

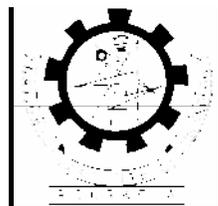
# **REDUCTION KINETICS OF IRON ORE PELLETS AND THE EFFECT OF BINDERS**

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF  
THE REQUIREMENTS FOR THE DEGREE OF

**Bachelor of Technology**  
**In**  
**Metallurgical and Materials Engineering**

By

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**2008**



National Institute of Technology

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## CERTIFICATE

This is to certify that thesis entitled, "**Reduction Kinetics of iron ore pellets and the effect of Binders**" submitted by Mr. Subhram Keshary Singh and Ms. Tintula Krishnan in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Metallurgical and Materials Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by her 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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# Reduction kinetics of iron ore pellets and effect of binders

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## **Abstract**

Reduction of Iron Ore Pellets with a particular percentage of binders i.e. 2% of Dextrine and 2% of Bentonite was carried out for the temperature range 900 to 1050°C. In reduction kinetic study the most satisfactory model was to taken, the slope of the initial linear region of fractional reduction vs. time curve was measured, which gives the rate constant (k). Ln k vs. 1/T plots were straight line from which Activation Energy was calculated. Pellets having different percentages of binders were reduced and compared to find the effect of binders.

## **Introduction**

Iron ore in a finely ground state is not easily transported or readily processed .Thus it is necessary to agglomerate the fine ground ore into pellet using binders. Inorganic binders introduce silica which decreases the final ore content of the pellet. Hence organic binders were developed. Use of pellets increases the productivity in blast furnace and reduces coke consumption. By using pre-reduced pellets an increase in production of at least 25 to 30% can be obtained in the existing blast furnace. Pellets haven't been widely used for production of steel because of poor weather resistance and high heating cost. Upgrading naturally found iron ores is accomplished by grinding the ores into fine particles so that iron containing materials can be liberated from unwanted gangue. This beneficiation process leaves the iron ore in finely ground state that is not easily transported or readily processed in steel making facilities. Therefore, it is necessary to agglomerate the fine ground particles into pellets using various binders, afterwards indurating the newly formed pellets to strength high enough to survive transportation.

## **Experimental**

Iron ore from Gandha Mardana mines and charcoal were used in the experiment .Analysis of the iron ore showed that it contained 63.7%Fe, 1.6%SiO<sub>2</sub>, and 1.4% Al<sub>2</sub>O<sub>3</sub>. The reaction carried out in the experiment is mainly of direct reduction because here we have used charcoal. The iron ore was crushed, ground and screened to 100# size and charcoal to 72# size. Pellets were made by hand rolling method by using water and different quantities of binder. The pellets were fired at 1300°C. Each crucible containing iron ore pellets were placed in a furnace and reduction was carried out at different temperature from 900-1050°C with time intervals of 15,30,45,60 and 90 minutes. Six crucibles containing pellets of

different % binder (2%, 5%, 8%) were taken & reduction was carried out at a constant temperature of 950°C and pellets were taken out at a time interval of 15, 30, 45, 60 and 90 minutes. The product obtained after reduction was then taken for the study and analysis of reduction behavior.

### Analysis

Percentage reduction is found as

$$R = \frac{\text{Initial oxygen content} - \text{Final oxygen content}}{100\% \text{ Total oxygen content initially}} \times$$

With the help of the Arrhenius equation  $K = A e^{-E/RT}$ , we can calculate the activation energy. Where,  $K$  = Rate Constant,  $A$  = Arrhenius Constant,

$E$  = Activation Energy,  $R$  = Gas Constant,  $T$  = Temperature.

We plotted the graph of  $\ln(K)$  vs.  $(1/T \times 10^4)$  for pellets with binder, with bentonite and with dextrin. Slope of this graph  $\times$  (universal gas constant) = activation energy ( $E$ )

### Results

With increase in temperature, the percentage reduction increases with increase in time. The percentage reduction in case of pellet with Dextrin was found more. This may be because of the lower activation energy of the pellets with dextrin as a binder.

A number of Models were considered out of which the model  $-\ln(1-f) = kT$  exactly fits to our experimental values.

Lower the binder percentage, greater the reducibility (2% > 5% > 8%). This is due to a decrease in the porosity with increasing binder percentage.

The activation energy of a pellet with **2% bentonite** binder is  **$E_a = 22.85$  Kcal/mole** and the activation energy for pellet with **2% dextrin** binder is  **$E_a = 18.86$  Kcal/mole**. So the rate of reaction in case of pellets with Dextrin is faster than the rate of reaction of pellets with Bentonite.

### Conclusions

1. Topochemical reaction phenomenon was observed.
2. With the increase of time, percentage reduction ( $O_2$  removal) increases in all the pellet samples.
3. With the increase of temperature, percentage reduction increases up to a certain extent.
4. Almost a mixed controlled reaction was obtained as the activation energy is in between 10 kcal/mole and 30 kcal/mole.
5. Reduction reaction is temperature dependant.
6. Lower the binder percentage, greater the reducibility (2% > 5% > 8%).

## References

1. Forsmo S. P. E, Apelqvist A. J., Bjorkman B. M. T, Samskog P.O, “Binding Mechanisms in wet iron ore green pellets with a bentonite binder” - Powder Technology 169 ((2006) 147-158
2. Coetsee T., Pistorius P.C, Villiers E.E D. “Rate determining steps for reduction in magnetite-coal pellets” –, Minerals Engineering 15 (2002) 919-929
3. Ripke S.J., Kawatra S. K. “Can fly-ash extend Bentonite binder for iron ore agglomeration” Int. J. of Mineral Process. 60 (2000) 181-198
4. Dutta S.K., Ghosh A., “Kinetics of gaseous reduction of Iron ore fines” ISIJ International, Vol.33 (1993), No-11, 1168-1173

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# **Chapter 1**

**INTRODUCTION**

**Background**

**Objectives**

## Introduction

Blast Furnace is used mainly for pig iron production all over the world. Thus because it has very high production rate and also greater degree of heat utilization to a remarkable extent as here counter current heat exchange principle is utilized. Modern heat capacity furnaces are producing around 12,000 THM per day.

With time the use of pellets as raw material for blast furnace has increased considerably. As blast furnace feed, it offers much scope for improving productivity and economy of coke consumption. By using pre reduced pellets an increase in production of at least 25-30% can be obtained in the existing blast furnace. In Electric Arc Furnaces pre reduced pellets have proved an adequate substitute for steel scrap.

Upgrading naturally found iron ores is accomplished by grinding the ore into fine particles so that the iron containing materials can be liberated from unwanted gangue. This beneficiation process leaves the iron ore in a finely ground state that is not easily transported or readily processed in steel making facilities. Therefore, it is necessary to agglomerate the fine ground material into pellets using various binders, afterwards indurating the newly formed pellets to strengths high enough to survive transportation.

The source of iron is its ore when iron exists mostly as oxides either as haematite( $\text{Fe}_2\text{O}_3$ ) or magnetite( $\text{Fe}_3\text{O}_4$ ) and sometimes in small proportions of hydroxides and carbonates. Of all the iron bearing minerals used for blast furnace smelting, haematite represents the largest proportion. When chemically pure haematite contains around 70% and magnetite around 72.4% of iron.

DRI or Sponge Iron is a porous solid-state product of direct reduction process, which is produced either in lump or pollet 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.

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.

Few examples of iron making industry by use of pellets are ESSAR STEELS, JINDAL STEELS, etc.

**Following are the aims and objectives of our Project:**

To characterize the reduction behavior of iron ore by charcoal.

To study the effect of addition of different binders on reduction behavior of iron ore pellets.

