TO STUDY THE REDUCTION & SWELLING BEHAVIOUR OF IRON ORE PELLETS

A REPORT SUBMITTED IN PARTIAL FULLFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
In

Metallurgical and Materials Engineering

By

Ripu Sudan Agarwal (109MM0433)

Sri Sachin Hembram (109MM0441)

Under the Guidance of

Prof. M.Kumar

Department Of Metallurgical & Materials Engineering

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CERTIFICATE

This is to certify that the thesis entitled "**To Study The Reduction & Swelling Behaviour Of Iron Ore Pellets** " submitted by **Mr Ripu Sudan Agarwal** and **Mr Sri Sachin Hembram** in partial fulfilment 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.

Date:

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Abstract

Due to low availability of coking coal and huge establishment cost of Blast Furnace plants, the predominant route of Iron making has meandered away from this conventional route to a modern route of Iron making. This route involves production of Directly Reduced Iron (DRI) using non-coking coal and gases as the reducing agent. The commercial name of DRI is Sponge Iron owing to its spongy appearance since the ore is reduced in solid rather than liquid state. Since DRI can work with low quality non-coking coal, it makes the best possible usage of cheap coal available in India. High availability of low- quality and iron-ore and coal, the low establishment cost of DRI plants has over the years attracted multitude of opportunist to earn a fortune in this sector. India is the leading producer of sponge iron in world, producing nearly about 30% of the total DRI world production. In spite of these hearting figures a very little research has been carried out regarding the physical and chemical behavior of Iron-ore pellets when reduced using non coking coal.

The present project work endeavors to study the reduction and swelling behavior of Iron-ore of Sakurruddin mines using coal obtained from Vasundhara mines. The first chapter gives a concise overview of the present DRI market and the position of India amongst other world players in its production. The second chapter deals with literature review, the third with the selection of ore, preparation of pellets and the reduction of the pellet ore. The chapter deals with the experimental findings of the scholars followed by conclusion, future work suggestions. At the end an inventory of references has been mentioned in order to allow the reader to carry out a more detailed investigation if required.

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Chapter 1

Introduction

1. Introduction –

Directly reduced iron (DRI) produced by the reduction of iron-ore pellets in solid state is an essential source of iron, in addition to iron scrap in the production of steel mainly through EAF(Electric Arc Furnace) route of steel making.

Originally EAF (Electric Arc Furnace) relied almost entirely on iron scrap charge. But since 1990's, DRI has emerged as a relatively cheaper feed for EAFs (Electric Arc Furnaces). The principal reason behind the popularity of DRI soaring is the EAF (Electric Arc Furnace) route of steel making. EAF is preferred to other conventional methods/routes of steel making.

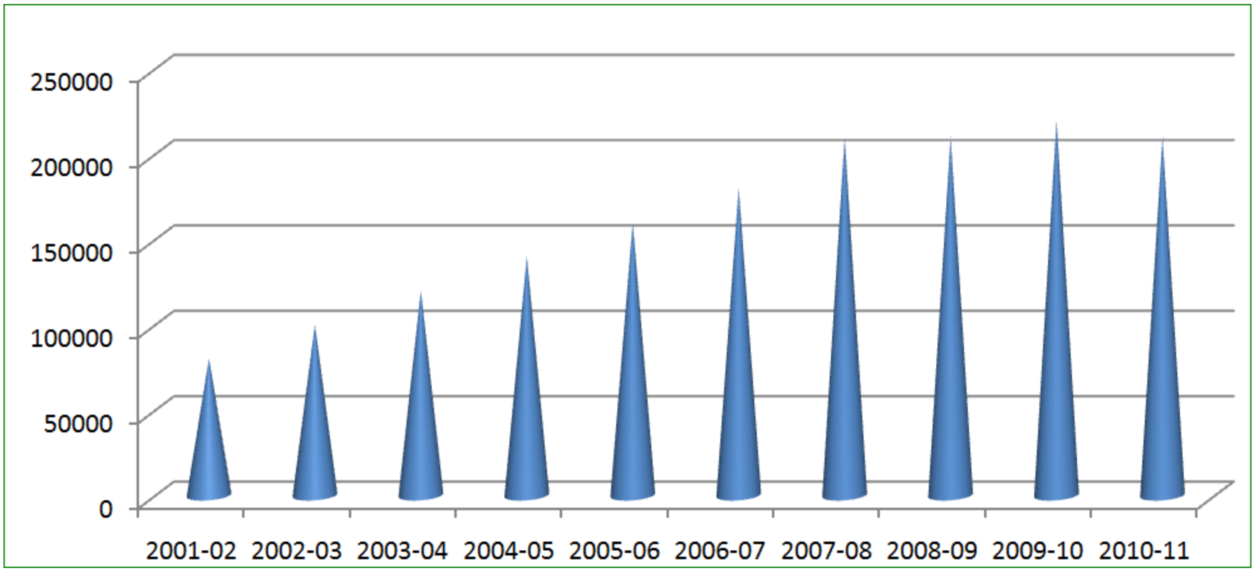
Other critical factors responsible for the rising demand for DRI is the low availability of Iron-scrape, sky-rocketing prices due to shortage of availability of good quality iron-scrape and fierce market competition due to increased efficacy of already established plants.

1.1 DRI production in the Indian context-

The total DRI production of the world was 73.7 million tons in the year 2011. This is a new world record. 2011 was the 9th year out of the past 10 years that a new world record was established. In the year 2011 gas based DRI process saw a growth of 7% while coal based DRI process shrank by 5%. This was essentially due to the economic slowdown in India where major and most of the coal based rotary kilns are situated.

Every year since 2003, India is the leading producer of DRI producing about 22.0 million tons out of 73.7 million tons in the year 2011 (although its production capacity in the previous year was 23.4 million tons, this fall in production capacity could be attributed to the economic slowdown the world witnessed that year). This production rate is twice that of the second largest producer of DRI, Iran.

Given below is a graph of India's DRI production from 2001-02 to 2010 -11



Graph-1

1.2 Iron-ore reserves in India-

India is an important producer of Iron-ore owing to its rich natural resources. It contributes more than 7% to the total world production of Iron-ore and ranks 4th in terms of quantity of ore mined, following China, Brazil and Australia. Iron-ore production was around 181 million tons in the year 2006-07 growing by 9% over the previous years since then. The share of Lumps in the total iron-ore production has been approximately 40% and the rest of it is accounted for by concentrates and Fines. However the share of Lumps in the total Iron-ore mined varies across the country depending upon various factors such as quality and standard of ore deposits, operating techniques, methods employed in mining of the ore and sagacity of miners.

Given below are the pie-charts of production capacity of Iron-ore in different states of India in 2010-11

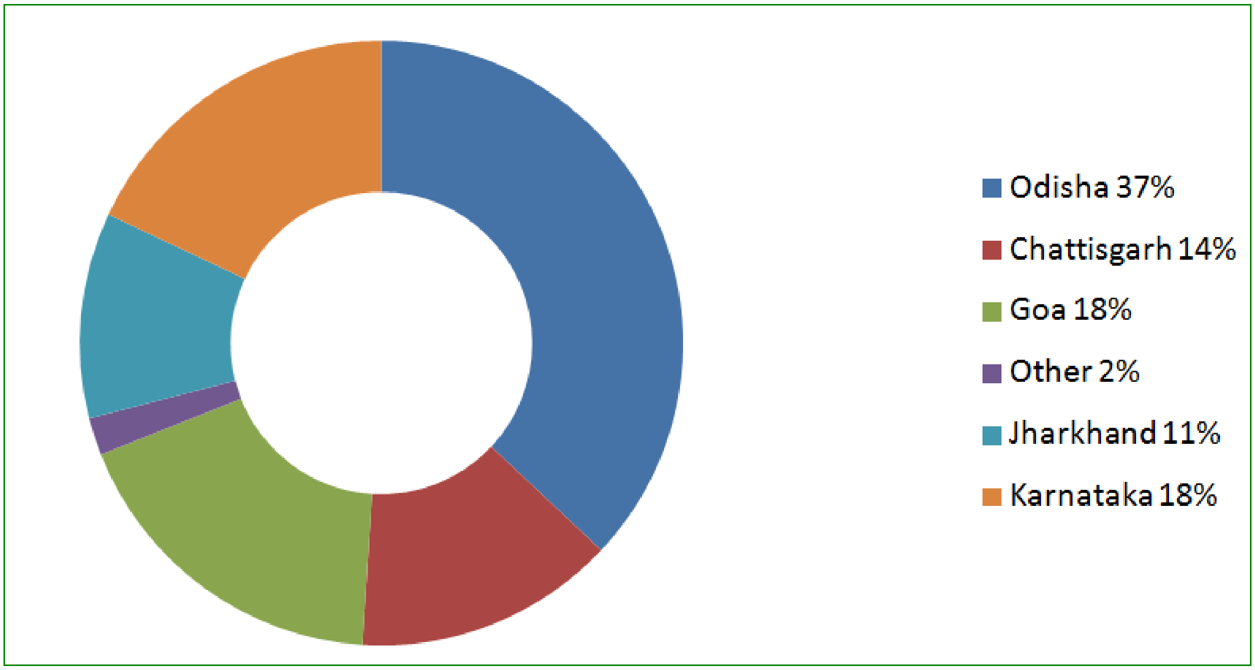


Chart 1

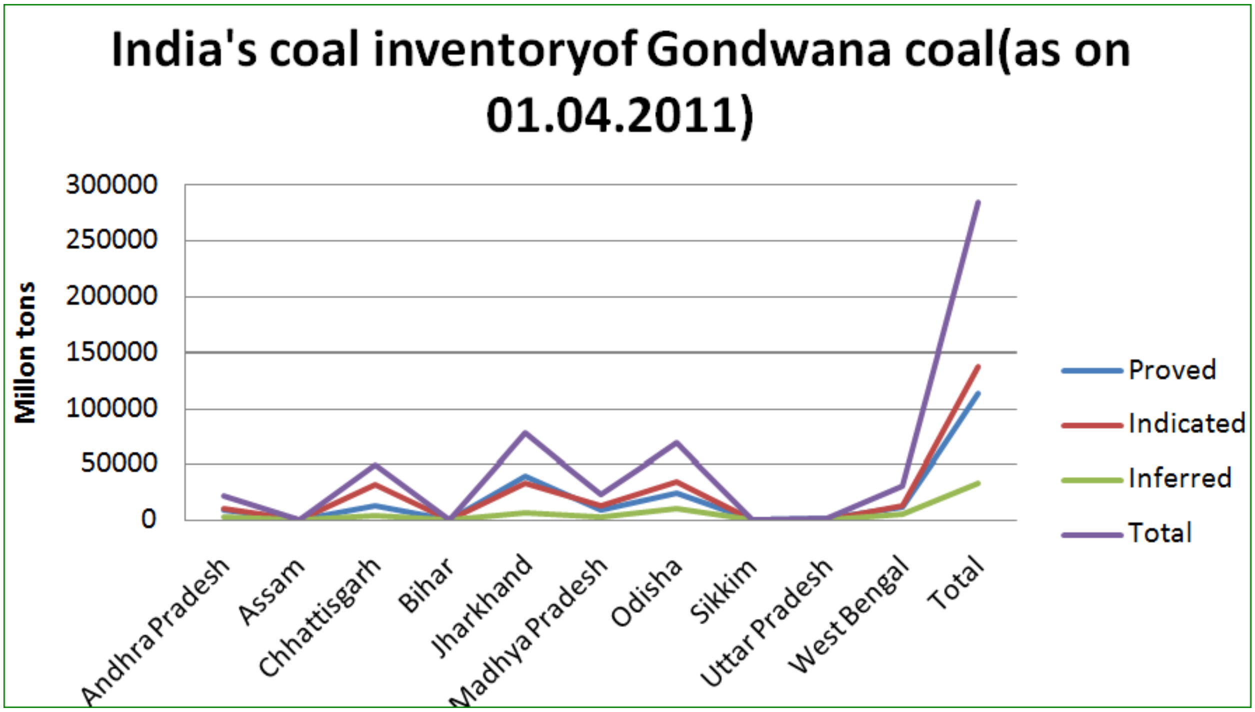
<u>1.3 Coal reserves in India-</u>

As a result of the explorations carried out upto a depth of 1.2 kms by various organizations such as GSI, CMPDI, SSCL, etc, a total of approximately 285,862.21 million tons of geological coal reserve has been estimated in the country insofar.

