REDUCTION BEHAVIOUR OF IRON ORE PELLETS

A THESIS SUBMITTED IN PARTIAL FULLFILLMENTOF

THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

Metallurgical and Materials Engineering

By

Rashmi Ranjan Pati

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Under the Guidance of

Prof. M.Kumar

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CERTIFICATE

This is to certify that the thesis entitled "**Reduction behaviour of iron ore pellets**" submitted by Mr. Rashmi Ranjan Pati in partial fulfillment of the requirements for the degree of Bachelor of Technology in Metallurgy and Materials engineering at 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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PREFACE

Demand of sponge iron and pre-reduced pellets for the manufacture of different varieties of steel is increasing day by day and new solid reductants based sponge iron plans are being commissioned. In the existing blast furnace an increase in production by at least 25 to 35% can be achieved by using pre reduced iron ore. Pre-reduced iron ore pellets have been established as a good substitute for steel scrap in an electric arc furnace which enhances the productivity of the arc furnace. A lot of investigations have been carried out on direct reduction process of iron oxides by carbonaceous materials, but little work has been done on the characterization of properties and reduction behavior of iron ore of. In the present project work, an attempt has been made to study the reduction behavior and kinetics of iron ore fired pellets. The effect of different reduction parameters such as temperature (850-1000ºC), time (15-120 minutes.), mixing of particles of different sizes at different ratios for pellet preparation etc. on the reduction behavior of iron ore pellets. These form the subject matter of the thesis. First chapter gives the introduction about the subject. It speaks about the need of DRI industry, scope, present status and future planning of DRI industry in India, world wise DRI production, etc. It gives a general idea of raw materials quality required for producing DRI, especially in Rotary Kiln. The second chapter deals with the literature survey. The third chapter deals with planning of experiments, selection of raw materials, preparation of samples, preparation of iron ore pellets, experimental procedure , evaluation of reduction and activation energies, etc. The results obtained and the discussions made from these observations have been outlined in chapter four. The result for fired iron ore pellets indicated an increase in degree of reduction with increase in reduction temperature (850-1000ºC) and time. The reduction kinetics of Zenith iron ore pellets were studied in temperature range of 850-1000ºC. The data were fitted on a differential model and the activation energies of reduction of pellets were calculated. Analysis of swelling behavior was also done.

 Results obtained from chapter four have been summarized in chapter five. Lastly, these conclusions have been followed by the list of references.

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CHAPTER-1
INTRODUCTION

1. INTRODUCTION

The blast furnace process is still the predominant method for primary iron production. However, the disadvantages inherent to the process led to the development of alternative processes such as the mini blast furnace process, smelting reduction process, and direct reduction process. Many of these alternative processes are still under development. However, direct reduction processes have reached some level of commercial applicability and are considered to be the most developed alternative iron making route.

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 variation of steel, a good deal of emphasis is being given to promote the study of direct reduction process.

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 coking 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 32 and 221 billion tons respectively[1]. 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.

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.

1.1 IRON ORE AND COAL RESERVES IN INDIA

India's global position is fifth in terms of iron ore reserves. It has 25 billion tons of reserves, of which 15 billion tons are reported to be hematite and rest magnetite at cut off grades of 55% iron as per Indian bureau of mines (IBM)[2]. India produces around 155 million tons of iron ore

(including both lumps and fines) out of which about 52 million tons were used by the domestic steel manufacturers.

Table 1.11

		2000-01	2001-02	2002-03	2003-04	2004-05	2005-06(P)
Crude steel production	(A) Main producers	17254	17762 (2.94)	18982 (6.87)	20012 (5.43)	20015 (0.01)	21694 (8.39)
	(B) Secondary producers	9703	10202 (5.14)	11461 (12.34)	14236 (24.21)	14806 (4.00)	19650 (6.38)
	TOTAL	26957	27964 (3.73)	30443 (8.86)	34248 (12.50)	34821 (1.67)	41344 (7.43)
Iron ore consumption		36020	37713 (4.70)	40936 (8.54)	44974 (9.86)	48150 (7.06)	52523 (9.08)
Iron ore exports		37270	41640 (11.72)	48020 (15.32)	62570 (30.30)	78145 (24.89)	89277 (14.25)
Iron ore production		80762	86226 (6.76)	99072 (14.90)	122838 (23.99)	145942 (18.81)	154436 (5.82)
Surplus iron ore		7472	6873	10116	15294	19647	12636

Source: 1 Joint Plant Committee, Kolkata
2 Indian Bureau of Mines, Nagpur

India is the third largest producer of coal and has the fourth largest coal reserves in the world consisting 10% of the world share of coal reserves. Non coking coal contributes to about 221 billion tons (85%) while coking coal amounts to 32 billion tons (the remaining 15%). Indian coal has high ash content (15- 45%) and low calorific value.