# **Chapter 2**

**Advantages**

**Disadvantages**

**Raw materials for Pelletisation**

**Organic & Inorganic Binders**

**Criteria of Binders for Pelletisation**

**Role of Binders**

**Bonding Mechanism**

## **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

### **Advantages of Pellets:**

Good Reducibility: Due to high porosity

Good bed Permeability: Due to Spherical shape and open pores

High Strength (150-250 kg/cm<sup>2</sup> ) or More

High Porosity (25-30%)

Less heat consumption than sintering

Uniform chemical composition

Easy handling and transportation

Good resistance to disintegration during charging

Resistance to weathering and freezing.

### **Disadvantages of Pellets:**

- High cost of production due to grinding and firing especially with oil burners;
- Swelling and loss of strength inside of furnace;
- Sticking during firing;
- Resistance to flow of gas more than that in sinter for the same size range due to lower voidage;
- Difficulty of producing fluxed pellets;
- Fluxed pellets break down under reducing conditions much more than acid and basic sinters and acid pellets;
- Stronger highly fluxed sinters, especially containing MgO, are being increasingly preferred to pellets.

**Binders are broadly classified into following categories:**

**Organic Binders:** Dextrin, Thermosetting Resin, Processed or natural oils, Peridur, Carbo-cel, carboxymethyl cellulose

**Inorganic Binders:** Bentonite, Cement, Lime, Olivine, etc

### **Criteria of binders for iron ore pelletization**

- 1) **Mechanical properties** . It should maintain good mechanical properties of green, dry, and fired pellets, e.g., deformation under load, resistance to fracture by impact and compression, resistance to abrasion.
- 2) **Chemical composition** . It should bring no environmentally and metallurgically harmful elements such as P, S, As, etc., into product pellets. It should not markedly reduce iron grade and increase impurities such as silica.
- 3) **Metallurgical performance**. It should maintain pellet's excellent metallurgical properties, e.g. reducibility, swelling during reduction.
- 4) **Processing behavior**. Adding, mixing, dispersion of binder, green ball preparation, pellet drying, etc., should not be too complicated or essentially change conventional pellet production method
- 5) **Cost factor**. Price should be acceptable for iron pellets production.

**Role of Binders:** Binders play an important role in pellet formation. They give strong, wet and dry balls in green state and increase fire strength.

### **Bonding Mechanism:**

Bonding Mechanism includes two stages viz.

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

**2. Induration (Heat Hardening)** – Solid state diffusion at particle surfaces at higher temperature cause recrystallisation & growth giving strength.

# **Chapter 3**

## **REDUCTION BEHAVIOUR**

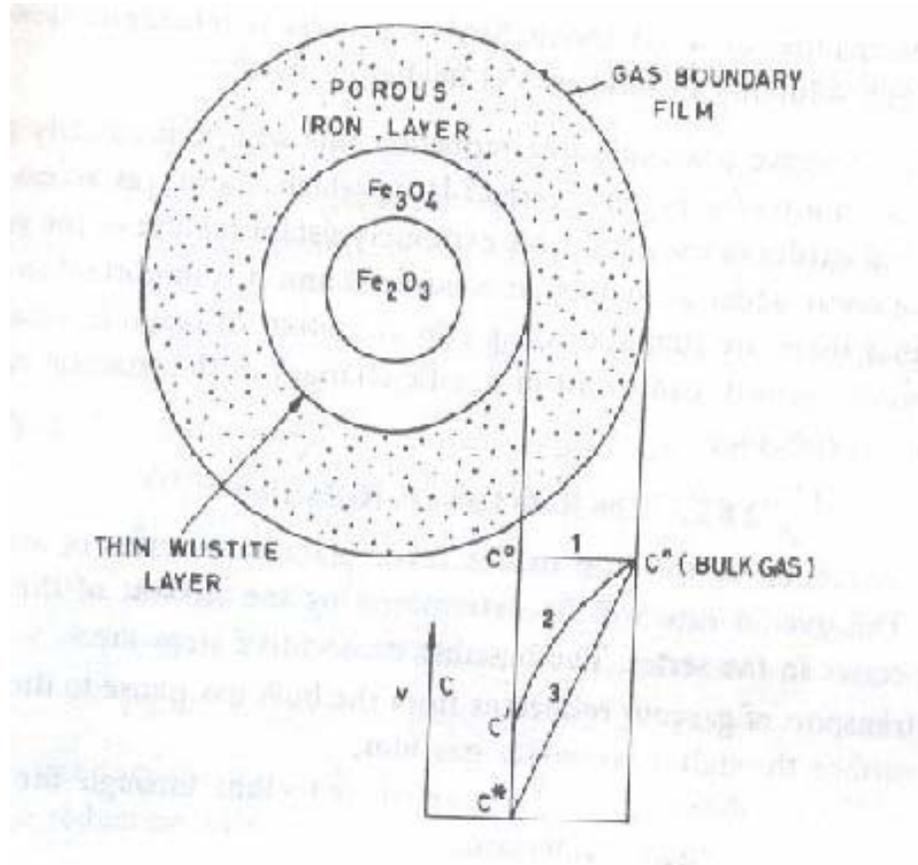
**Rate Laws in Reduction**

**Reduction Reactions**

**Mechanism**

**Kinetics of reduction**

Reduction kinetics of iron ore reduction deals with the rate at which iron oxide is converted to metallic iron by removal of oxygen. This influences production rate of the process, which ultimately determines the economic feasibility and competitiveness of the technologies involved.



***A schematic diagram of the mode of gaseous reduction of a spherical sample of ferric oxide. possible concentration gradients of the reducing gas across the iron layer are also shown.***

**Fig. 1**

A shell or layer of metallic iron in contact with a layer of wustite will be formed as shown in the figure. Such a structure is typical of topochemical reactions where the reacting interface between the solid reactants and the solid products move parallel to the original solid surface.

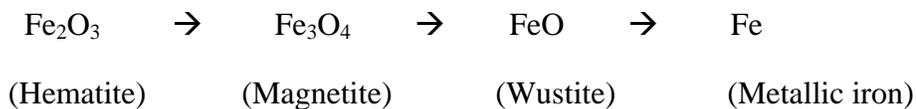
### The Rate Laws in Reduction:

The reduction of the iron oxides takes place in a series of sequential steps. The overall rate will be determined by the slowest of the process or processes in the series. The possible consecutive steps are:

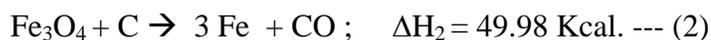
- i. Transport of gaseous reductant from the bulk gas phase to the particle surface through a boundary gas film;
- ii. Molecular diffusion of the gaseous reductant through the product layer to the reaction interface ;
- iii. Adsorption of the gaseous reductant at the interface;
- iv. Reaction at the interface (reaction between adsorbed reductant and oxygen of the lattice);
- v. Desorption of the gaseous products from the interface;
- vi. Mass transport of iron and oxygen ions and transformations in the solid phase; formation and growth of the reaction products, viz. , magnetite, wustite and iron;
- vii. Molecular diffusion of gaseous products through the product layer to the particle surface;
- viii. Transport of the gaseous products from the particle surface through the boundary gas film to the bulk gas phase.

The rate limiting cases are chemical control (steps iii to vi) and diffusion control (steps I & viii ; ii ; vi & vii)

### Mechanism of DR process:



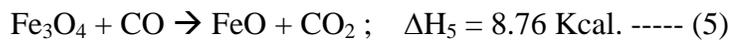
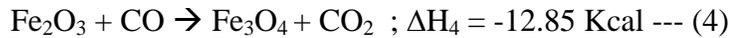
### Stages of iron oxide reduction by solid carbon:





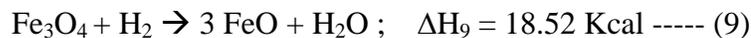
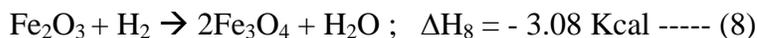
The reduction of iron oxides initiated by solid carbon as per the above mention reaction, and the CO gas evolved again participate n the further reduction of iron oxides.