The coal reserves of India is scattered across the country, but the Gondwana Formation in peninsular India and the Tertiary Formation of North-Eastern India as major sites of coal exploration. Based on the results obtained through Regional/Promotional Explorations, in which boreholes are usually placed 1-2 kms apart, the resources classified as 'Indicated' or 'Inferred'.

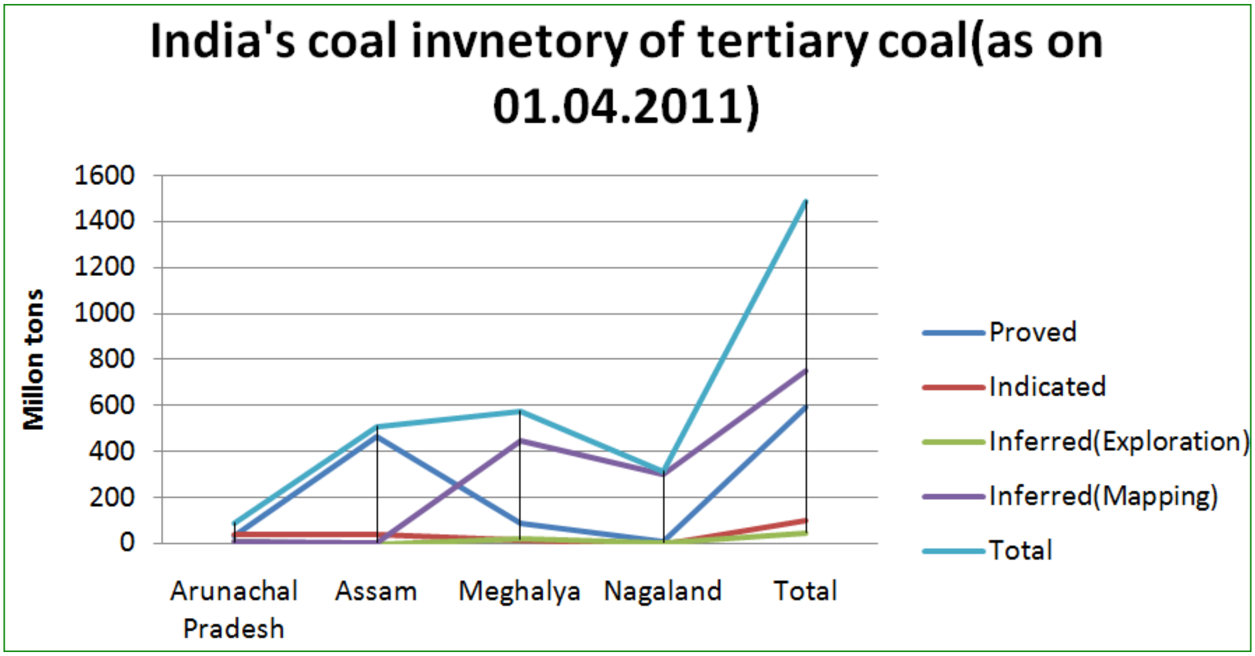
If the boreholes are situated less than 400 meters i.e. if the boreholes are less than 400 meters apart, then the resource gets classified as ‘Proved”.

Given below is a graph of state-wise distribution of Gondwana Coal reserves in India-



Graph-2

Given below is a graph of state-wise distribution of Tertiary Coal reserves in India-



Graph -3

The different categories in which coal can be categorized are-

1. Coking coal
2. Non-coking coal
3. Tertiary coal

Coking coal can be further be categorized into three types –

1. Prime coking coal
2. Medium coking coal
3. Semi coking coal

1.4 Future Prospect of DRI productions in India-

If time can be divided into ages, and ages attributed to the metal predominately used in it, then presently we are living in the Iron Age. Iron is the discovery of the age, and it plays a vital role in the development of a nation. It forms the backbone of India's economy. Jamshedji Tata became a vanguard of the Sawdeshi movement by commissioning the first indigenous steel plant of India in the year 1907. Steel is the building block of any developing nation be it an agrarian country India. This makes large-scale production of steel a necessary perquisite for the overall societal and economical development of India.

Out of two different Iron-making routes available to us, Direct reduced Iron (DRI) using coal or gas as the primary source of heat and energy is preferred to the more conventional technique/route of steel making using blast furnaces. The use of blast furnace is constrained by the non-availability of good quality coking coal in India. This fact is clearly evident from the data mention in the previous section.

DRI route of Iron-making makes use of domestic iron-ore and coal and resources naturally available in the country thus reducing the cost of production and encourages large-scale production due high availability of the raw material and charge feed. Since Iron-making is the first step in steel making, it should consume least energy and satisfactorily address the environmental challenges.

Keeping in mind India faces a scarcity of good quality primary coking coal and low availability and high price of scrape DRI turns out to be the only viable option with India. Further the establishment cost of a DRI plant is far less compared to Blast furnace plant; it attracts lots of indigenous players into the steel market and thus increasing the production and quality of steel.

1.5 Objective of the project work-

The following are the objectives of the project work-

- To study the effect of reduction temperature on the degree of reduction of Iron-ore pellets
- To study the effect of firing temperature on the degree of reduction and swelling of Iron-ore pellets
- To study the effect of coarser particles on the degree of reduction of the Iron-ore pellets
- To study the effect of reduction temperature on the degree of swelling of Iron-ore pellets
- To study the effect of reduction time on the degree of reduction and degree of swelling of Iron-ore pellets.
- To study the effect of firing temperature on drop number of Iron-ore pellets

Chapter -2

Literature survey

2. Literature survey

2.1 Pellets-

Pellets are indurated spheres of ore with a high iron content and uniform quality formed by agglomeration of iron ore fines, binders, moisture, etc. at 1200-1350c. Pellets are of two types

i. Blast furnace pellets
ii. Direct reduction pellets

Blast furnace pellets are used in the coke-based blast furnace process, producing molten iron for steelmaking.

Direct Reduction pellets are used in the direct reduction processes to produce sponge iron, which is an alternative method.

2.2 Mechanism of Pellet Formation-

Ball Formation–during ball formation pressure on particles is created by the surface tension of water & gravitational force, so they coalesce together & form nuclei which grow in size into ball

Induration-in this process recrystallization and grain growth takes place due to solid state diffusion at the surface of the particle

2.3 Advantages of pellets-

- Uniform size distribution within a main range of 9-15mm
- High & even porosity of 25-30%
- High iron content of more than 63% iron
- Practically no loss on ignition & volatiles

- High and uniform mechanical strength
- Low tendency to abrasion and good behavior during transportation
- Sufficient mechanical strength even at thermal stress under reducing atmosphere

Two important theories were found at a very stage which in principle is also valid, i.e.

a) Insufficiently pellets with a low mechanical initial strength swell and disintegrate during reduction irrespective of the type and additives used.
b) Pellets both high and low gangue have a different behavior during reduction. Pellets with high gangue content are more resistant to swelling &disintegration, where pellets with low gangue content swell and disintegrate intensively if no counteraction is taken, despite numerous investigations, the reason for the pellet behavior during reduction have not been fully classified. Nevertheless, parameters are nowadays known according to which pellets can be produced from different raw materials and the quality required for the blast furnace and direct reduction plant.

2.4 Swelling of iron ore pellets-

Most iron ore pellets swell during reduction, but some show excessive swelling. Swelling affects the strength of metalized pellet to a great extent .some ore/pellet soften during reduction, softening of the ore may cause sticking problem, which cause channeling in the shaft furnace and adversely affect the operation of kiln by ring operation

2.5 Industrial significance

In the blast furnace the compression of such a material under load reduces bed-permeability and causes serious resistance to gas through flow. Highly porous reduction products are formed because swelling increases the rate of iron oxide reduction. During reduction at temperatures 900-1200°C maximum reduction takes place. Compared to iron ore pellets which are prone to swelling, ores and sinters seldom swell to such an extent.

2.6 Mechanism of swelling-

The phenomenon of swelling is intimately associated with the mode of nucleation and growth during reduction of wustite. Whisker formation occurs during the reduction stage wustite/iron from pellets impregnated with oxides of sodium, potassium and calcium. In extreme cases of preferential nucleation, caused by a pronounced lattice distortion when a large foreignication is introduced, the diffusion of iron ions will be greatly enhanced and they will stream towards the preferred sites and the iron will grow as needles or whiskers. The growth of whiskers may be deemed to be an extreme case of preferential nucleation which occurs when the relative rates of iron ion diffusion and oxygen removal are comparatively high, i.e., when the reduction potential of the gas is low and the iron ore diffusion high.. Freshly reduced iron ions tend to diffuse towards these rather than form new nuclei, resulting in further elongation and growth of whisker. The swelling is predominant at 900-1000oC is probably due to about 100 times more mobility of ferrous ions at 900oC than 600oC.

Swelling of pellets depends upon many factors

- Composition, nature and quantity of impurities.

- Time & temperature of induration.
- Degree of oxidation.
- Time, Temperature and degree of reduction.
- Gas composition
- .Porosity, before and during reduction.