Fig: 1.11 Coal state wise distributions
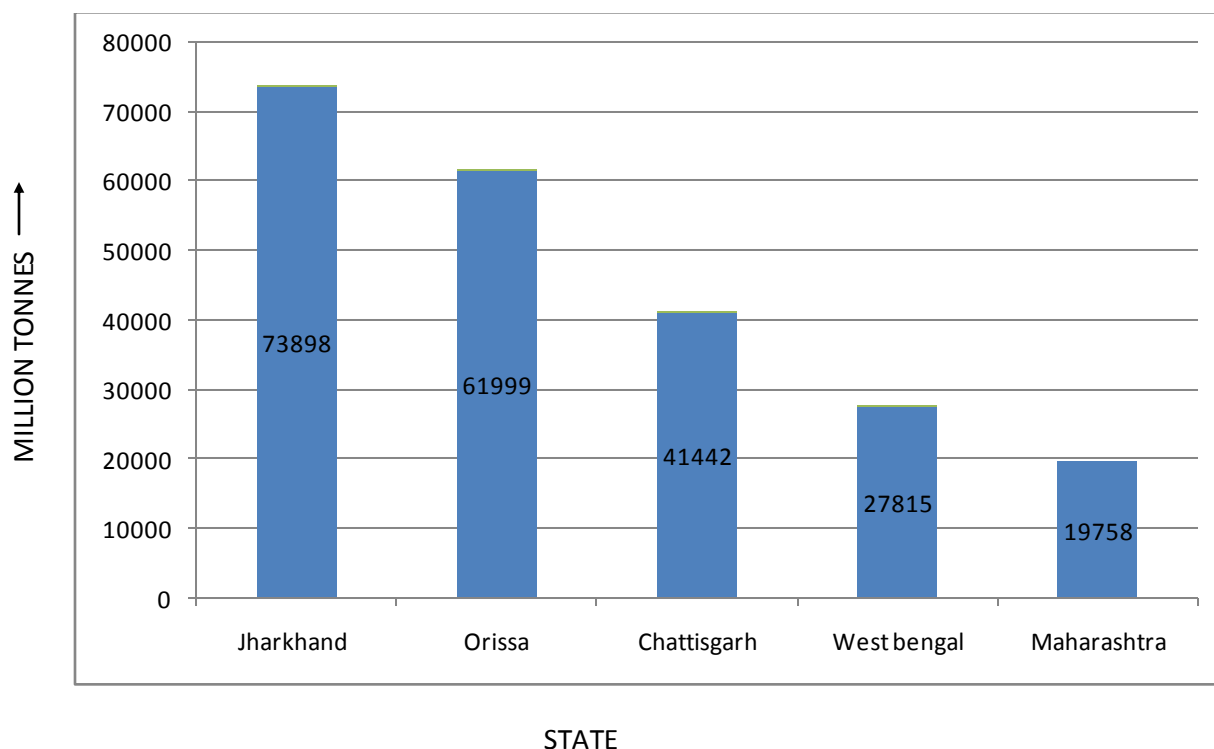
1.2 PRODUCTION, CONSUMPTION, EXPORT AND SURPLUS AVAILABILITY OF IRON ORE LUMPS AND FINES IN INDIA

Some data of Production, Consumption, Export and Surplus availability of Iron Ore in India, in the year 2003-04, 2004-05, 2005-06 are given in the Table-2.

From the Table it is quite clear that, the ratio of fines in total export is increasing year by year. About 78.50% in year 2003-04 and has increased to around 84% in the year 2005-06. So it is quite obvious that the fines generated don't find there market in India. After meeting the entire domestic demand and export demand, there was still Iron Ore surplus of 15.30 MT, 19.65 MT, and 12.93 MT, in the year 2003-04, 2004-05 and 2005-06 respectively. Moreover, around 84% of fines are exported to foreign countries at a throw away pricing which causes huge economic loss to our countries. If these fines can find their utilization in the country, it would be a great contribution towards our economic growth.

Table 1.21

Year wise production, consumption, export and surplus availability of iron ore lump and fines in India
In Million tons

year	Iron ore production	Domestic consumption	Export of iron ore			Surplus availability
			Lumps	Fines	Total	
2003-04	122.84	44.97	13.45 (78.50)	49.12 (21.50)	62.57 (100)	15.30
2004-05	145.95	48.15	13.54 (82.67)	64.60 (17.33)	78.14 (100)	19.65
2005-06	154.43	52.23	14.30 (83.99)	74.97 (16.01)	89.27 (100)	12.93

(Figures in parenthesis are the percentage of total export)
Source: Indian Bureau of Mines, Nagpur, GMOEA, KIOCL, NMDC, MMTC

1.3 YEAR WISE DRI PRODUCTION IN INDIA AND WORLD

A year-wise production of sponge iron in the world including India is given in Table-1.1. According to recent analysis, it has been observed that beginning with a meager production of 0.79 million tons in 1970; the world sponge iron production went upto 68.5 million tons in 2008, as shown in table-1.1, it is clear from the table that the world sponge iron production has been increased. In the year 2002 India became the largest producer of sponge iron in the world with a production of 5.48 million ton and still it has retained its first slot in the world rating of sponge

iron production. Out of 20 MT of sponge iron produced in 2007-08 the contribution of coal based sponge iron units is around 14.14 MT and that of has based units are 5.84 MT. This large difference is due to scarcity of natural gas and abundant availability of non-coking coal in India. This phenomenal growth of DRI industries is driven by increasing demand of steel in India and as well as in the world.

Table1.31

Year wise DRI production in India and World

Year	World scenario Production(MT)	India scenario Production(MT)
1990-91	17.68	-
1991-92	19.32	1.31
1992-93	20.51	1.44
1993-94	23.65	2.40
1994-95	27.37	3.39
1995-96	30.67	4.40
1996-97	33.30	5.00
1997-98	36.19	5.30
1998-99	36.96	5.22
1999-2000	38.60	5.34
2000-2001	43.78	5.48
2001-2002	40.32	5.43
2002-2003	45.08	6.9
2003-2004	49.45	8.08
2004-2005	54.60	10.30
2005-2006	55.85	11.47
2006-2007	59.8	16.27
2007-2008	68.5	20

SOURCE: STEELWORLD.COM

1.4 RAW MATERIALS FOR DRI AND CRITERIA FOR THEIR SELECTION

Iron Ore Fines: In rotary kiln, usually the ore of size between 5 to 18 mm are used. This size range of the ore is produced by crushing and screening the lumpy ore received from the mines. In this process nearly 35% of the ore is produced in the form of fines. For per ton of sponge iron produced, nearly 0.8 tons of iron ore fines are used. The typical sieve analysis of iron ore fines are given below

- -1mm (30- 40%)
- -3mm (35-38%)
- +3,-5mm (28-45%)

Utilization of Iron Ore Fines: The Iron Ore Fines, which are produced as a waste material, can be utilized in the following manner:

- Some quantity of +3 to -5mm can be used along with the charge in rotary kiln by adjusting positive size of coal, etc.
- The iron ore fines can be pelletized and used in the blast furnace for producing pig iron or in rotary kiln for sponge iron making.
- Sinters can be made for iron ore fines and used in the blast furnace.
- Composite pre-reduced pellets (CPR) can be made from iron ore and coal fines for use in iron blast furnace or EAF.
- Sponge iron rods, granules, etc can be made by iron ore fines in coal.

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

- Chemical Composition
- Reducibility
- Physical Characteristics (size, strength etc)

Coal Fines: The Sponge Iron plants generally use 6mm size coal partially the finer fraction which contains around 32-40% ash is considered as a waste. In Sponge Iron plants around 15-20% fines are generated.

Utilization of Coal Fines: The Coal fines thus produced can be used in the following manner.

- Generation of Power through fluidized bed combustion boiler.