### **Stages of iron oxide reduction by CO:**



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<sub>2</sub> 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

### **Stages of iron oxide reduction by H<sub>2</sub> :**



The H<sub>2</sub> 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<sub>2</sub> and CO gas as per reaction (11) and the H<sub>2</sub> and CO gas again participate in the reduction of iron oxides.

### **Oxidation of solid carbon**



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.

### **Kinetics of DR process:**

Reaction kinetics of iron ore reduction deals with the rate at which iron oxide is converted to metallic iron by removal of oxygen. The rate at which the ore is reduced influences the production rate, which ultimately determines the economic feasibility and competitiveness of the process technology involved. Thus the reaction rate in DR process is of prime importance.

The reduction of iron oxide to metallic iron proceed through various kinetic steps and one of them is the slowest step, which control the overall reaction rate. The different rate controlling factors which control the overall rate of reduction are given below:

### **Boundary Layer Control**

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

### **Phase Boundary Reaction Control**

The chemical reaction at the wustite -iron interface is the rate controlling factor. In this case the rate of reduction per unit area of the remaining iron oxide is found to be constant with time. This mechanism is called "Phase Boundary Reaction Control".

When counter diffusion of reducing gas and product gas on the reduced outer layer is sufficiently fast, the concentration of reducing gas at the reacting surface is effectively the same as it's concentration at the particle surface. In such case the rate of reaction at the

wustite-iron interface would control the overall reduction rate. This mechanism is unlikely at the very start of the reduction, when the iron layer is very thin., or for very small porous grains of iron oxide.

## **Gaseous Diffusion Control**

The rate of reducing gas inward and product gas outward through the reduced iron layer can control the rate of reduction of iron oxides. This phenomenon is generally associated with large ore particle and is known as “Gaseous Diffusion Control”.

When gaseous diffusion is the rate controlling step, the rate of diffusion of reducing gas inward and product gas outward through the porous layer of metallic iron surrounding the unreduced inner core particle, is slower than the rate of reaction. During such occurrence the concentration of the reducing gas will decrease that of product gas will increase at the interface. The change in the gas composition will slow down the reduction rate until a pseudo steady state is established. This is the pre dominant rate controlling mechanism for high temperature reduction of large (greater than 7 mm) particle beyond 50% reduction, when iron layer thickness exceeds about 1mm.

## **Mixed Control**

When both Gaseous Diffusion Control and Phase Boundary Reaction Control combinely influence the rate of reduction, the mechanism is referred to as “Mixed Control”

Mixed control has been proposed by several experiments to reconcile the complexities and conflicting results obtained from direct reduction of iron oxides with simpler mechanism. In mixed control, the gas boundary layer, the phase boundary reaction and gaseous diffusion act together under pseudo steady state condition to determine the overall reaction rate.

Different mathematical models equations are proposed to represent different rate controlling steps, which are given below

<u>EQUATION</u>	<u>CONTROLLNG STEP</u>
$1 - (1-f)^{1/3} = kt$	Chemically controlled
$-\ln(1-f) = kt$	Chemically controlled
$[1 - (1-f)^{1/3}]^2 = kt$	Diffusion Controlled
$1 - 2/3f - (1-f)^{2/3} = kt$	Diffusion Controlle
$k'[1 - 2/3f - (1-f)^{2/3}] + D/r_0[1 - (1-f)^{1/3}] = kt$	Mixed Controlled

## EXPERIMENTAL PROCEDURE

Gandha Mardan Iron ore and charcoal was taken.

Chemical analysis of iron ore & charcoal was done

Grinding of the ore to -100# size.

Crushing of the charcoal to -72# size.

Making of pellets by hand rolling using different types and quantities of binder (2 to 8% ) along with water.

Air drying of pellets followed by oven drying at 110 °C to remove moisture.

To obtain proper strength in the pellet by heat hardening i.e. by recrystallisation or gangue particles fusing to form slag phase, Firing was done in a muffle furnace at 1300°C.

The pellet that is formed is taken inside a metallic crucible. Then the pellet is surrounded by charcoal and then reduced.

1st case-Each crucible containing iron ore pellets were placed in a furnace and reduction was carried out with charcoal at different temperature from 900-1050°C

2nd case-6 crucibles containing pellets of different % binder(2%,5%,8%)were taken & reduction was carried out at a constant temperature of 950°C and pellets were taken out at a time interval of 15,30,45,60 and 90 minutes.

Then initial weight of the iron oxide pellet and the final weight of the iron oxide pellet is measured and the percentage reduction is calculated. In both the cases, from the loss in weight plot was made between % reduction and time. Then a straight line plot between  $1-(1-R)^{1/3}$  vs time was drawn. The slope of the graph gives K (rate constant).

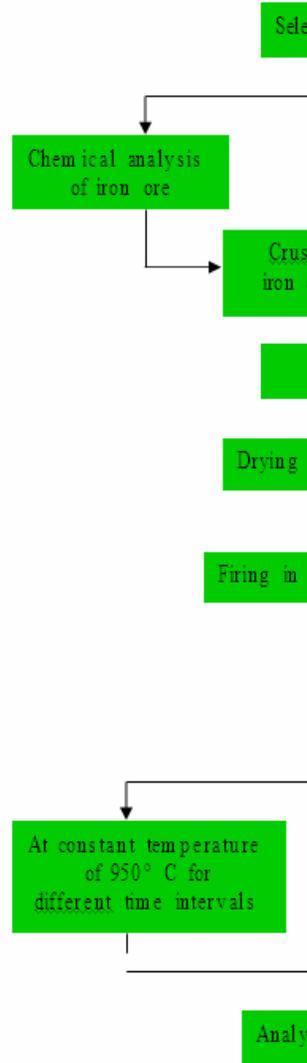
Then graphs were drawn for  $\ln(K)$  vs  $1/T \times 10^4$ . Slope of the graph gives the value of activation energy which was calculated from Arrhenius Equation:  $K=Ae^{-E/RT}$ .

Percentage reduction can be calculated as

$$R = \frac{\text{Initial oxygen content} - \text{Final oxygen content}}{\text{Total oxygen content initially}} \times 100\%$$

# **FLWSHEET**

% Moisture	4%
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**OBSERVATIONS:**