Swelling can be avoided by following measures

- Prolonged indurations of pellets at high temperature
- Addition of pre-reduced ore or return fines or certain ores from different sources
- Minimization of alkali metals input through ore

2.7 Thermodynamics and kinetics of iron ore reduction-

On heating

Coal → char + tar + gases (CO, CO_2, H_2, C_nH_m and N_2)

$Fe_2O_3(s) + 3C(s) \rightarrow 2Fe(s) + 3CO(g)$

Reduction of hematite:

$Fe_2O_3(s) + CO(g) / H_2(g) \rightarrow 2Fe_3O_4(s) + CO_2(g) / H_2O(g)$

Reduction of magnetite:

$Fe_3O_4(s) + CO(g) / H_2(g) \rightarrow 3FeO(s) + CO_2(g) / H_2O(g)$

Reduction of wustite:

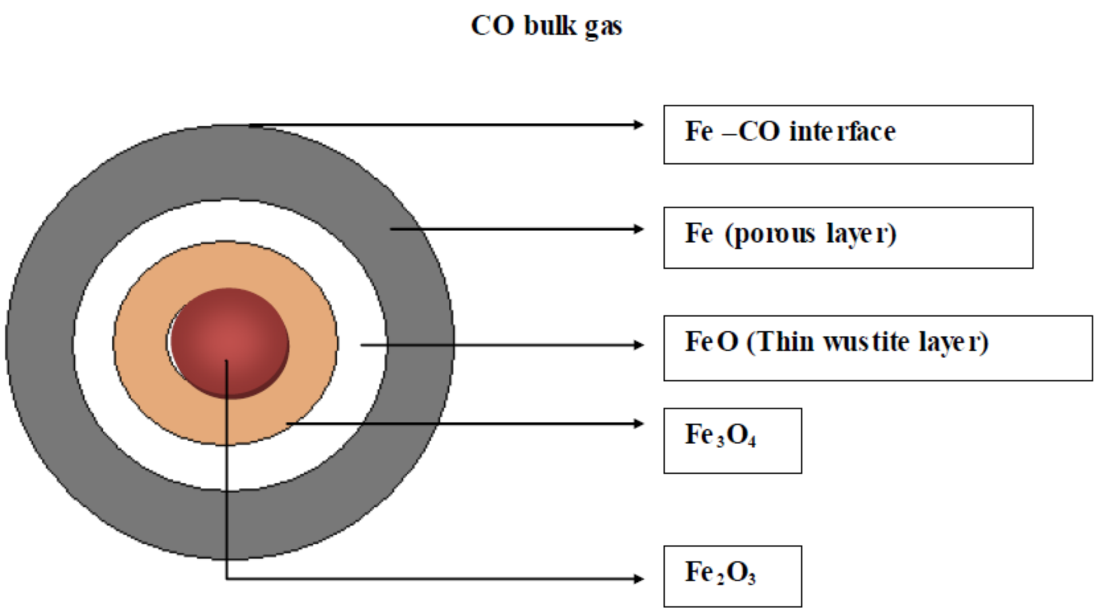
$FeO(s) + CO(g) / H_2(g) \rightarrow Fe(s) + CO_2(g) / H_2O(g)$

Besides the above mentioned reactions, the next three possible reactions are :

$C(s) + CO_2 (g) \rightarrow 2CO (g)$

$C(s) + H_2O (g) \rightarrow H_2 (g) + CO(g)$

A schematic diagram in modes of reduction of iron oxide-



Before the formation of Metallic Layer

The kinetic steps involved in reduction of hematite iron ore by CO/H2 gas are as follows:

• Transport of CO/H2 gas from bulk gas phase to Fe2O3-CO/H2interface.

• Adsorption of CO/H2 gas at the Fe2O3- CO/H2interface.

- Chemical reaction between $Fe_2O_3$and CO/H_2gas at the Fe_2O_3- CO/H_2interface and desorption of the product gas CO_2/H_2O from this interface.
- Transport of product gas from Fe_2O_3- CO/H_2interface to the bulk gas phase.

After the Formation of Metallic layer

- Transport of CO/H_2 gas from bulk gas phase to the Fe-CO/H_2 interface.
- Adsorption of CO/H_2 gas at the Fe- CO/H_2 interface.
- Transport of CO/H_2 gas from Fe- CO/H_2 interface to the Fe_2O_3 - Fe interface.
- Chemical reaction b/w Fe_2O_3 and CO/H_2 at Fe_2O_3 - Fe interface.
- Desorption of the product gas CO_2/H_2O from this interface.
- Transport of CO_2/H_2O gas from Fe_2O_3 - Fe interface to Fe-CO/H_2 interface.
- Transport of the product gas from Fe-CO/H_2 interface to the bulk gas phase.

Chapter-3

Experimental

3. Experimental

3.1 Material Selection-

- Selection of Iron-ore- About 1/2kg of Iron-ore of Sakarruddin mines was procured for experimentation. Chemical properties and composition of the ore was also noted.

Given below is a tabulation of the chemical composition of Iron-ore thus obtained from Sakarruddin mines-

Tabulation 1-

Fe (total)	% Fe2o3	% Al2O3	%SiO2	%TiO2	%MnO	%others
64.51	91.74	3.06	1.43	0.14	0.02	3.61

- Selection of coal- Coal of Vasundhara mines was procured from the department of mining engineering for experimentation. Before the coal was used proximately analysis was carried out on it, to determine the chemical composition of the coal.

Given below is the tabulation of the proximate analysis of Vasundhara coal-

Tabulation-2

%Volatile matter	%ash	%fixed carbon
27.27	31.67	41.06

3.2 Experimental Procedure-

- Preparation of Iron-ore pellets-

The Iron-ore obtained from Sakarruddin mines was grounded to -100 mesh size and a small quantity of it was grounded to -16 to 25 mesh size. Pellets of approximately 15 mm diameter were prepared. Pellets of different composition i.e 100% -100 mesh size, 95%+ 5% (-16 to 25) and 85%+15% (-16to25) were prepared. This is to study the effect of coarser particles on degree of reduction and swelling of the pellets. 2% by wt. of binder was used for the making of pellets to impart necessary strength.

- Preparation of binder-

Sugarcane juice was used as the binding agent. The binder was prepared by heating sugarcane juice at 110 C. This prior heating of binder was done to impart good binding properties.

- Firing of pellets-

  Pellets were fired at different temperature 1000, 1100, and 1300 C for 1hr. This was done in order to study the effect of firing temperature on degree of reduction and swelling of Iron-ore pellets at a particular reduction temperature and reduction time.

- Preparation of coal for reduction- Coal of Vasundhara mines was crushed to a size of 2-4 mm (diameter) using mortar and pestle.

3.3 Determination of degree of reduction of Iron-ore pellets-

Iron-ore pellets prepared were first oven-dried at a temperature of 110C for 30 mins. This was done in order to drive away the moisture present in the pellets. These oven-dried pellets were then taken in sets of 3, 5 in stainless steel tumblers of 50mm diameter and 100mm height. These pellets were kept over a bed of crushed coal. After the placement of the pellet at the centre of the bed, more coal was added so that the pellets are completely surrounded by coal and reduction takes uniformly on all sides. A hole is made at the centre of the lid of the tumbler to allow the passage of various gases evolved during reduction of Iron-ore pellets. The pellets were reduced at predetermined temperature 820,870, 920, 970 C and for different time periods 15, 30, 45, 60 and 90 mins to study and calculate the degree of reduction at different temperatures, time period, of pellets fired at different temperature and of different composition. After pellet reduction, the pellets were allowed to cool gradually within the tumbler in order to prevent cracking due to sudden fall in temperature of the surroundings.

Initial (Wi) and Final (Wf) weight of the pellets after reduction were noted

Degree of reduction is determined by the following formula-

% reduction= (loss of weight/ original weight of oxygen in the pellet) X 100%

3.4 Determination of degree of swelling of Iron-ore pellets-

Swelling of pellet is defined as the volumetric expansion of pellets when reduced at high temperatures.

Initial and final diameter of the pellets after reduction were noted using manual Vernier calipers and the swelling of the pellets were calculated using the formula –

% swelling= (Final volume – Initial volume)/ Initial volume X 100%.

Swelling usually less than 25% is acceptable but above this value it is considered catastrophic and is thus not desired.

3.5 **Determination of Drop Number-**

Drop No. - Drop No. is defined as the number of times a pellet is dropped from a height of 45 meters on a cast iron plate before the pellets crack under the action of repeated falling.

Chapter-4

Results and Discussion

4. Results and Discussion-

4.1 Effect of firing temperature on degree of reduction and swelling of Iron-ore pellets-

From the experimental data in tabulation 7 and graph 10, 11 collected and ploted during the project work, it was found that the degree of reduction decreases with the increase of firing temperature. Pellets of -100 mesh size were fired at three different temperatures 1000, 1100, 1300 C. Initial and final weight of the pellets were noted and %reduction was calculated accordingly.

The decrease in reduction is apparently due to decrease in porosity of the pellets and hence less surface area for reduction.

Degree of swelling decreases with the increase in firing temperature due to loss of porosity and restricted growth of Iron whiskers which inhibits the swelling of the pellet.

4.2 Effect of reduction temperature on degree of reduction of Iron-ore pellets-

From the experimental data in tabulation 3,4,5,6 and graph 9 collected and plotted during the project work, it was found that the degree of reduction increases with the increase in reduction temperature. Pellets were reduced at 4 different temperatures 820. 870. 920 and 970 and the degree of reduction were calculated accordingly.

This increase in %reduction is apparently due to greater involvement of gaseous reducing agents like CO and H2, which are exuded during devolatization of coal inside the tumblers and formation CO. Higher diffusion rate caused due to increase in reducing temperature also contributes to the increase of degree of reduction.

4.3 Effect of reduction temperature on degree of swelling of Iron-ore pellets-

From the experimental data collected in tabulation 3,4,5,6 and graph 8 plotted collected during the project work, it was found that the degree of swelling increases with the increase in temperature till 920 C and after that decreases with further increase in temperature.

This anomalous swelling behavior above around 920 C can be attributed to nucleation and sintering of Iron-ore powder. Sintering is defined as the fusion of powder particles due to atomic diffusion when heated at a temperature below its melting point. Sintering of Iron-ore fines causes the pellets to become more compact and densely packed resulting in its shrinkage.

However the increase in %swelling below 920C is due to higher rate of diffusion of gasses.

4.4 Effect of reduction time on the degree of reduction and degree of swelling of Iron-ore pellets-

From the experimental data collected in tabulation 3,4,5,6 and graphs 4,5,6,7 plotted during the project-work. It was found that the degree of reduction increases with the increase in reduction time at a particular temperature.

This is apparently caused due to greater time of exposure of pellets to reducing gasses CO, H2 and gases evolved during volatilization of coal.

Degree of Swelling increases with an increase in reduction time. This is due to nucleation and growth of fibrous Iron whiskers in matrix of the pellet.

4.5 Effect of firing temperature on drop number of Iron-ore pellets-

From the experimental data collected during the project work it was found that the drop no. of iron-ore pellets increases with the increase of firing temperature. This is ascribed to the loss of porosity due to densification of the pellets.

4.6 Effect of coarser particles on degree of reduction of Iron-ore pellets-

From the experimental data collected in tabulation 8 and graph 12 plotted during the project work it was found that addition of small percentage of coarser particles significantly influences the degree of reduction. Degree of reduction increases with an increase in % of coarser particles. This is apparently due to increases in porosity of the pellets and thus greater number of reduction sites.

4.7 Microstructure of reduced Iron-ore pellets-

Photographs of four different samples were taken using Scanning Electron Microscope. The samples were neatly prepared first for the photographs to be taken. Using these photographs the microstructures of the pellets were keen studied to account for its different behavior at different reduction temperature and reduction time.