6

- For heat hardening of the iron ore pellets produced from waste iron ore fines.
- It can be used in the sinter mixture after beneficiation.

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

- Proximate Analysis (Fixed Carbon, Volatile matter, Ash, Moisture).
- Sulphur
- Ash fusion temperature
- Ash chemistry

Char fines: The char fines came out of the kiln along with the sponge iron. The generation of the char fines is about 15% of the sponge iron produced. However, the fixed carbon present in the coal char is only 19-21% with 1-2% of volatile matters.

Utilization: The coal Char produced can be utilized, after suitable treatment in the following areas.

- Preparation of smokeless domestic fuel briquettes along with small amount of coal fines / coke breeze / saw dusts, wood charcoal etc.
- For generation of power, along with coal fines.
- For treating industrial effluents to remove toxic elements.

1.5 OBJECTIVES OF THE PROJECT

- Study of the effect of temperature on the degree of reduction of iron ore pellets.
- Study of the effect of time on the degree of reduction of iron ore pellets.
- Study of effect of mixing of iron ore particles of different sizes in different ratios on the reduction characteristics of the resulting iron ore pellets.
- Calculation of activation energy.
- Study of swelling behavior.

CHAPTER-2

LITERATURE SURVEY

2. LITERATURE SURVEY
2.1 What are Pellets?

Pellets are approximately spherical lumps formed by agglomeration of the crushed iron ore fines in presence of moisture and binder, on subsequent induration at 1300°C.

2.2 MECHANISM OF PELLET FORMATION[3]

- . Ball Formation – Surface tension of water & gravitational force creates pressure on particles, so they coalesce together & form nuclei which grow in size into ball.
- Induration (Heat Hardening) – Solid state diffusion at particle surfaces at higher temperature cause recrystallisation & growth giving strength

Theory of ball formation-

Surface tension of water & gravitational force creates pressure on particles, so they coalesce together & form nuclei which grow in size into ball.

Induration (Heat Hardening)-

Solid state diffusion at particle surfaces at higher temperature causes recrystallisation and growth giving strength. The force responsible for the agglomeration of ore fines are capillary action of water and gravitational force of particles. The ball forces occur because of surface tension forces of water and collision between particles. Initially, nuclei of pellet are form from addition of water and the nuclei grow bigger in balls and then into pellets as they pick up loose grain particles during their travel through the drum, which is slightly tilted the angle of tilt determines the time of residence, pellet size and productivity. The size and shape of drum should be such as to obtain the most favorable condition of motion and pressure that is more of rolling as offer to sliding motion. This ensures more effective collision between particles. The capillary action of water under interstitials of the grain causes a contracting effect on then. The pressure of water on the course of ball is sufficiently high so as t compact the constitute grain into a dense mass. The compressive force is directly proportional to the fineness of the grain since the capillary action rises if the decrease in pore radius and the later decreases with increase in fineness. When one particle falls and comes into the gravitational force filled of another particle of which it falls and its neighbors, they adhere because of pressure generated due to gravitational force. Due to this force tremendous amount of pressure is built up which leads to molecular adhesion. The green

pellets obtain are then fired at 1100ºC to ensure complete removal of moisture and then these are heat hardened at 1300ºC or 1 hour in order to ensure the strength of pellets which is due to recrystallisation and grain growth.

2.3 ADVANTAGES OF PELLETS

- **Good Reducibility**: Because of their high porosity that is (25-30%), pellets usually reduced considerably faster than hard burden sinter or hard natural ores.
- **Good bed Permeability**: Because of their spherical shapes and containing open pores, these are formed very good bed permeability. The shape, size and low angle of repose give minimal segregation and an even charge distribution in the furnace, extending more towards the axis.
- **High Strength (150-250 kg/cm2) or more:** Pellets should have sufficient structural strength to with stand, without significant breakage, the normal handling which occurs in the various transportation and handling steps between the pellet furnace and the blast furnace skip.
- **High Porosity (25-30%):** Because of high porosity of pellets, these are easily reducible.
- **Less heat consumption than sintering.**
- **Uniform chemical composition:** The chemical analysis is to degree controllable in the concentration processing within limits dictated by economics.
- **Easy handling and transportation.**
- **Good resistance to disintegration.**

2.4 DISADVANTAGES OF PELLETS

- High cost of production.
- Swelling and loss of strength inside the furnace.
- Difficulty of producing fluxed pellets.
- Maximum basicity of the pellets is 1.2.

2.5 REDUCTION REACTIONS[4]

- $3Fe_2O_3 + CO/H_2 = 2Fe_3O_4 + CO_2/H_2O$
- $Fe_3O_4 + CO/H_2 = 3FeO + CO_2/H_2O$
- $FeO + CO/H_2 = Fe + CO_2/H_2O$
- $Fe_2O_3 + C = Fe_3O_4 + CO$
- $Fe_3O_4 + C = FeO + CO$
- $FeO + C = Fe + CO$

- $C + CO_2 = 2CO$

Reduction of iron oxide by carbon is known as Direct Reduction.

Reaction and reduction of iron oxide by CO/H_2 is known as Indirect Reduction.

$C + CO_2 = 2CO$ is known as solution loss reaction.