**Table No-1: Charcoal Proximate Analysis Results**

% Volatile matter	15%
% Ash	26%
% Fixed Carbon	55%

**Table No-2: Iron ore Chemical Analysis Results**

Fe	
MnO	
SiO <sub>2</sub>	
Al <sub>2</sub> O <sub>3</sub>	

### **GRAPHICAL ANALYSIS:**

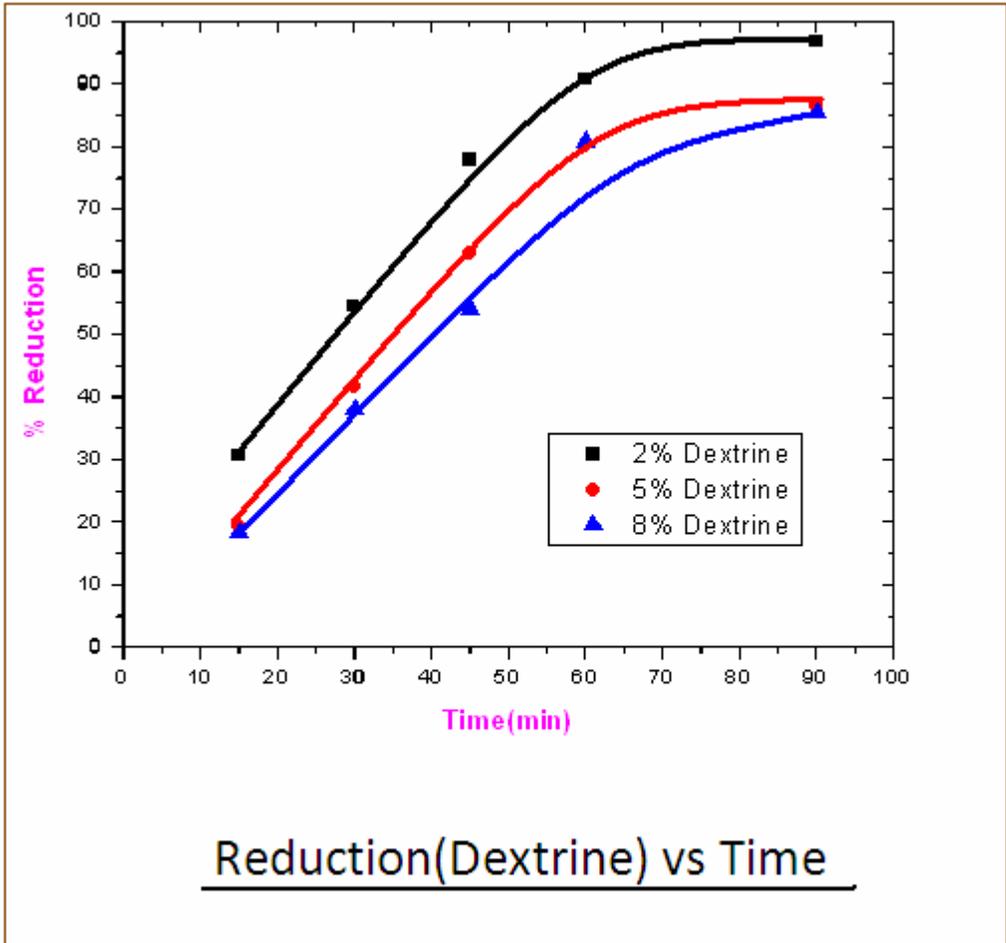
The graphical analysis was done by plotting a graph of **reduction vs. time** and the effect of different binders on reduction time will be studied.

Reducibility of pellets decreases with the increase of binder. This is due to a decrease in the porosity.

**Table No-3: Percentage Reduction versus time for Pellet with Dextrine**

Time(in minutes)	2% Dextrine (in %)	5% Dextrine (in %)	8% Dextrine (in %)
15	30.72	19.26	18.19
30	54.62	41.56	37.95
45	77.90	62.99	53.86
60	90.84	79.98	80.75
90	96.65	86.49	85.25

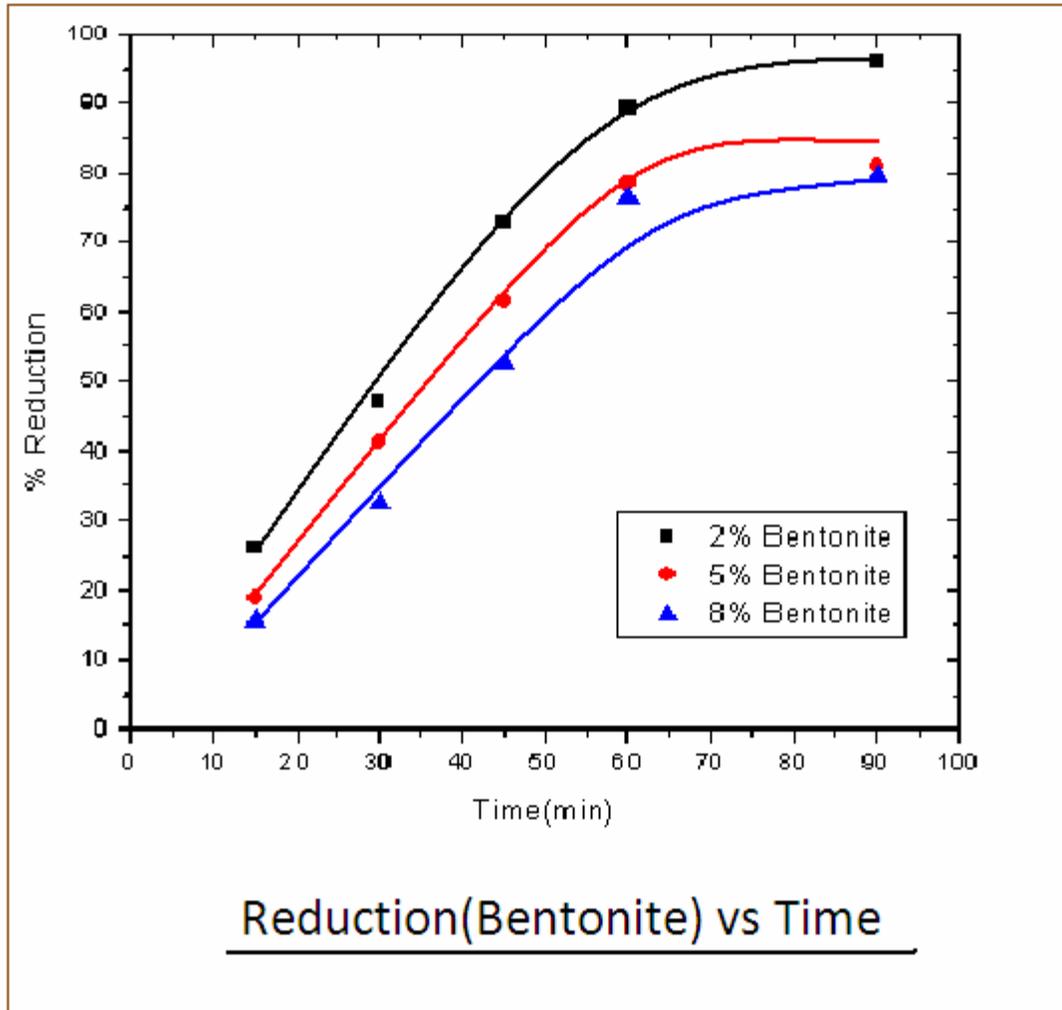
**Figure No 2- Percentage Reduction versus time for Pellet with Dextrine**



**Table No-4: Percentage Reduction versus time for Pellet with Bentonite**

Time(in minutes)	2% Bentonite(in %)	5% Bentonite(in %)	8% Bentonite(in %)
15	26.14	18.88	15.58
30	47.16	41.31	32.73
45	72.95	61.74	52.76
60	89.45	78.55	76.29
90	96.05	81.09	79.70