Photograph 1, 2, 5, 6 shows the formation of Iron whiskers in pellet matrix, which gives a possible explanation for the shrinkage of Iron-ore pellets when reduced near and above 920C.

Photograph 3, 4 shows the microstructure of the pellets and the possible sites of reduction.

Tabulation- 3 Data for the degree of reduction and swelling of fired Iron-ore pellets reduced at 820C.

Sample No	Wt, before reduction(gm)	Diameter before reduction(cm)	Time(min)	Wt. after reduction(gm)	Diameter after reduction(cm)	% swelling	% reduction
1.	6.02	15.72	15	5.51	16.23	10.23	30.23
2.	5.93	15.43	30	5.35	16.05	12.39	35.03

3.	6.23	15.89	45	5.44	16.48	11.63	45.62
4.	6.54	15.93	60	5.46	16.65	14.23	59.72
5.	5.63	15.32	90	4.56	16.07	15.56	63.23

(Pellets of -100 mesh size (100%), fired at 1100 C and binder used sugarcane juice 2% (by wt%))

Tabulation 4- Data for the degree of reduction and swelling of fired Iron-ore pellets reduced at 870C.

Sample No.	Wt. before Reduction (gm)	Diameter before reduction(cm)	Time(min)	Wt. after Reduction(gm)	Diameter after reduction(cm)	%swelling	%reduction
1.	6.60	15.47	15	5.75	16.02	11.23	46.53
2.	6.50	16.18	30	5.43	16.81	12.24	59.36
3.	7.00	16.01	45	5.82	16,80	15.63	60.98
4.	6.93	16.02	60	5.37	16.77	14.72	81.80
5.	5.90	15.02	90	4.55	15.77	15.87	82.90

(Pellets of -100 mesh size (100%), fired at 1100 C; binder used sugarcane juice 2% (by wt%)

Tabulation 5- Data for the degree of reduction and swelling of fired Iron-ore pellets reduced at 920C.

Sample No.	Wt. before Reduction (gm)	Diameter before reduction(cm)	Time(min)	Wt. after Reduction(gm)	Diameter after reduction(cm)	%swelling	%reduction
1.	6.37	15.43	15	5.49	16.10	13.63	49.98
2.	6.93	15.80	30	5.84	16.54	14.92	57.03
3.	5.98	15.08	45	4.82	15.74	13.78	69.98
4.	7.20	16.03	60	5.83	17.54	16.23	68.80
5.	5.50	14.93	90	4.72	15.77	17.91	83.01

(Pellets of -100 mesh size (100%), fired at 1100 C; binder used sugarcane juice 2% (by wt %))

Tabulation 6- Data for the degree of reduction and swelling of fired Iron-ore pellets reduced at 970C.

Sample No.	Wt. before Reduction (gm)	Diameter before reduction(cm)	Time(min)	Wt. after Reduction(gm)	Diameter after reduction(cm)	%swelling	%reduction
1.	5.36	14.69	5	4.76	14.54	-3.03	40.36
2.	6.29	15.43	10	5.25	15.29	-2.62	59.59
3.	5.69	14.96	20	4.44	14.79	-3.23	79.36
4.	6.53	15.82	30	4.91	15.64	-3.29	89.90
5.	6.26	16.01	45	4.77	15.81	-3.53	86.23

(Pellets of -100 mesh size (100%), fired at 1100 C; binder used sugarcane juice 2% (by wt%))

Tabulation 7- Data for the degree of reduction and swelling of Iron-ore pellets reduced at different firing temperature-

Sample No.	Firing Temp. C	Wt. before Reduction (gm)	Diameter before reduction(cm)	Wt. after Reduction(gm)	Diameter after reduction(cm)	%swelling	%reduction
1.	1000	5.99	15.09	5.83	15.75	14.92	57.04
2.	1100	6.31	15.45	5.40	16.42	14.62	52.03
3.	1300	6.50	16.18	5.58	16.90	14.13	51.92

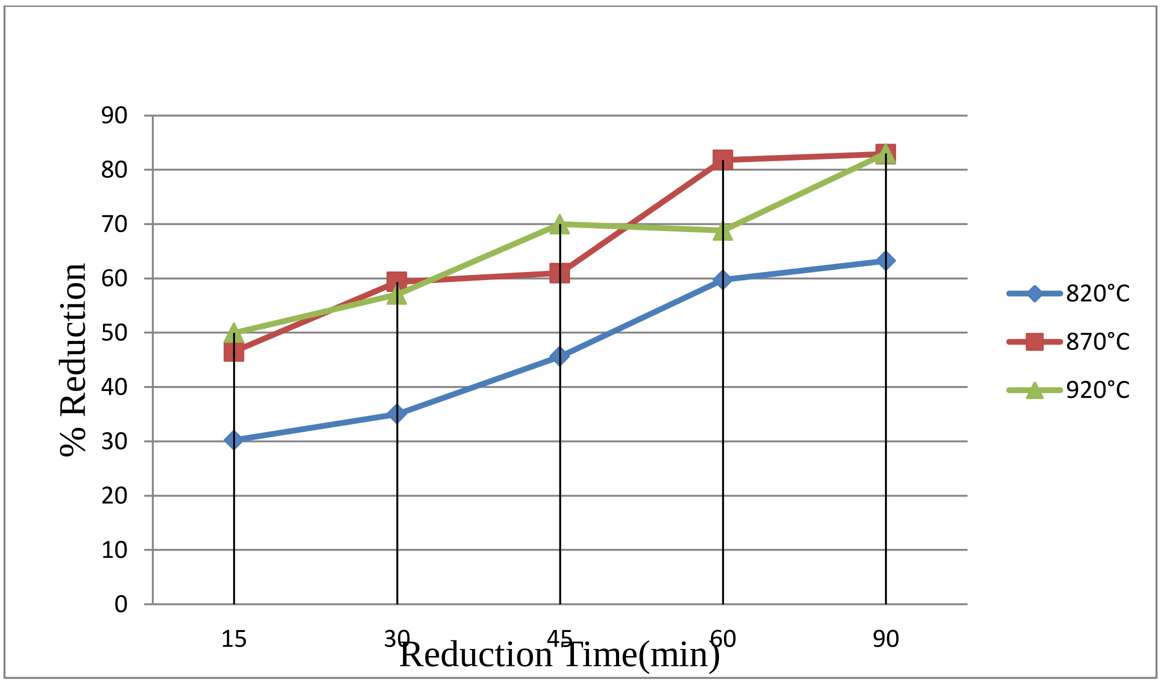
(Pellets of -100 mesh size (100%), reduced at 920 C for 30 mins ; binder used sugarcane juice 2% (by wt%))

Tabulation 8- Data for the degree of reduction of fired Iron-ore pellets of different compositions-

Sample No.	Composition %-100+%16 to 25	Wt. before Reduction (gm)	Wt. after Reduction(gm)	%reduction
1.	95+5	6.54	5.55	54.84
2.	90+10	5.87	4.94	57.47
3.	85+15%	5.30	4.40	61.66

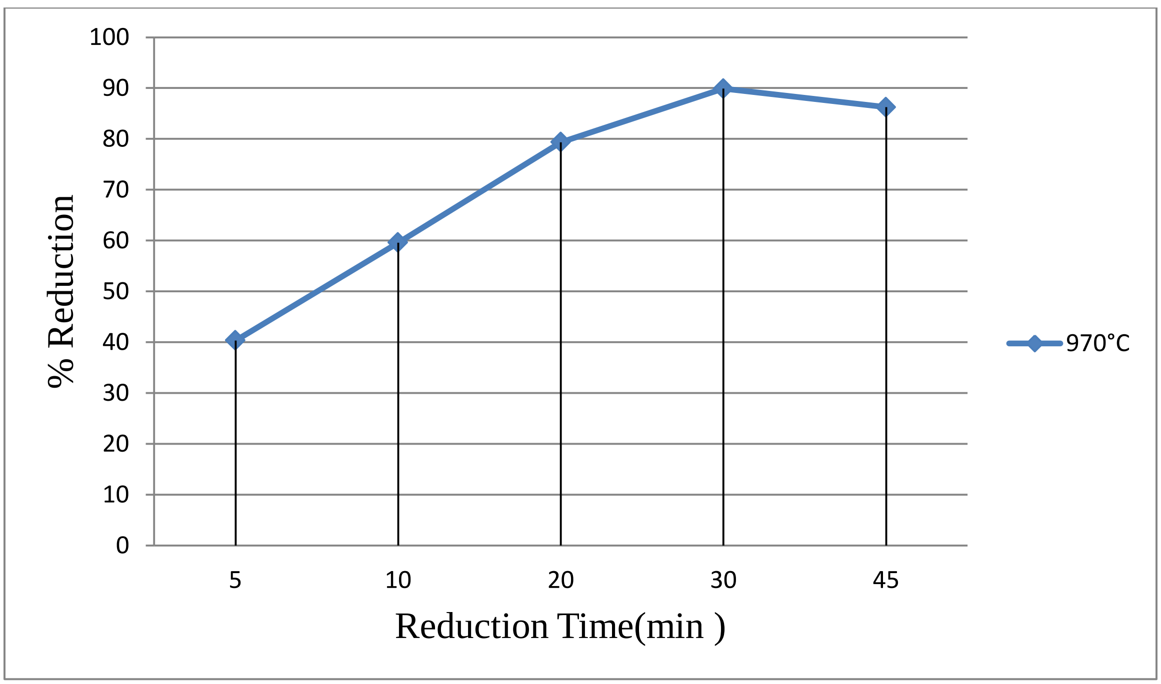
(Pellets fired at 1100, reduced at 920 C for 30 mins ; binder used sugarcane juice 2% (by wt%))

Graph- 4 Graph for the degree of reduction fired Iron-ore pellets reduced at 820,870 and920 C at different time –



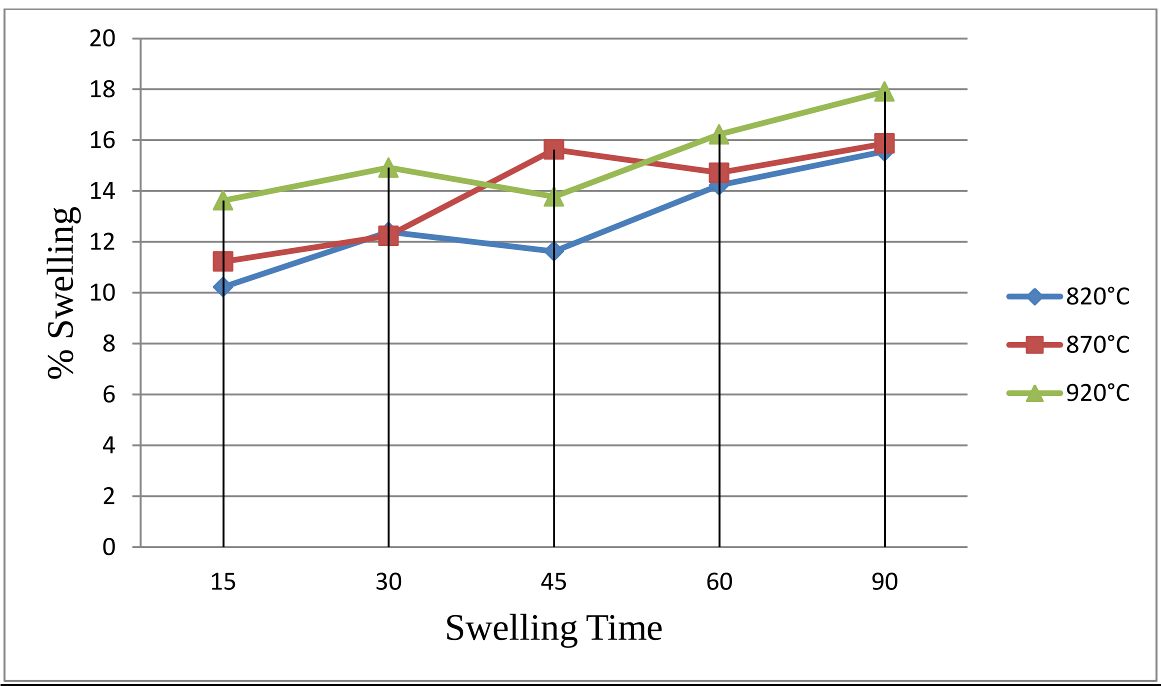
(Pellets of -100 mesh size (100%), fired at 1100 C and binder used sugarcane juice 2% (by wt %))