2.6 SEQUENTIAL STEPS IN REDUCTION OF IRON OXIDE
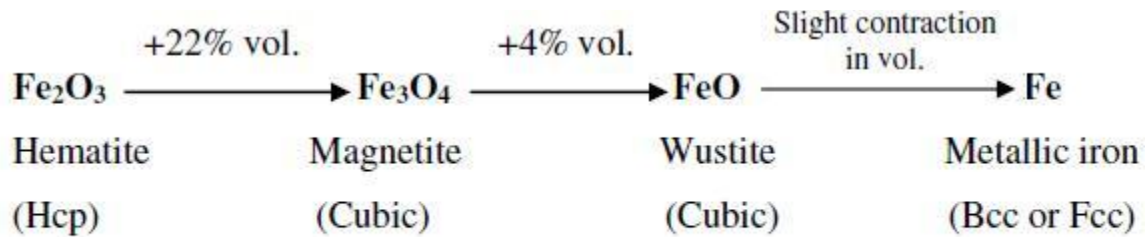
2.7 KINETICS STEPS IN REDUCTION OF IRON OXIDE
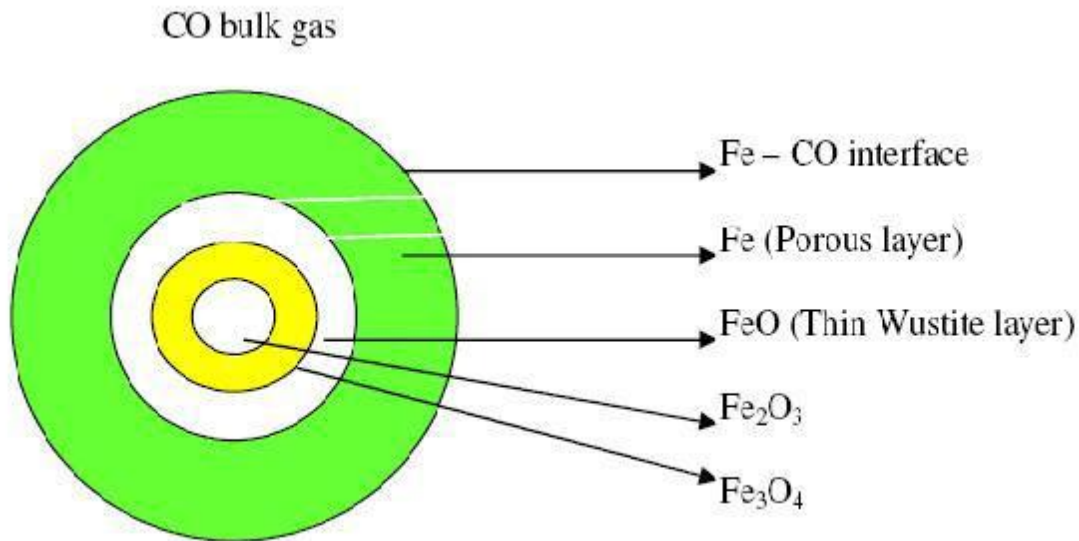
Fig: 2.71 A schematic diagram in modes of reduction of iron oxide

Steps

- Transport of CO gas from bulk gas phase to Fe-CO interface.
- Adsorption of CO gas at the Fe-CO interface.

- Transport of CO gas from Fe-CO interface to Fe-Fe_2O_3 interface.

- Adsorption of CO gas at the Fe-Fe_2O_3 interface.

- Chemical reaction between Fe_2O_3 and CO gas at the Fe- Fe_2O_3 interface.

$$Fe_2O_3 + CO = Fe + CO_2$$

- Desorption of the product gas CO_2 from Fe- Fe_2O_3 interface to Fe-CO interface.

- Transport of CO_2 from Fe- Fe_2O_3 interface to Fe-CO interface.

- Diffusion of CO_2 from Fe-CO interface to the bulk gas phase.

- Diffusion of tiny iron nuclei and merging into bigger nuclei.

2.8 FACTORS AFFECTING THE RATE OF REDUCTION[5]

- Temperature of reduction.

- Time of reduction.

- Particle size of iron ore.

- Pellet size.

- Presence of catalyst.

- Reactivity of solid carbon.

- Chemical nature of oxide.

- Fe_2O_3/C ratio.

CHAPTER-3
EXPERIMENTAL

3 EXPERIMENTAL

3.1 EXPERIMENTAL PROCEDURE

- Iron ore was collected from Zenith mines of Orissa

- Coal from Lingaraj mines was taken.

- Chemical analysis of the ore and proximate analysis of coal was done which is given in table 3.11 and 3.12 respectively.

- Grinding of the ore to -100#, (-18+25) # and (-10+16) #.

- Crushing of coal to (-6+16) #.

- Making of pellets by hand rolling adding proper amount of water.

- Pellets were made in size range of about 15 mm of -100# and adding 80% amounts of -100#, 10% amounts of(-18+25) # and 10% amounts of (-10+16) #.

- Air drying of the pellets followed by oven drying at 110ºC to remove moisture.

- To obtain proper strength in the pellet firing was done in a muffle furnace at 1300ºC for 1 hour.

- Reduction studies of the fired pellets were carried out in a stainless steel reactor.

- The reactor was made half full with non coking coal of size (-6+16) # mesh and the weighed (fired) pellet was placed centrally on this coal bed and the remaining portion of the stainless steel reactor was filled with coal. The reactor lid had a hole centrally for the escape of the gas.

- The reactor was then introduced into the furnace and heated from room temperature to the required temperature of 850ºC, 900ºC, 950ºC, 1000ºC & soaked there for 15, 30, 45, 60, 90, 120 minutes respectively.

- The reactors were then taken out and cooled in air. The weight losses in pellets were recorded by an electronic balance and calculation for degree of reductions were made.

3.2 DEGREE OF REDUCTION

The degree of reduction was calculated by using the following formula:

Degree of reduction = (weight loss in pellet/total oxygen content in the pellet) ×100

