6+16#

CHAPTER-3

RESULT AND DISCUSSION

3.1Comparison of reduction characteristics of pellets (fired) and lumps

In this study, reduction behaviours of dried hematite iron ore lumps (size: 15 mm approx.) have been compared with those of corresponding fired pellets reduced (in coal) under identical slow heating conditions (heating rate: 70C min-1, temperature: 900C, soak time: 1 hr.). Data for their degree of reduction values have been recorded and plotted as a function of their total iron contents. The results established lower degree of reduction in lumps than the corresponding fired pellets. the dried iron ore lumps have much lower porosity values than those of corresponding fired pellets. The appreciably lower porosity in iron ore lumps appears to be the most likely reason for their lower reducibility. As outlined in the literature ,hematite pellets tend to form disordered and hence more reactive/easily reducible wustite (FeO) . This may be the another reason for relatively higher reducibility of pellets, as observed in the present investigation. It was noted that Zenith, and lumps cracked into fine fragments during reduction at 900C, and hence their degree of reduction values could not be measured. The breakdown in these lumps may be attributed to the higher rate of Fe_2O_3 - Fe_3O_4 transformation and generation of higher therma1 strain. An increased degree of Fe_2O_3 - Fe_3O_4 transformation increases the volumetric strain (abnormal swelling) and thus the cracking tendency.

3.2 Effect of time on degree of reduction

Rapid heating indicate that the reduction time has an approximately identical effect on the reduction behaviour of almost all the iron ore lumps studied. As shown in Table 3, all the fired iron ore pellets showed highest degree of reduction in the first 30 minutes (i.e. up to about 40 — 50 % reduction) and thereafter the rate of reduction decreased with increasing reduction time up to the range studied (i.e. 120 minutes) . It was also observed that all the fired iron ore pellets were almost completely reduced (more than 90% reduction) in about 120 minutes. This indicates that the utilization of these iron ores in sponge ironmaking is likely to allow the rotary kiln operations to be carried out at low temperatures (i.e. less than 10000 C) resulting in greater savings of energy and kiln life. the excessively high degree of reduction in the first 30 minutes is mainly associated with the release of volatiles from coal, their reformation into H_2 , CO, etc. and major participation of these reducing gases in the reduction of iron oxide (i.e. an appreciable presence of H_2 and CO in the reduction chamber gives a boost in the reduction rate). The decrease in reduction rate with increasing time above 30 minutes is undoubtedly due to the combined effects of an increase in product metallic layer thickness and diminished evolution of volatile matter from coal. An increase in the thickness of product iron layer offers greater resistance in the diffusion of carbon and reducing gas to the surface of unreduced iron oxide.

3.3 Effect of heating mode on degree of reduction

In order to study the effect of mode of heating, the fired iron ore pellets were reduced in coal at 900°C (soak time at this temperature: 1 hr.) under rapid and slow heating conditions. It is fairly clear that in comparison to rapid heating, the slow heating to reduction temperature gives appreciably higher degree of reduction. It is more likely that rapid heating to 900°C causes a higher rate of volatile matter escape from coal, thereby providing less time for H_2 and CO (reducing gases) to be in contact with iron ore pellet. The result is thus lower degree of reduction in rapid heating. During slow heating operation, volatile matters are released from coal at a slower rate and hydrocarbons get sufficient time to undergo the process of cracking ($C_nH_m = nC + mH$). The more deposition of highly reactive pyrolytic carbon, and increased time of contact of carbon and reducing gases (H_2 and CO) with the pellet appear to be the obvious reasons for the higher degree of reduction. heating of hematite pellet from room temperature to the required reduction temperature (900°C) in reducing atmosphere, to some extent, is also responsible' for higher degree of reduction under slow heating condition.

CHAPTER – 4

CONCLUSION

From the results of the present study, the following conclusions may be drawn.

- Reduction time and temperature had marked influence on the degree of reduction. The degree of reduction increased with increase in reduction temperature from 850-1000^{0}C. In studied time period of 15-120 minutes the rate of reduction was higher up to 50-70% reduction and decreased in latter stages.
- There was no effect of type of coal on the degree of reduction of iron ore lumps. The reduction behavior of iron ore pellets was identical in all the studied coals.
- The kinetic data of non isothermal reduction (heating from room temperature to required reduction temperature and then soaking at that temperature for required period of time) of Zeineith iron ore lumps by the selected coals in the temperature range of 850-1000^{0}C were found to be fit well in the differential model, ln t Vs 1/T. The apparent activation energy values of the above mentioned iron ores were found to be in the range of 79.81-140.51KJ/mole. The overall rate thus appears to be controlled by C/CO_2 reaction or carbon gasification reaction.
- The difference in the reduction behavior of iron ore lumps, in coal and, was apparent in initial stages of reduction at lower temperature.
- The result demonstrated that, iron ore lumps were less reducible than their corresponding iron ore pellets.
- The reduced iron ore pellets, in general, showed a decrease in their compressive strength with increase in degree of reduction up to 60 - 65%, followed by a slight decrease at about 85 – 90% reduction and then remained approximately constant.

- The reduction behavior of iron ore lumps with lingaraj coal (-6# +16 #) size.

SUGGESTION FOR FUTURE WORK

The following works are suggested to be carried out in future.

- Detailed reduction kinetic study of remaining iron ores of Orissa by different coals of Orissa and Jharkhand
- Reduction study of iron ore pellets made up of +100# iron ore particles need to be carried out.
- Studies on the reduction kinetics of all these iron ore pellets by coal-char mixture.
- Studies on the reduction kinetics of ore-coal composite pellets for all these iron ores.
- Studies on the kinetics of carbon pick-up during reduction of all these iron ores under different condition need to be carried out.

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