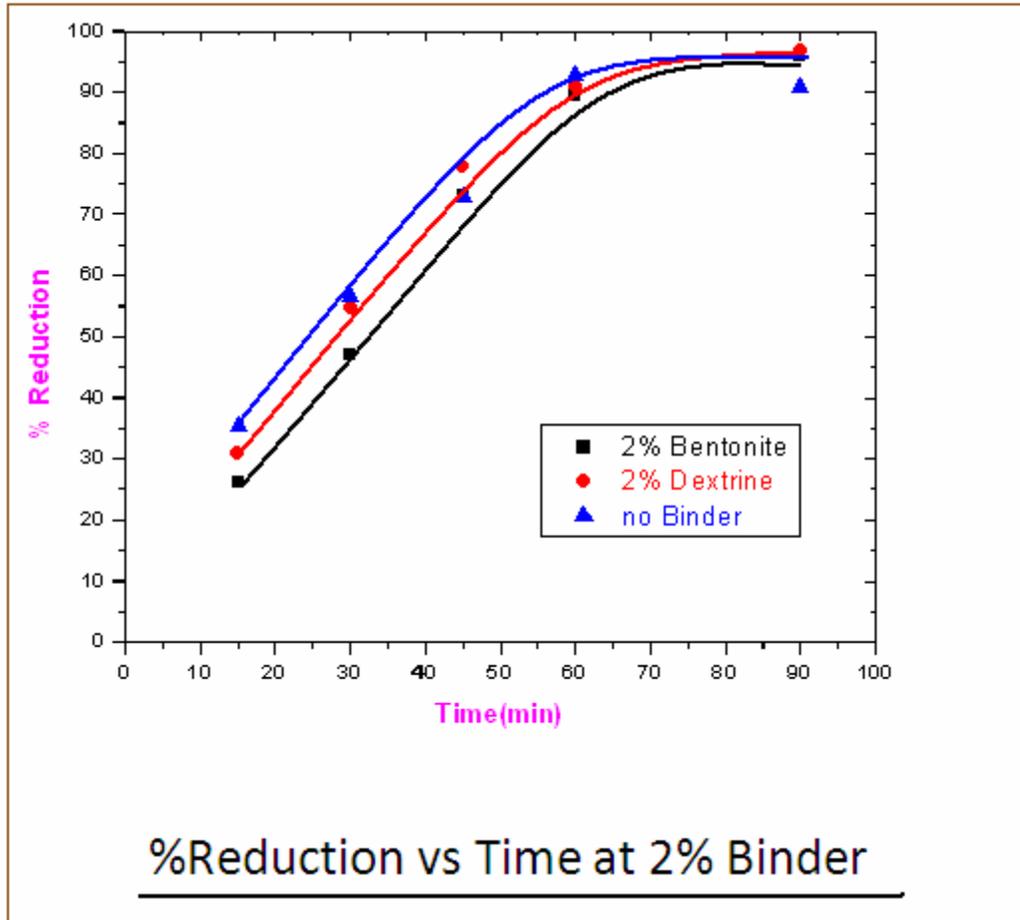
**Figure No 3: Percentage Reduction versus time for Pellet with Bentonite**



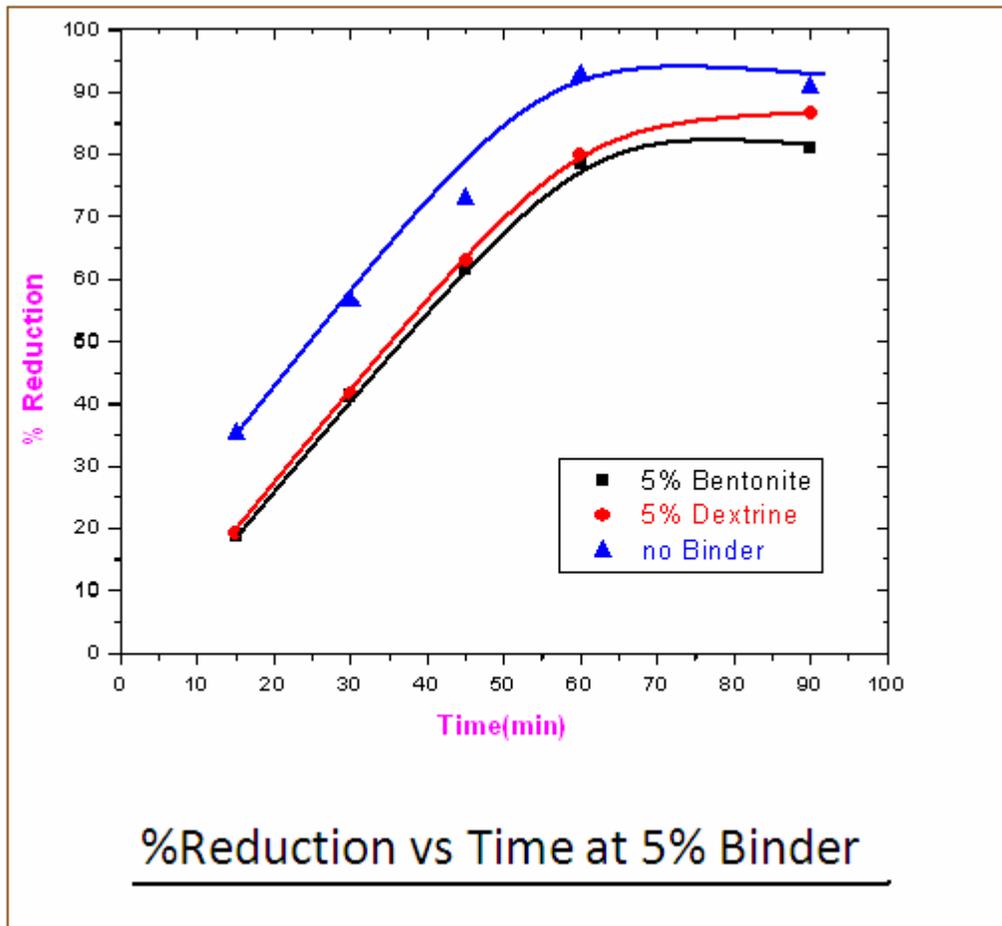
**Table No-5: Percentage Reduction versus time for Pellet without Binder**

Time(in minutes)	Without binder(in %)
15	35.24
30	56.41
45	72.91
60	92.74
90	90.81

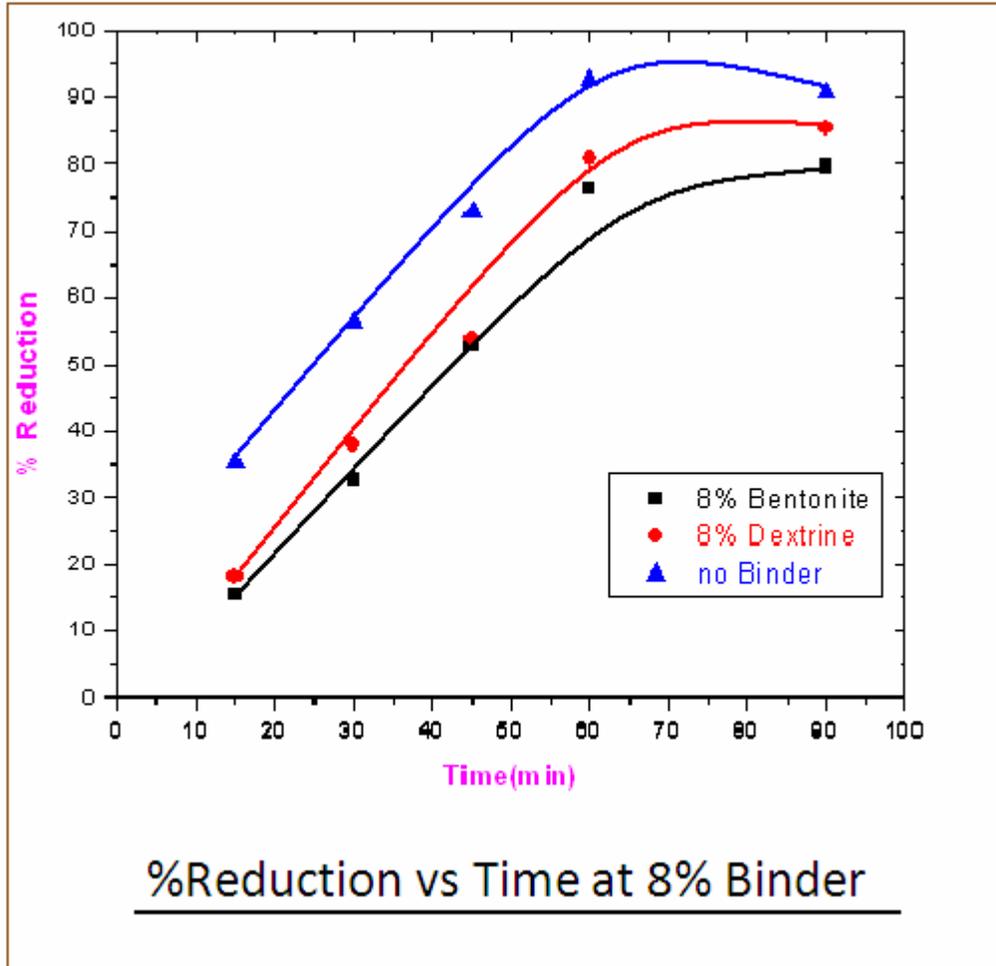
**Figure No. 4:-Comparison of reduction of pellets with 2% binder with bentonite and dextrine and pellets without binder**