3.3 PROCESS FLOW CHART

```
┌──────────────────────────────────────────────────┐
│  Selection of iron ore from Zenith mines and non  │
│     coking coal (F grade) from Lingaraj mines     │
└──────────────────────────────────────────────────┘
```
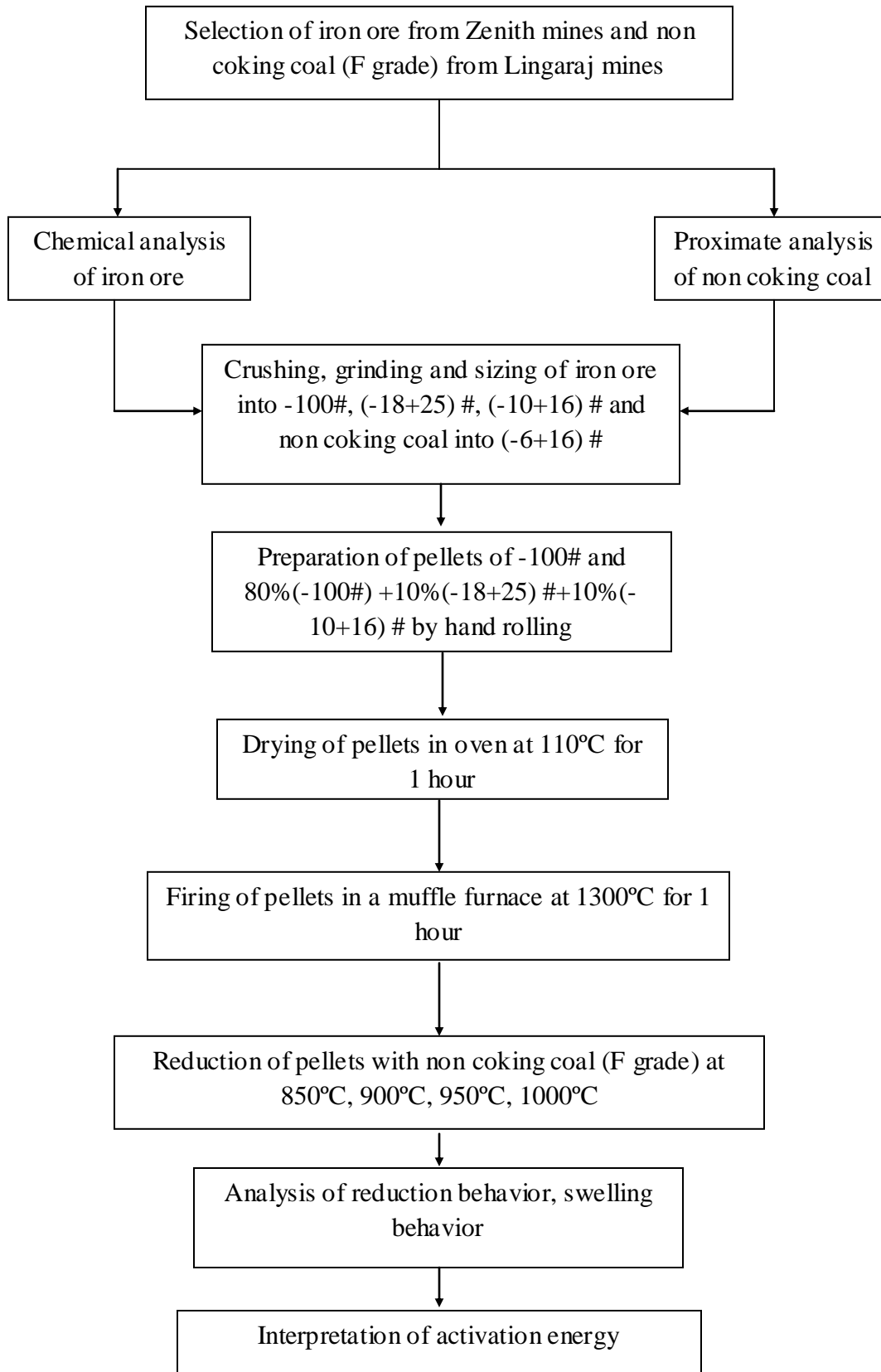
```
┌─────────────────────┐          ┌─────────────────────┐
│  Chemical analysis  │          │  Proximate analysis │
│     of iron ore     │          │  of non coking coal │
└─────────────────────┘          └─────────────────────┘
```

```
┌──────────────────────────────────────────────────┐
│  Crushing, grinding and sizing of iron ore        │
│  into -100#, (-18+25) #, (-10+16) # and           │
│  non coking coal into (-6+16) #                   │
└──────────────────────────────────────────────────┘
```

```
┌──────────────────────────────────────────────────┐
│  Preparation of pellets of -100# and              │
│  80%(-100#) +10%(-18+25) #+10%(-                  │
│  10+16) # by hand rolling                         │
└──────────────────────────────────────────────────┘
```

```
┌──────────────────────────────────────────────────┐
│  Drying of pellets in oven at 110ºC for           │
│  1 hour                                           │
└──────────────────────────────────────────────────┘
```

```
┌──────────────────────────────────────────────────┐
│  Firing of pellets in a muffle furnace at 1300ºC for 1 │
│  hour                                             │
└──────────────────────────────────────────────────┘
```

```
┌──────────────────────────────────────────────────┐
│  Reduction of pellets with non coking coal (F grade) at │
│  850ºC, 900ºC, 950ºC, 1000ºC                      │
└──────────────────────────────────────────────────┘
```

```
┌──────────────────────────────────────────────────┐
│  Analysis of reduction behavior, swelling         │
│  behavior                                         │
└──────────────────────────────────────────────────┘
```