Graph- 5 Graph for the degree of reduction fired Iron-ore pellets reduced at 970 C at different time –



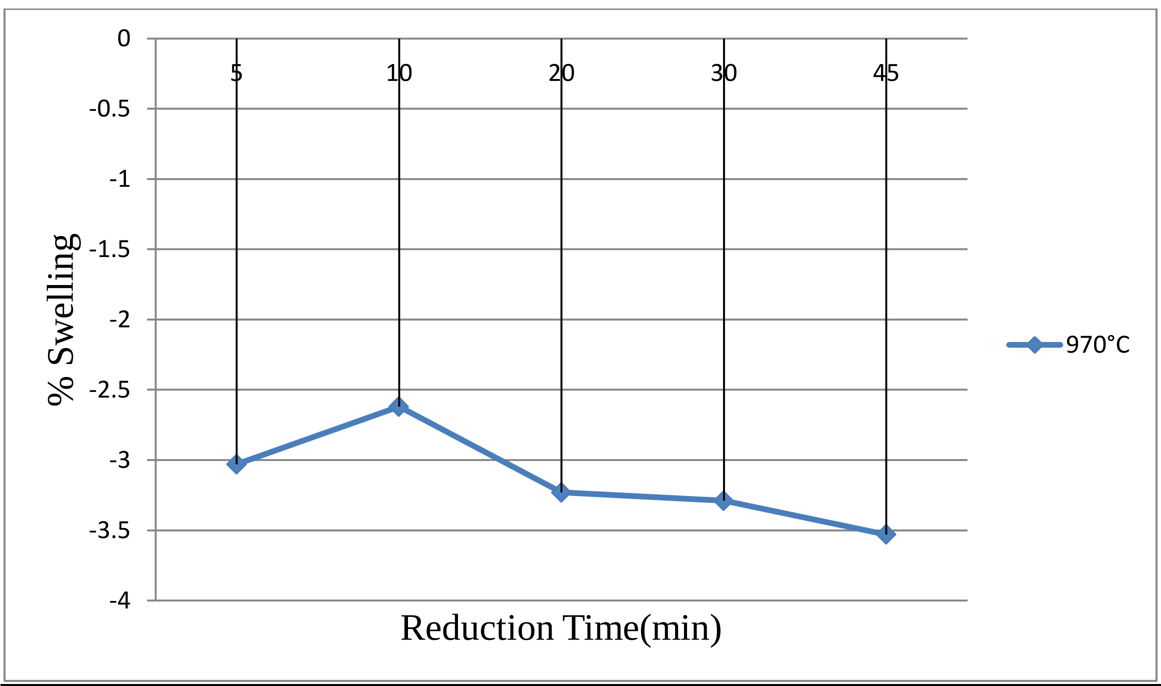
(Pellets of -100 mesh size (100%), fired at 1100 C and binder used sugarcane juice 2% (by wt %))

Graph- 6 Graph for the degree of swelling fired Iron-ore pellets reduced at 820, 870, 920 C at different time –



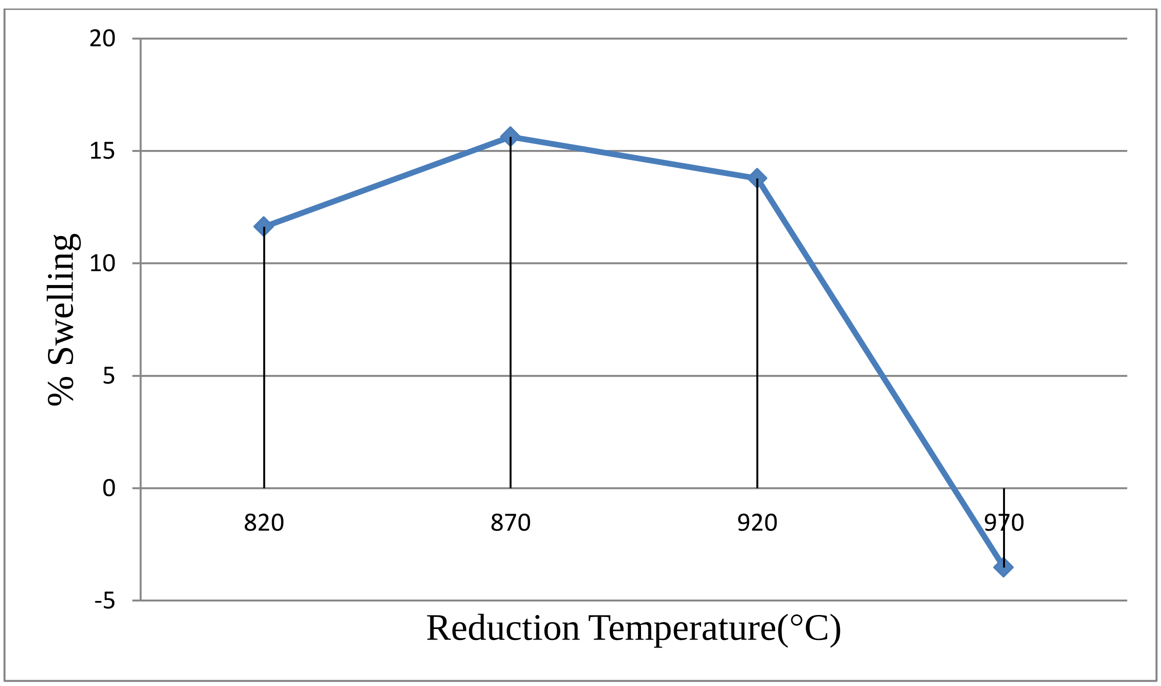
(Pellets of -100 mesh size (100%), fired at 1100 C and binder used sugarcane juice 2% (by wt %))

Graph- 7 Graph for the degree of swelling fired Iron-ore pellets reduced at 970 C at different time –



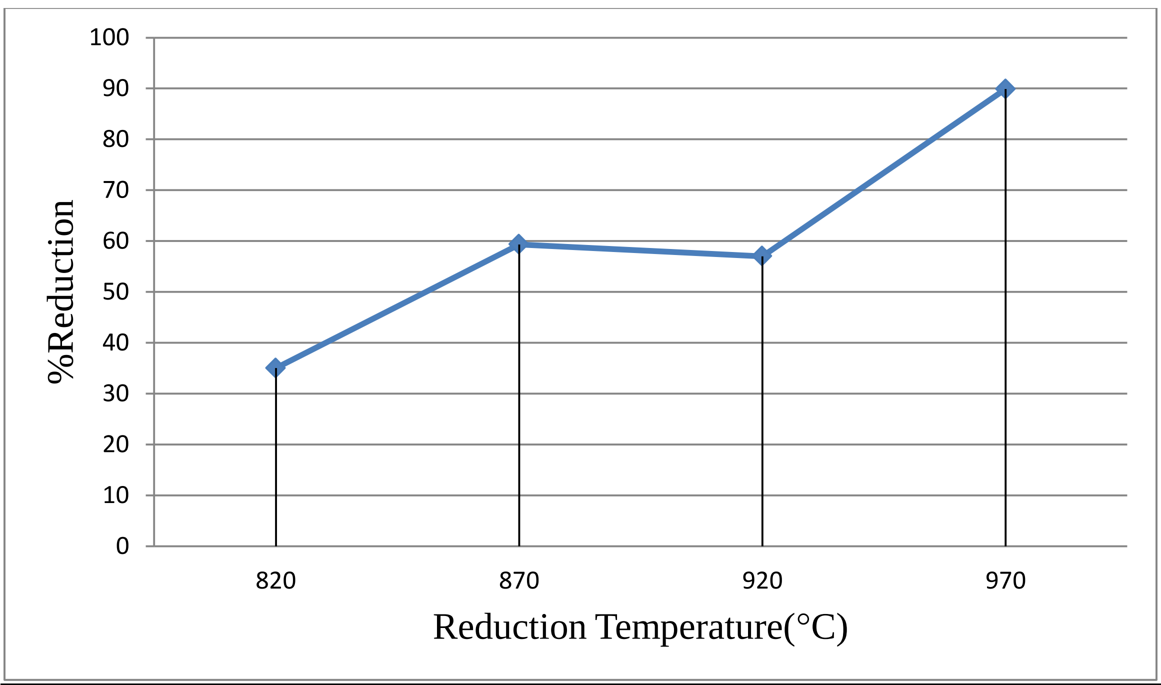
(Pellets of -100 mesh size (100%), fired at 1100 C and binder used sugarcane juice 2% (by wt %))

Graph- 8 Graph for the degree of swelling of fired Iron-ore pellets reduced at different reduction temperature–