**Figure No .5:-Comparison of reduction of pellets with 5% binder with bentonite and dextrine and pellets without binder**



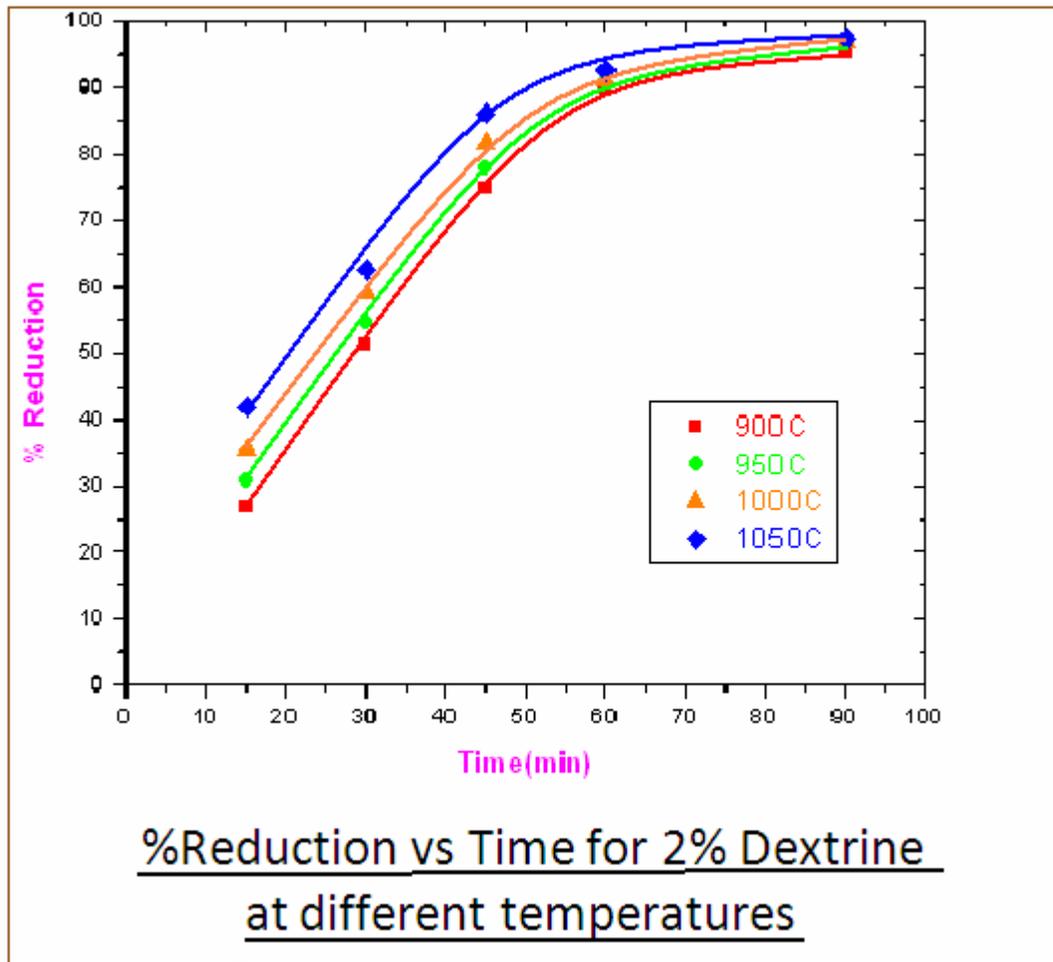
**Figure No.6:-Comparison of reduction of pellets with 8% binder with bentonite and dextrine and pellets without binder.**



**Table No-6: Percentage Reduction versus time for Pellet with 2% Dextrine reduced at different temperatures.**

Time (in min)	At 900°C (in %)	At 950°C (in %)	At 1000°C (in %)	At 1050°C (in %)
15	26.68	30.72	35.32	41.79
30	51.39	54.62	59.04	62.56
45	74.81	77.90	81.52	86.01
60	89.94	90.84	91.06	92.47
90	95.36	96.65	96.78	97.31

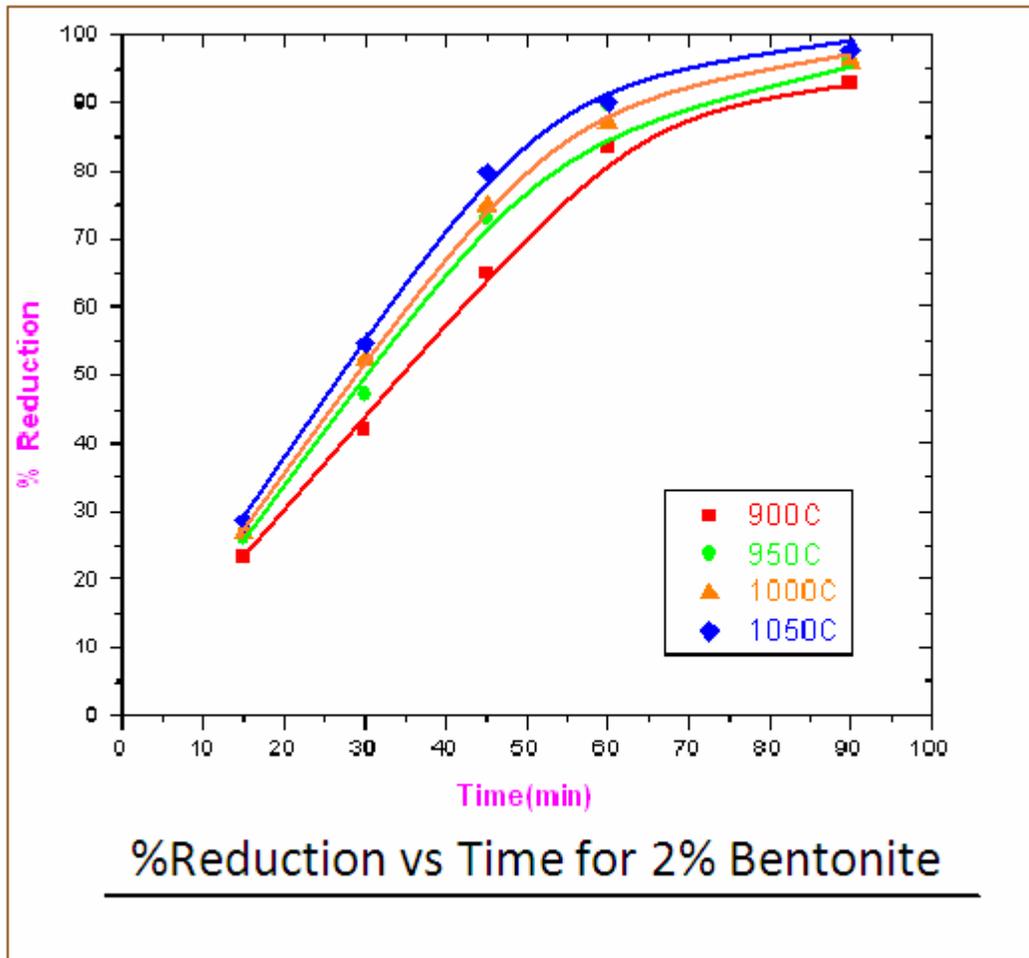
**Figure No.7:-Comparison of reduction of pellets with 2% Dextrine reduced at different temperatures.**