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┌──────────────────────────────────────────────────┐
│  Interpretation of activation energy              │
└──────────────────────────────────────────────────┘
```

Table 3.11

Chemical analysis of iron ore[6]

Iron ore	Fe (total)	Fe_2O_3	Al_2O_3	SiO_2	TiO_2	MnO	Loss on ignition
Zenith mines	64.51	92.25	2.34	1.55	0.14	0.03	3.69

Table 3.12

Proximate analysis of non coking coal

Moisture	5%
Volatile matter	29%
Ash	22%
Fixed carbon	44%

The reactivity of Lingaraj coal was found to be 4.19 cc/gm of CO/seconds.

CHAPTER-4

RESULTS AND DISCUSSIONS

4 RESULTS AND DISCUSSIONS

4.1 EFFECT OF REDUCTION TIME ON DEGREE OF REDUCTION OF IRON ORE PELLETS

Data given in table 4.11, 4.12 and represented graphically in figures 4.11and 4.12 illustrate the effect of time at different reduction temperatures of 850, 900, 950, 1000ºC for the two types of iron ore pellets reduced by Lingaraj coal (F grade). It can be observed from the figures () that the reduction time has an approximate identical effect on the reduction behavior of the two iron ore-coal combination. With increase in reduction time the degree of reduction increased at all the temperature under consideration.

4.2 EFFECT OF REDUCTION TEMPERATURE ON DEGREE OF REDUCTION OF IRON ORE PELLETS

The reduction curves (reduction Vs time) for iron ore pellets reduced by non coking coal (Lingaraj mines) at temperatures of 850, 900, 950, 1000ºC are shown in figures 4.11 and 4.12respectively. It is clear from both the figures that reduction was enhanced with increase in temperature. The degree of reduction is 86.09% at 850ºC carried out for two hours and is 99.4% at 1000ºC carried out for one hour for pellets made of -100# size. Likewise, the degree of reduction is 95% at 850ºC carried for two hours and is 100% at1000ºC carried out for one hour for pellets made of 80%(-100#), 10%(-18+25) #, 10%(-10+16) # size. Reduction at 850ºC and 900ºC was not completed within the stipulated time period (2 hours) and stopped at 86.09% for 850ºC and 96.34% for 900ºC for pellets made of -100#. Likewise, the reduction stopped at 95% for 850ºC and 98.2% for 900ºC for pellets made of 80%(-100#), 10 %(-18+25) #, 10%(-10+16) # size.

It is believed that as the temperature increases, the initially formed iron layer grow through further reduction leading to higher degree of reduction at higher temperatures.

4.3 EFFECT OF ADDITION OF COARSER SIZE PARTICLES IN PELLETS

It is seen that addition of coarser particles in pellets leads to higher degree of reduction at all temperatures taken in account. It is probably due to slight increase in porosity which is achieved due to addition of coarser particles.

Table 4.11