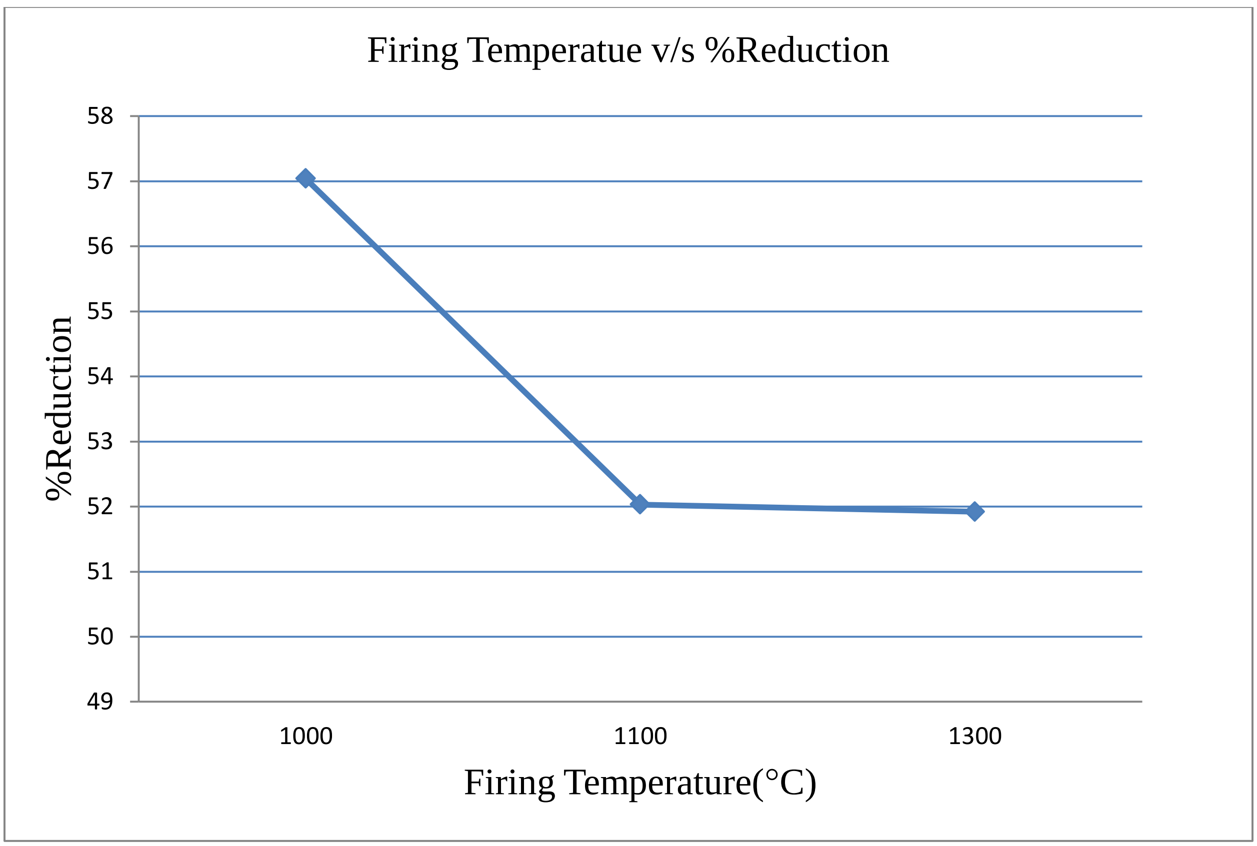
(Pellets of -100 mesh size (100%), fired at 1100 C and reduced for 45 mins; binder used sugarcane juice 2% (by wt %))

<u>Graph- 9 Graph for the degree of reduction of fired Iron-ore pellets reduced at different reduction temperature–</u>



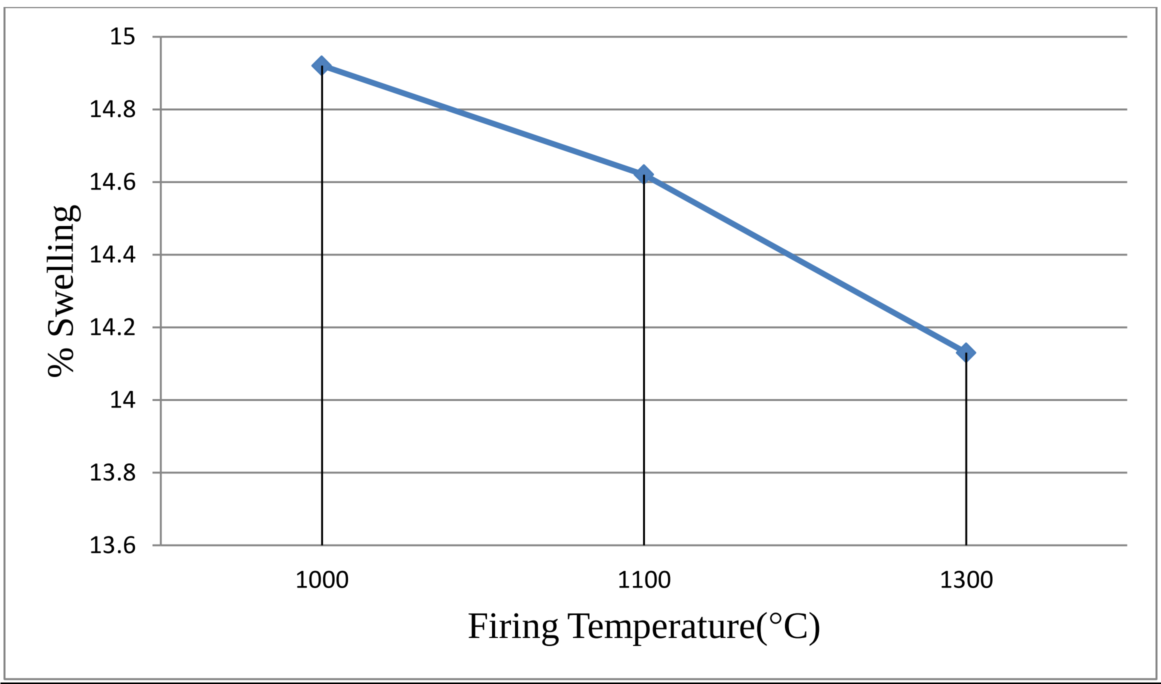
(Pellets of -100 mesh size (100%), fired at 1100 C and reduced for 30 mins; binder used sugarcane juice 2% (by wt %))

Graph-10 Graph for the degree of reduction of Iron-ore pellets fired at different temperatures–



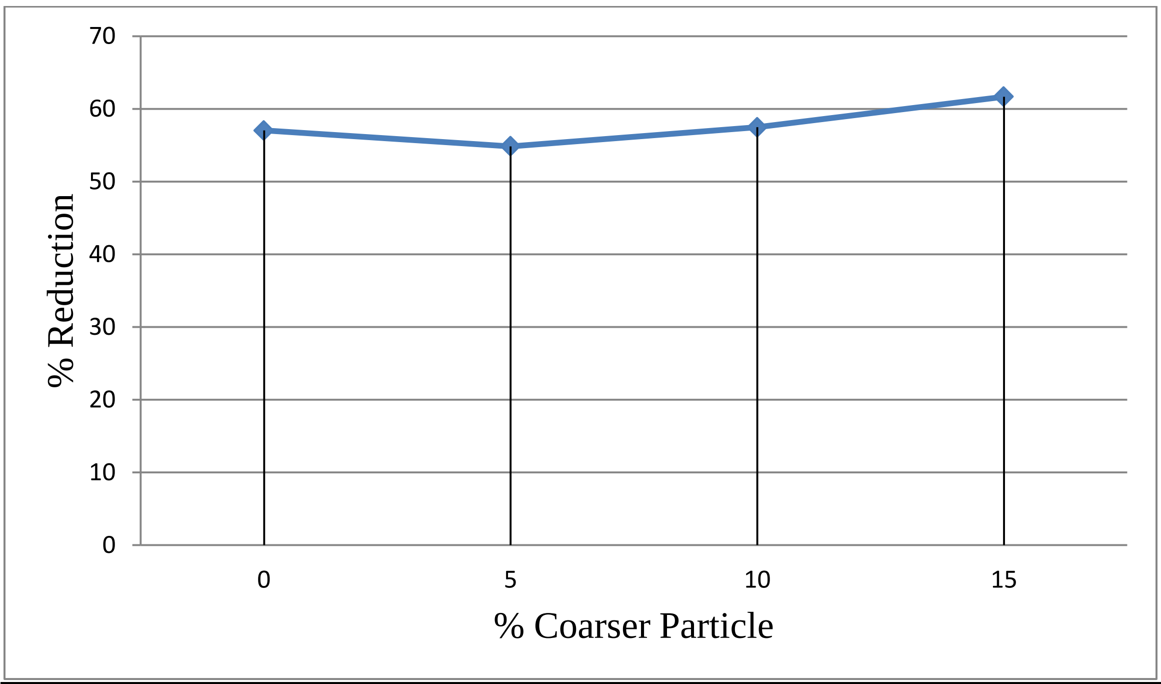
(Pellets of -100 mesh size (100%), reduced at 920C for 30 mins; binder used sugarcane juice 2% (by wt %))

Graph-11 Graph for the degree of swelling of Iron-ore pellets fired at different temperatures–

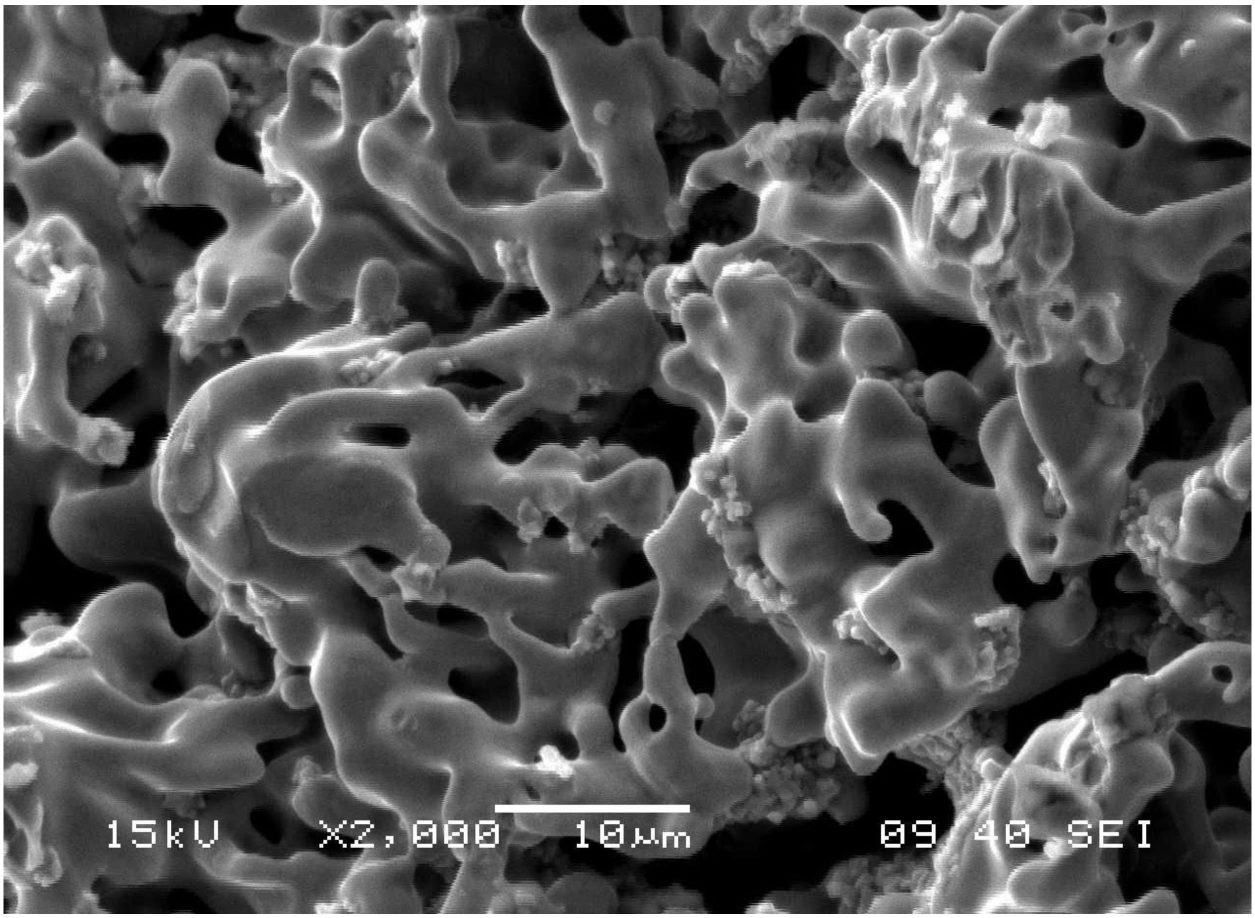


(Pellets of -100 mesh size (100%), reduced at 920C for 30 mins; binder used sugarcane juice 2% (by wt %))