**Table No-7: Percentage Reduction versus time for Pellet with 2% Bentonite reduced at different temperatures.**

Time (in min)	At 900°C (in %)	At 950°C (in %)	At1000°C (in %)	At1050°C (in %)
15	23.32	26.14	27.01	28.61
30	51.39	47.16	52.30	54.69
45	74.81	72.95	74.89	79.80
60	89.94	89.45	86.89	90.01
90	95.36	96.05	95.85	97.82

**Figure No.8:-Comparison of reduction of pellets with 2% Bentonite reduced at different temperatures.**

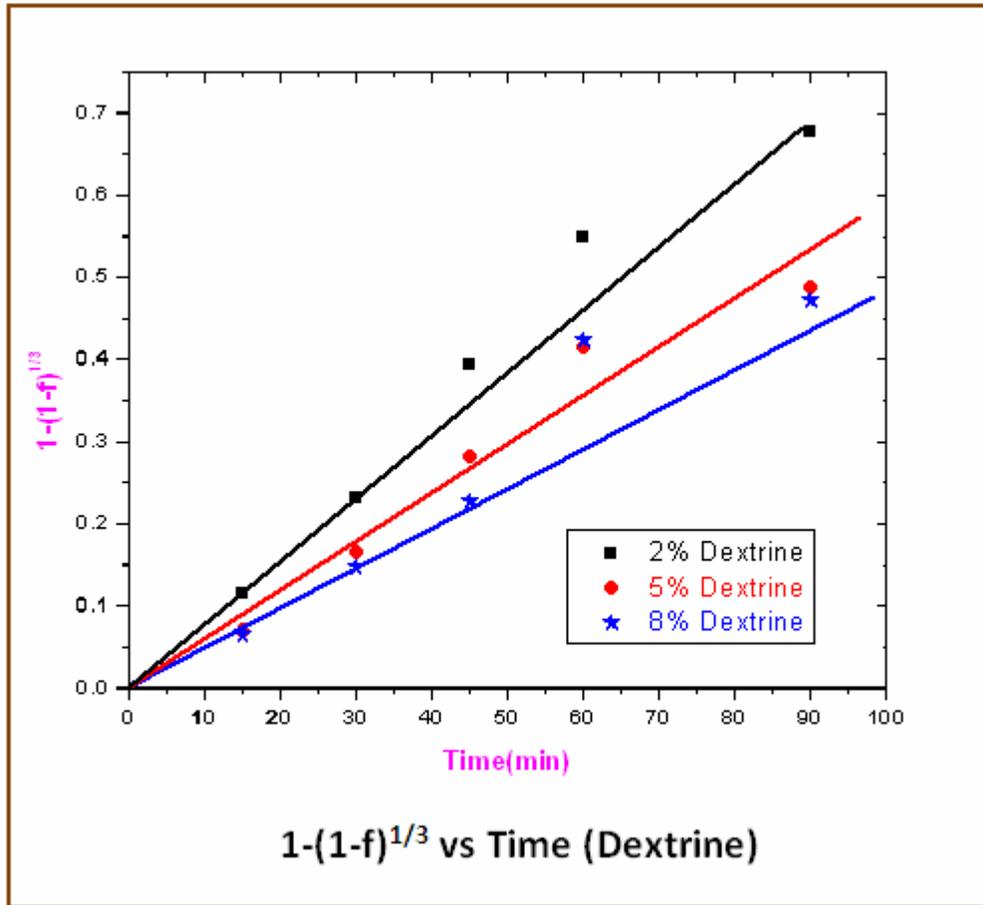


A number of models were considered but the model  $1-(1-f)^{1/3} = Kt$  exactly suits our experimental values and gives us a straight line, so that we can evaluate the value of K.

**Table No-8:  $1-(1-f)^{1/3}$  versus Time for pellets with Dextrine**

Time (min)	2% Dextrine	5% Dextrine	8% Dextrine
15	.115	.069	.065
30	.231	.164	.147
45	.395	.282	.227
60	.549	.415	.423
90	.677	.487	.472

**Figure No.9:  $1-(1-f)^{1/3}$  versus Time for pellets with Dextrine.**



**Table No. 9:  $1-(1-R)^{1/3}$  versus Time for Pellets with Bentonite.**

Time(min)	2% Bentonite	5% Bentonite	8% Bentonite
15	0.096	0.067	0.055
30	0.191	0.163	0.124
45	0.353	0.274	0.221
60	0.527	0.401	0.381
90	0.659	0.426	0.412

Figure No.10:- $1-(1-f)^{1/3}$  versus Time for pellets with Bentonite.