Reduction of zenith iron ore pellets (-100#) with Lingaraj non coking coal (-6+16) #

Temperature (ºC)	Time (minutes)	Degree of reduction (%)
850	15	60
	30	66.48
	45	72.56
	60	73.08
	90	83.97
	120	86.09
900	15	68.33
	30	71.08
	45	80.61
	60	90.05
	90	96.32
	120	96.34
950	15	80
	30	89.29
	45	92.49
	60	96.13
	90	98.6
	120	99
1000	15	84.07
	30	92.82
	45	98.77
	60	99.4
	90	100
	120	100

Table 4.12

Reduction of zenith iron ore pellets 80%(-100#), 10%(-18+25) #, 10%(-10+16) # with

Lingaraj non coking coal (-6+16) #

Temperature (°C)	Time (minutes)	Degree of reduction (%)
850	15	75.4
	30	78.48
	45	81.7
	60	87.43
	90	94
	120	95
900	15	92.73
	30	94.5
	45	96.3
	60	97.7
	90	98.2
	120	98.2
950	15	95.4
	30	97
	45	98.6
	60	99
	90	99
	120	99.5
1000	15	97.5
	30	98.5
	45	99.9
	60	100
	90	100
	120	100
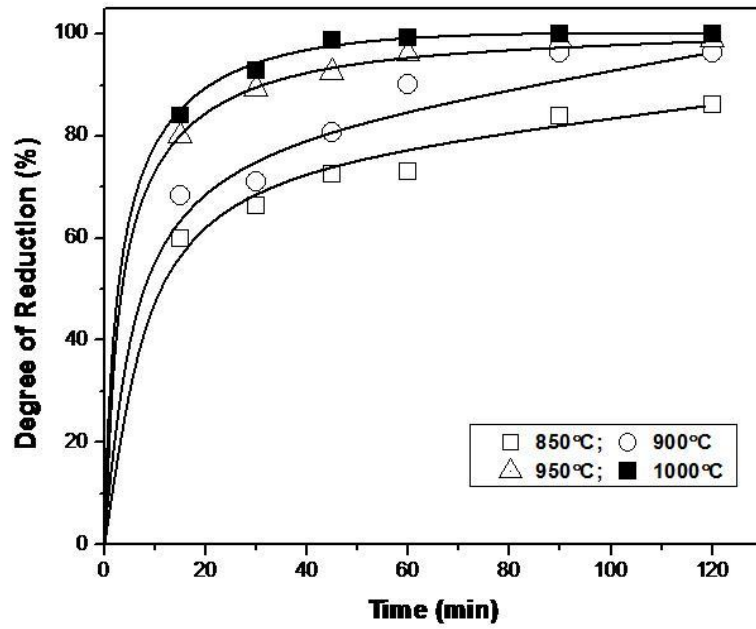
Fig: 4.11 Reduction (%) Vs Time for -100# size iron ore pellet
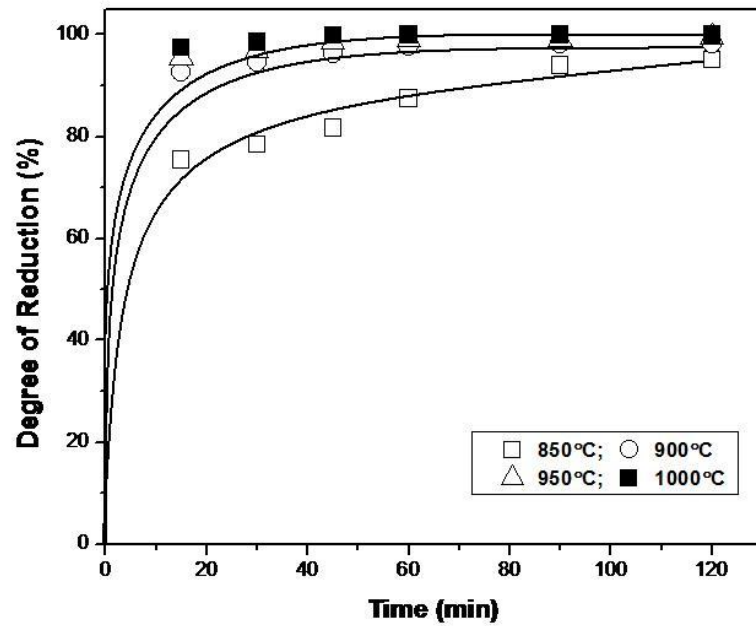
Fig: 4.12 Reduction (%) Vs Time for 80%(-100#)+10%(-18+25)#+10%(-10+16)# size iron ore pellet

4.4 REDUCTION KINETICS OF IRON ORE PELLETS

Kinetic studies for estimation of apparent activation energies were carried out for Zenith iron ore pellets in 'F' grade non coking coal (Lingaraj Mines) at four different temperatures of 850, 900, 950 and 1000ºC for different time intervals in the range of 15 – 120 minutes.

A large number of reaction models have been formulated. These kinetic models include nucleation, chemical control and diffusion control models. The reduction behaviors shown by the pellets were not satisfying any of the above models, so differential model was taken into account. In this model fractional reduction at 20, 40, 60, 80 percentage reductions was taken and graph was plotted between lnt and 1/T. Arrhenius equation was used to calculate the activation energy. Arrhenius equation is as follows

$K = Ae-E/RT$

Or $lnK = lnA – E/RT$

Where,

K = Reaction rate constant

A = Frequency factor

E = Activation energy

T = Temperature (ºK)

R= Universal gas constant

The plot of lnt Vs 1/T results in a straight line. The slope of the plot is –E/R. So activation energy can be obtained by multiplying slope $\times$ R.

The value of lnt is obtained from the reductions Vs time graphs for 20, 40, 60, 80 percent reduction at different temperatures (850, 900, 950, 1000ºC) respectively.
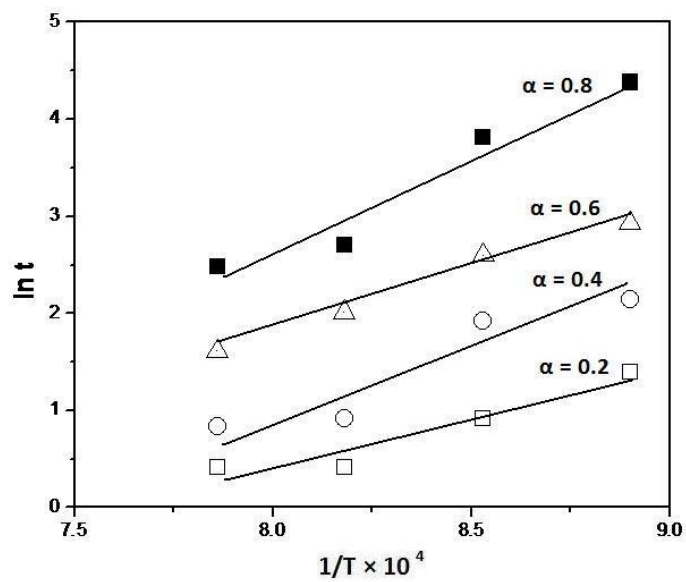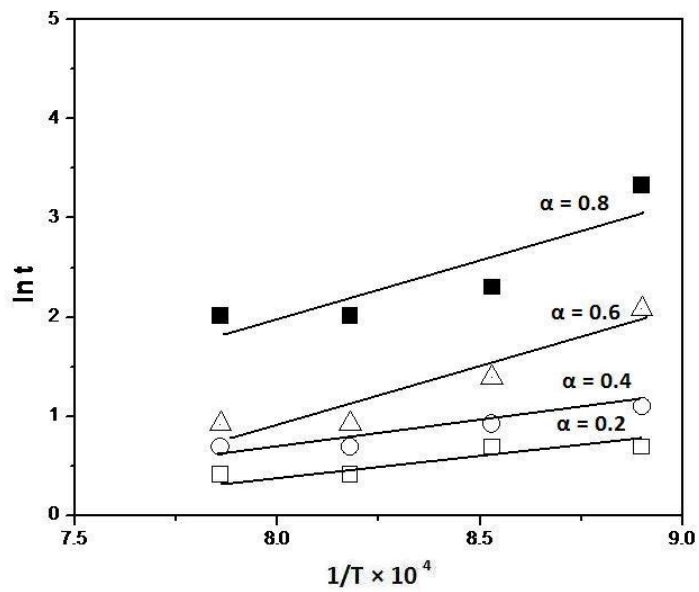
Fig4.41 lnt Vs 1/T for pellets of -100# size

Fig4.42 lnt Vs 1/T for pellets of 80%(-100#)+10%(-18+25)#+10%(-10+16)# size

Table: 4.41 Activation energy of reduction reaction for pellets of -100#

Fractional reduction(α)	Slope ($\times 10^4$)	Activation energy(KJ/mole)
0.2	0.95	78.98
0.4	1.5	124.71
0.6	1.49	123.87
0.8	2	166.28