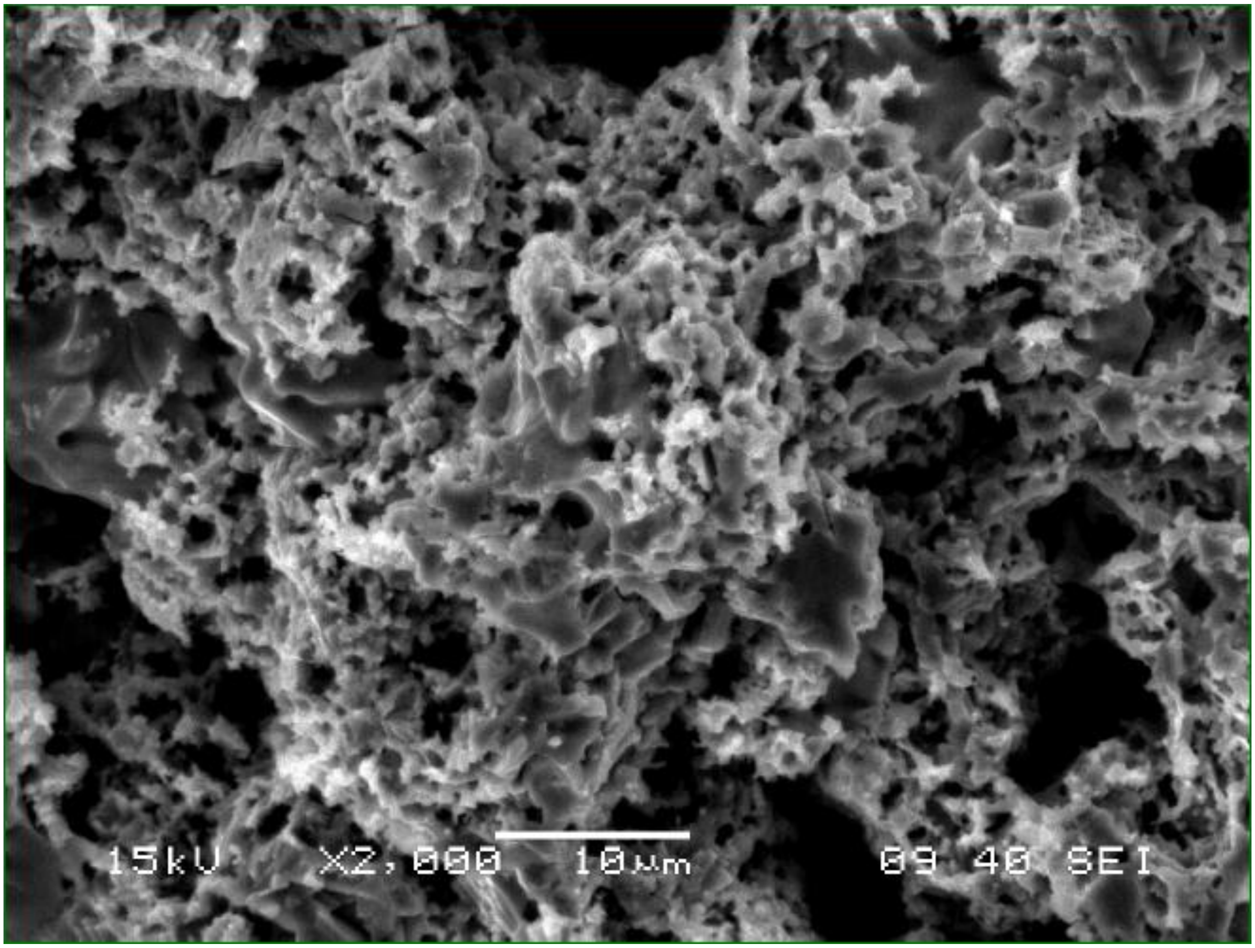
Graph-12 Graph for the degree of reduction of Iron-ore pellets of different compositions-



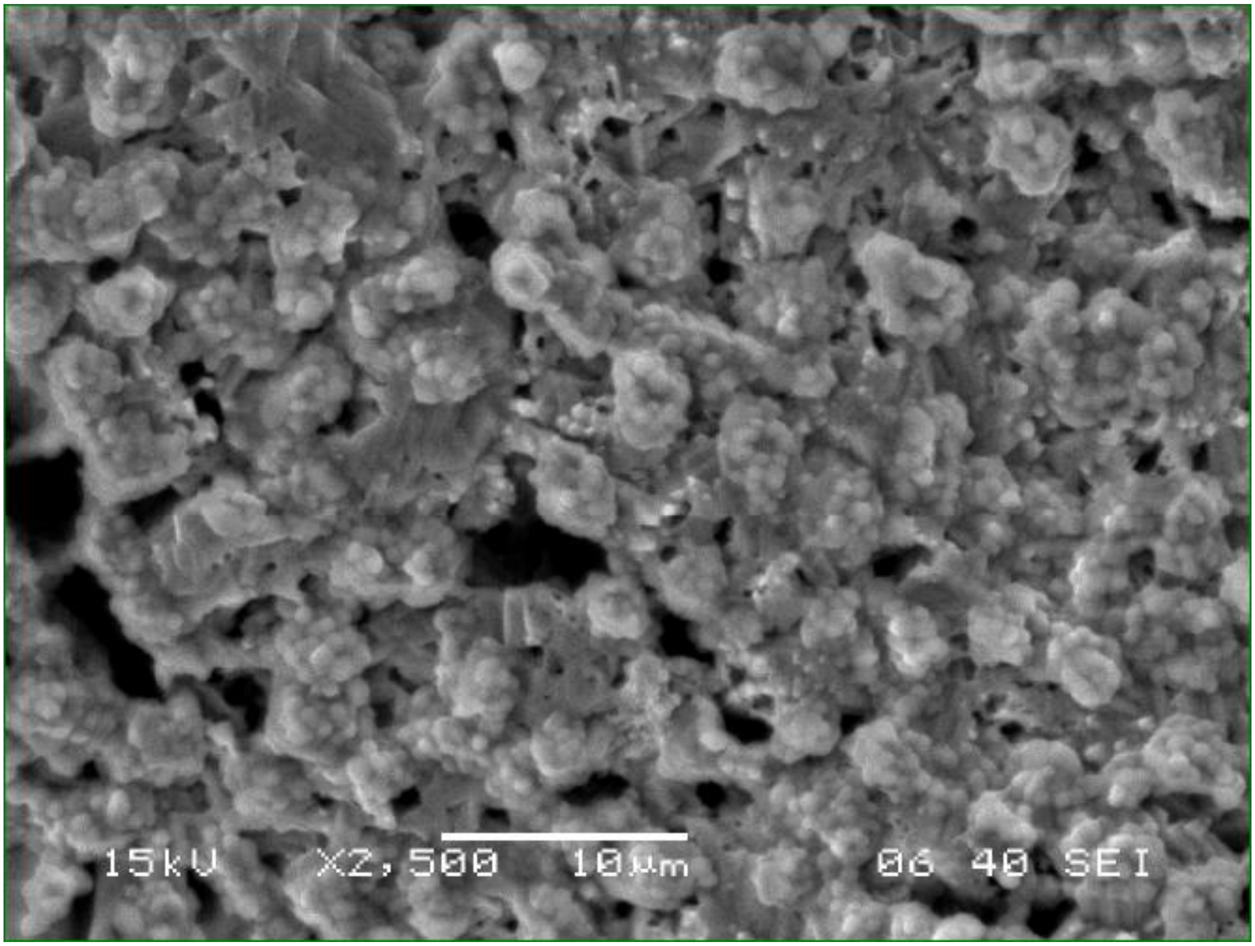
(Pellets reduced at 920C for 30 mins; binder used sugarcane juice 2% (by wt %))



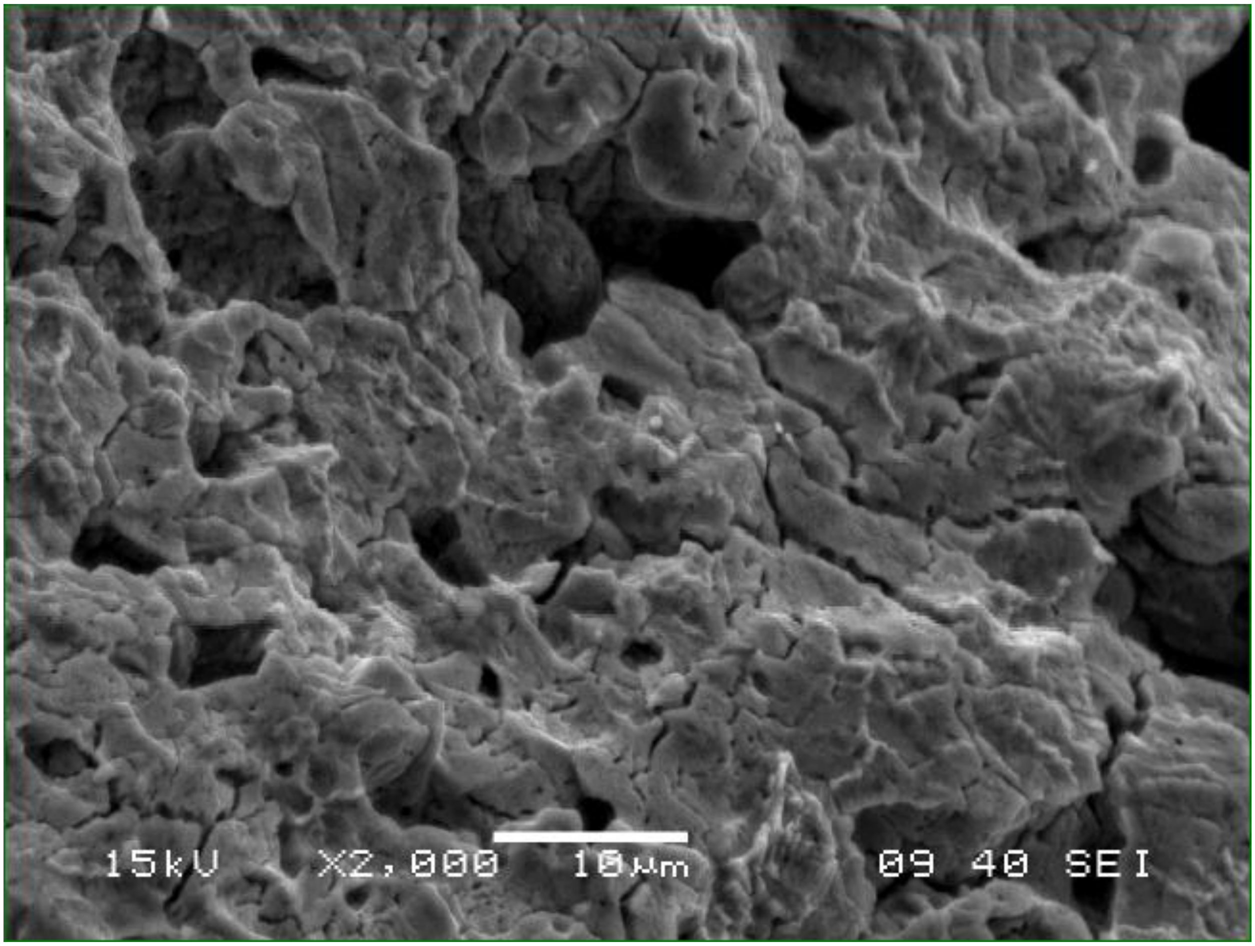
Photograph 1.- the above image is the SEM photograph of Iron-ore pellet of -100 mesh size (100%), fired at 1100C, reduced at 970C, for 30 mins;