Table: 4.42 Activation energy of reduction reaction for pellets of 80%(-100#)+10%(-18+25)#+10%(-10+16)# size

Fractional reduction(α)	Slope ($\times 10^4$)	Activation energy(KJ/mole)
0.2	0.55	45.73
0.4	0.5	41.57
0.6	1.25	103.92
0.8	1.14	94.78

4.5 ANALYSIS OF SWELLING BEHAVIOR

Data represented graphically in figures 4.51, 4.52, 4.53and 4.54 illustrate the effect of swelling Vs degree of reduction and time respectively at different reduction temperatures of 850, 900, 950, 1000ºC for the two types of iron ore pellets reduced by Lingaraj coal (F grade). It seen that for both the types of pellets swelling percentage increases for 850ºC and 900ºC while the pellets subjected to 950ºC and 1000ºC has undergone shrinkage.

The main causes of swelling proposed in the literature are as follows[7-8]:

- The disruptive stresses set up during the transformation of Fe_2O_3 to Fe_3O_4 (Hayes and Grieveson 1981).
- Formation of iron whiskers during ''FeO''-Fe reduction step (Nascimento et al. 1997). Iron-bearing material nature (iron ore or dusts containing iron oxide) and the presence of components such as Na_2O, K_2O, CaO, etc. (Bleifuss 1970; Lu 1973).

- Temperature of reduction and reducing gas composition (Moon and Walker 1975; Nicolle and Rist 1979).
- Disintegration of iron grains during carbon monoxide reduction (Mantovani et al. 2000).

The pellets subjected to 950ºC and 1000ºC have undergone shrinkage because the heat intensity is high. At such high intensity, nucleation and sintering of iron is favored. Due to sintering bonding between particles occur and particles become compact. This results in shrinkage of pellets at higher temperatures.
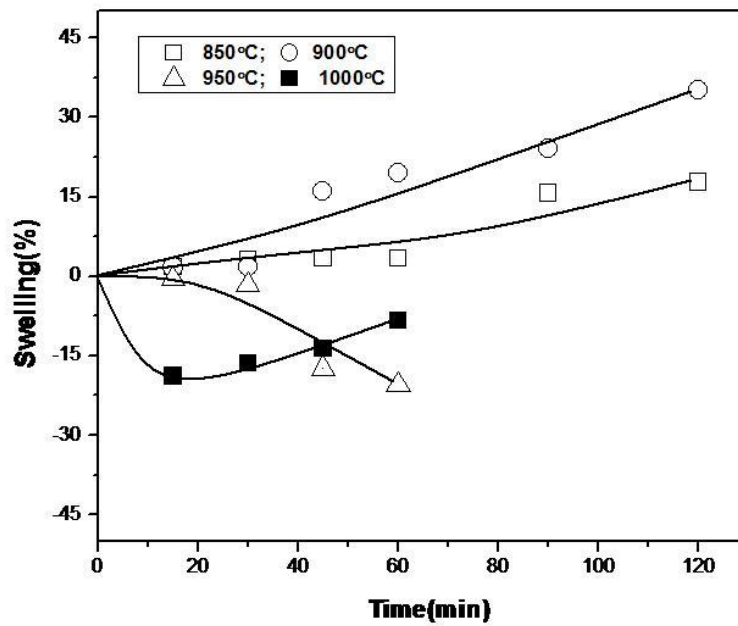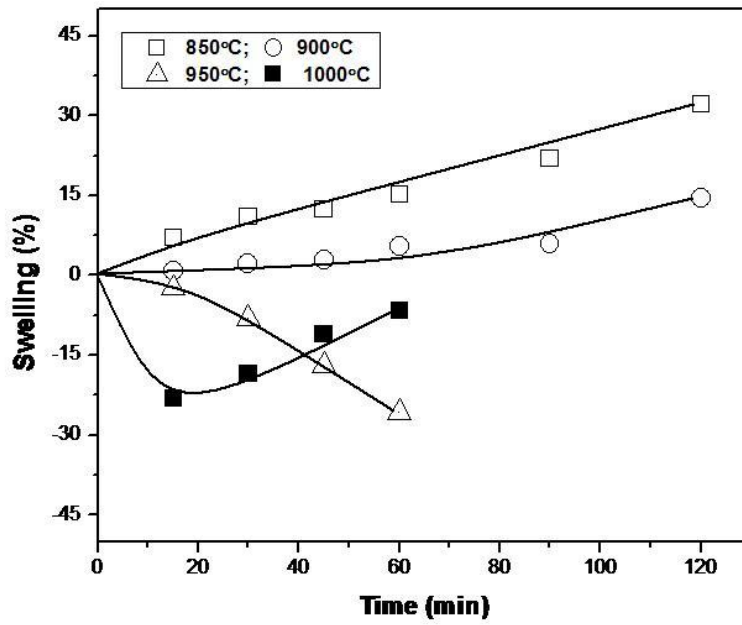

Fig 4.51 Swelling Vs Time for -100# pellets

Fig 4.52 Swelling Vs Time for pellets of 80%(-100#)+10%(-18+25)#+10%(-10+16)# size
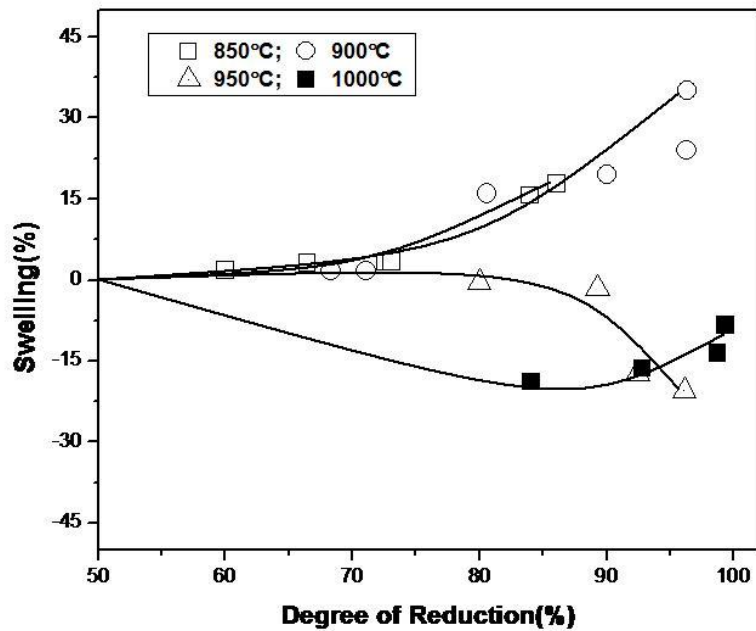

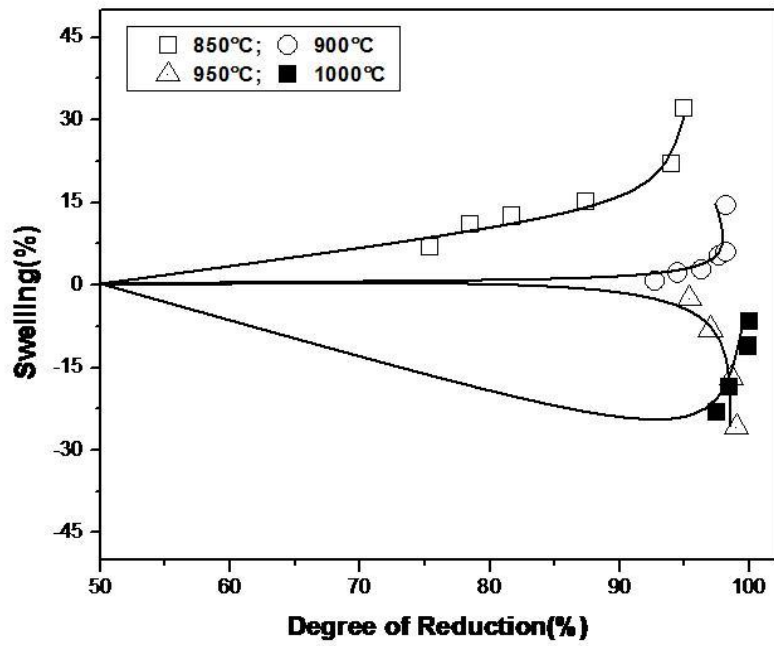**Fig 4.53 Swelling Vs Degree of reduction for -100# pellets**

Fig 4.54 Swelling Vs Degree of reduction for pellets of 80%(-100#)+10%(-18+25)#+10%(-10+16)# size

CHAPTER-5
CONCLUSIONS

5 CONCLUSIONS

- With increase in temperature degree of reduction of pellets increases from850-1000ºC.

- With increase in time degree of reduction of pellets increases from 15-120 minutes.

- The reduction behavior of mixed iron ore pellets of composition (-100# 80%, -18+25# 10%, -10+16# 10%) was found to be greater than the iron ore pellets made by -100# iron ore fines, by Lingaraj coal (F grade).

- The swelling behavior of iron ore pellets increased for temperatures of 850ºC, 900ºC, while for temperatures of 950ºC and 1000ºC pellets showed shrinkage behavior.

6 REFERENCES

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