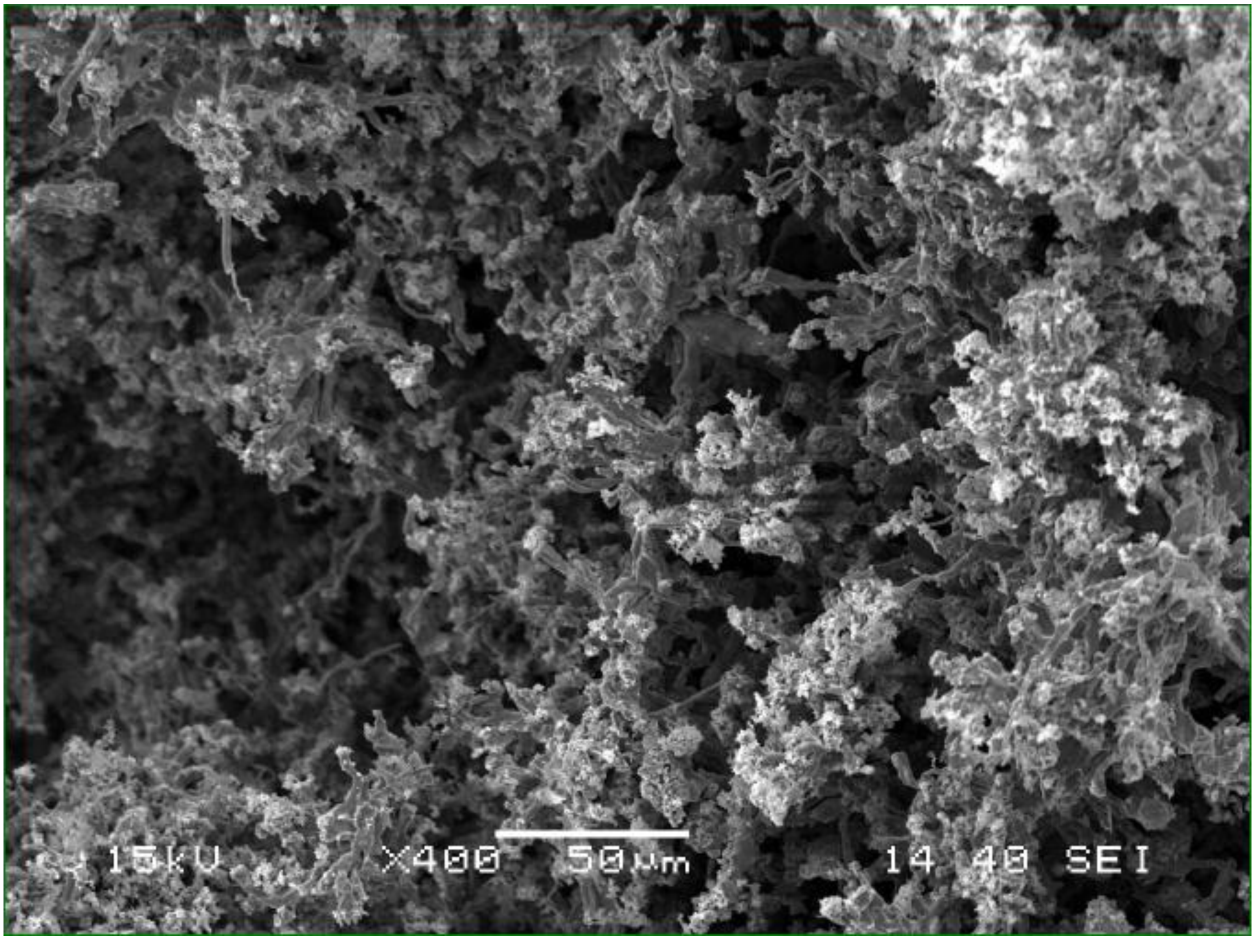
<u>Photograph 2- the above image is the SEM photograph of Iron-ore pellets of -100 mesh size(100%),fired at1100 for 1hr and reduced at 920C for 60 mins.</u>



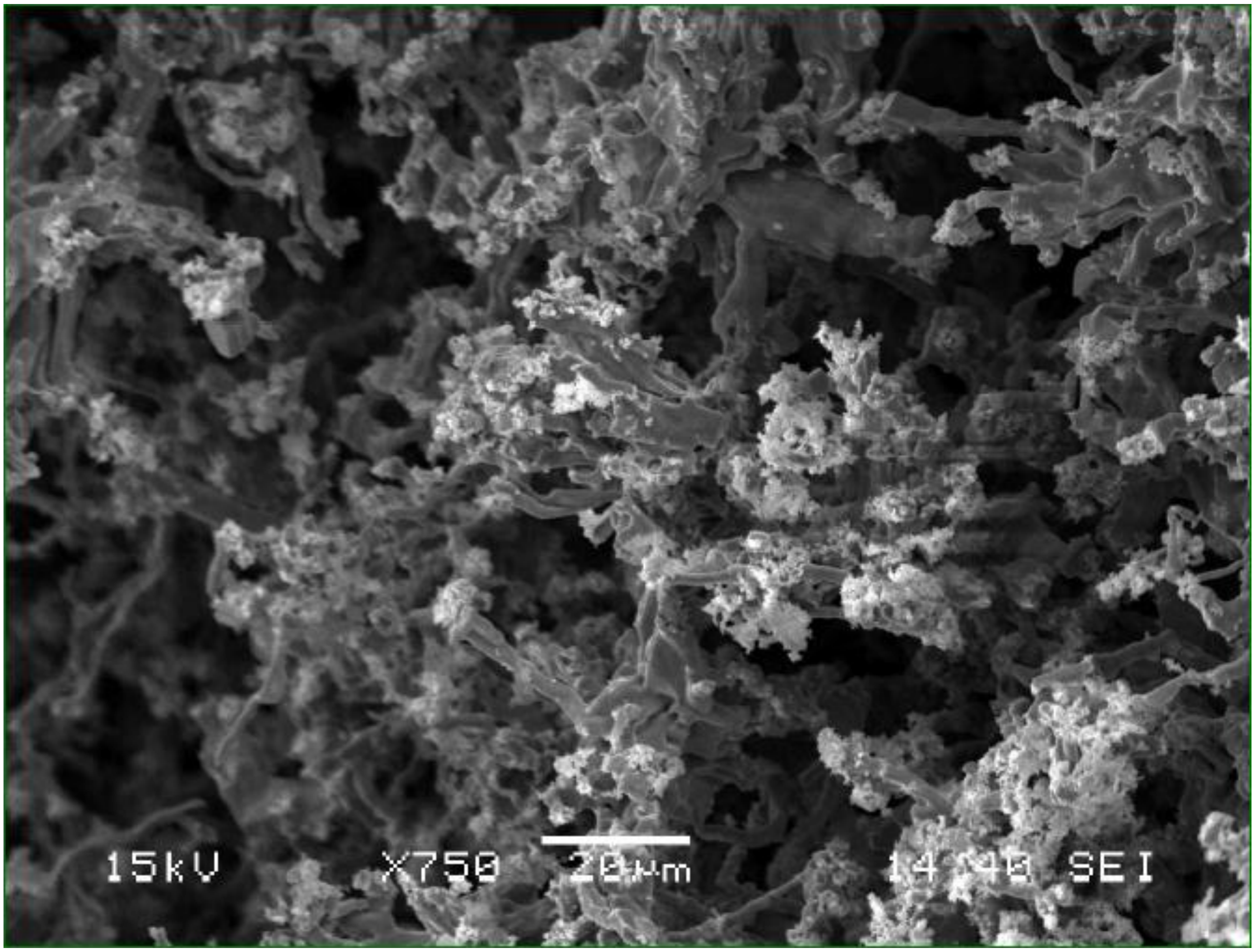
Photograph 3- the above image is the SEM photograph of Iron-ore pellets of -100 mesh size(100%),fired at 1100C for 1hr and reduced at 870C for 30 mins.



Photograph 4- the above image is the SEM photograph of Iron-ore pellets of -100 mesh size(100%),fired at 1100C for 1hr and reduced at 820C for 45 mins.



Photograph 5- the above image is the SEM photograph of Iron-ore pellets of -100 mesh size(100%),fired at 1100C for 1hr and reduced at 920C for 60 mins.



Photograph 6- the above image is the SEM photograph of Iron-ore pellets of -100 mesh size(100%),fired at 1100C for 1hr and reduced at 920C for 60 mins.

Chapter-5

Conclusion

5. Conclusion-

- Porosity of Iron-ore pellets decreases with the increase in firing temperature. This is due to increase in compactness of pellet.
- Degree of reduction decreases with increase of firing temperature. This is due to decrease in porosity of pellets and hence there are less number of reduction sites.
- Degree of reduction increases with an increase in reduction time at a particular reduction temperature. This is due to greater exposure of pellets to reducing gases.
- Degree of swelling increases with an increase of reduction time upto around 920 C after which it decreases with an increase in temperature. This decrease in % swelling above 920 C due to nucleation and sintering of Iron-ore powder. Sintering of Iron-ore fines causes the pellets to become more compact and densely packed resulting in its shrinkage.
- Drop No. increases with an increase of firing temperature. This is due to greater compactness and loss of porosity.
- Degree of reduction increases with increase of %coarse particle. This is due to greater surface area for reduction to take place as the porosity increases with %coarse particle.

Chapter 6

Future work

6. Future work-

- Similar study can be done for Iron-ore and non-coking coal obtained from different mines
- The effects of using different binder and different weight percent of binder on degree of reduction and swelling can also be studied.
- Various other physical and chemical properties of the Iron-ore pellets can be studied depending upon the industrial requirements.

Chapter 7

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- Quantitative Image Analysis -A Focus on Automated Characterization of Structures in Optical Microscopy of Iron Ore Pellets, Frida Nellros, Lulea University Of Technology