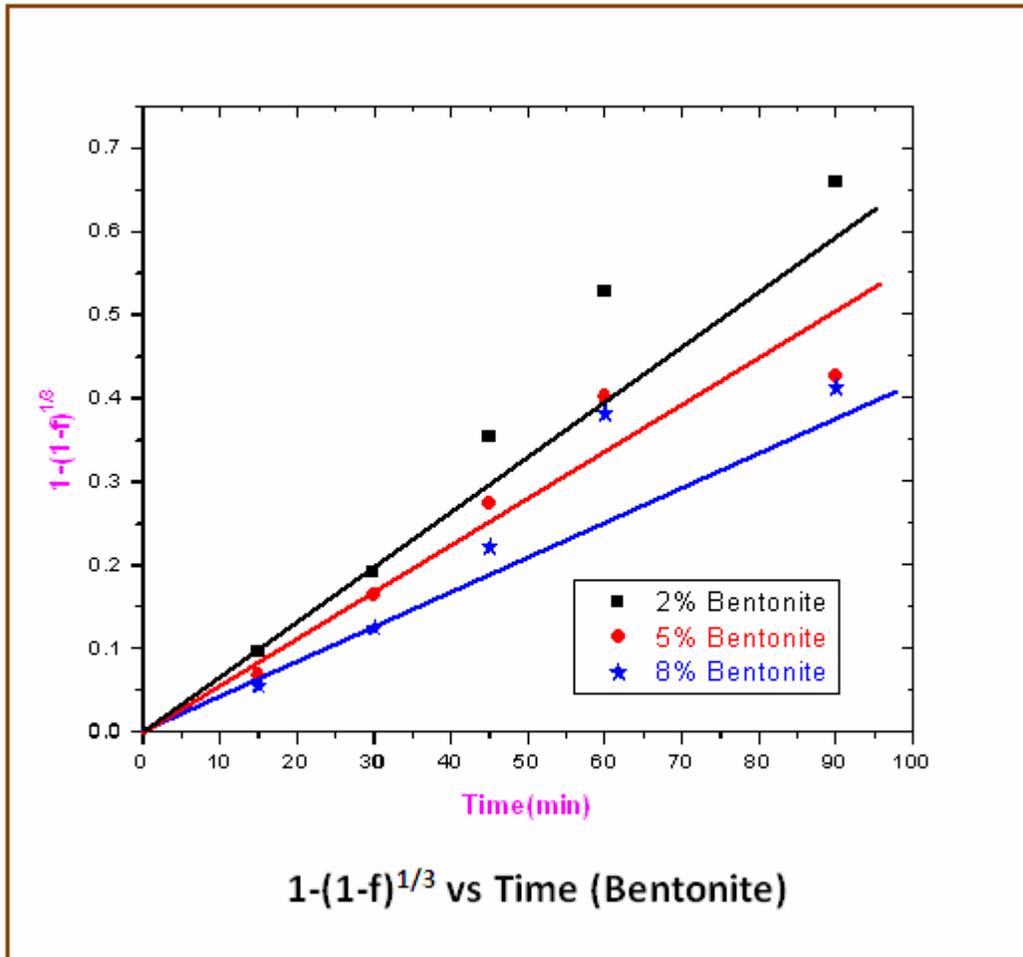
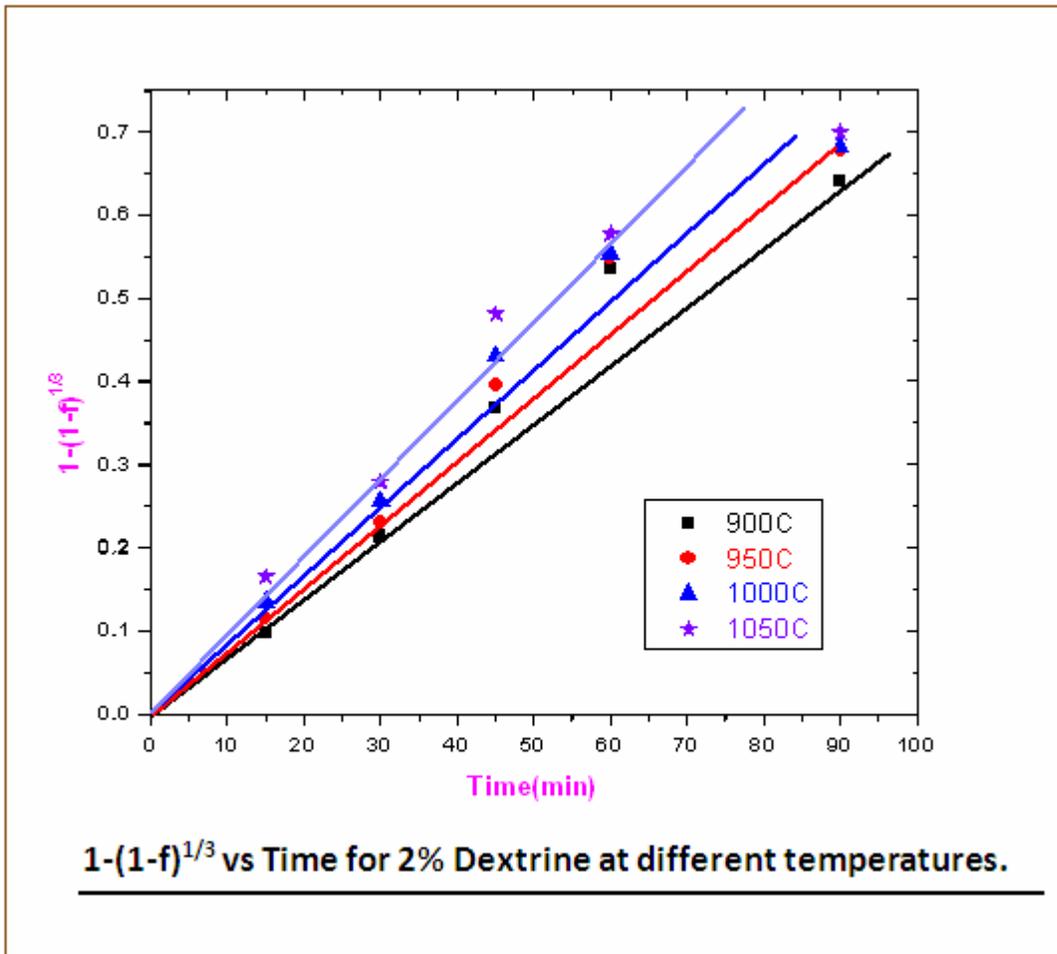


Table No. 10:  $1-(1-R)^{1/3}$  versus Time for Pellets with 2%Dextrine for different temperatures.

Time(min)	900°C	950°C	1000°C	1050°C
15	0.098	0.115	0.135	0.165
30	0.214	0.231	0.257	0.279
45	0.368	0.395	0.430	0.481
60	0.535	0.549	0.553	0.578
90	0.641	0.677	0.682	0.700

Figure No.11:- $1-(1-f)^{1/3}$  versus Time for pellets with 2% Dextrine for different temperatures.

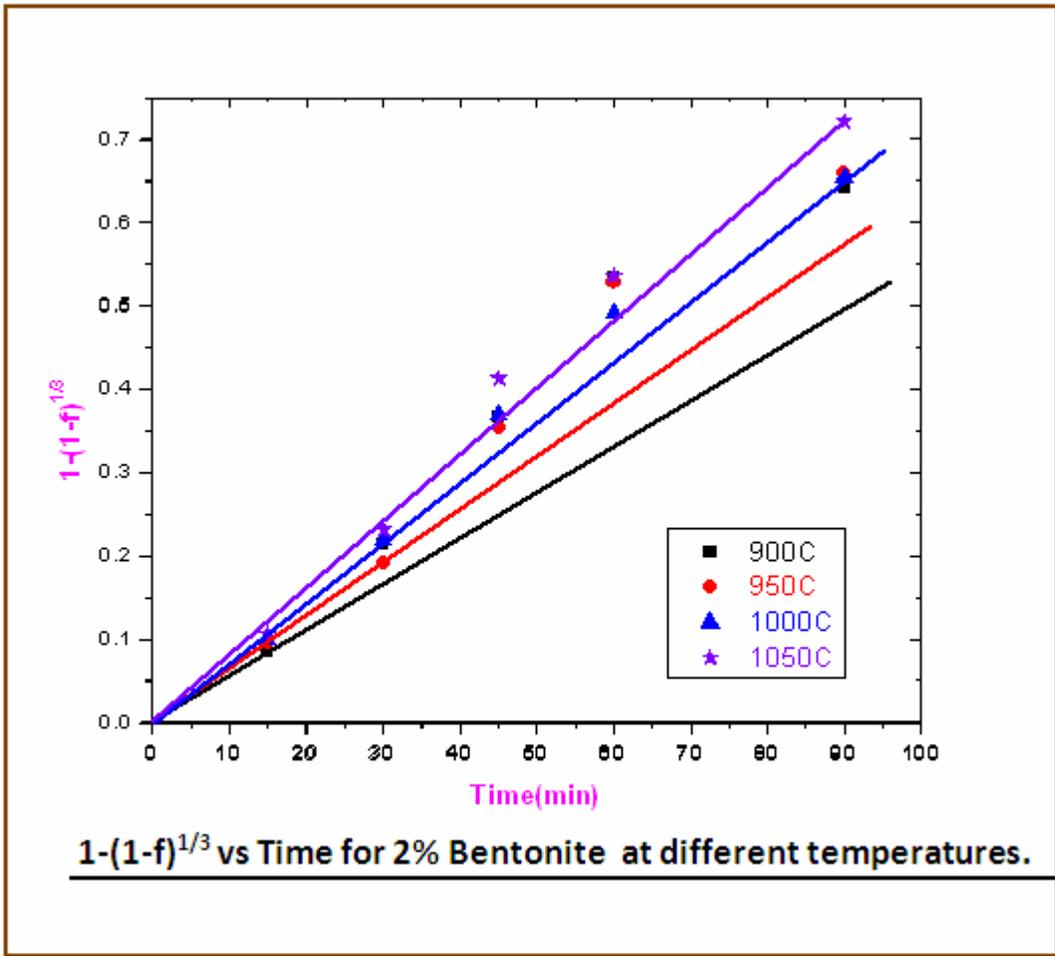


**Table No. 11:  $1-(1-R)^{1/3}$  versus Time for Pellets with 2%Bentonite for different temperatures.**

Dhgdh

Time(min)	900°C	950°C	1000°C	1050°C
15	0.085	0.096	0.099	0.106
30	0.214	0.191	0.219	0.232
45	0.368	0.353	0.369	0.413
60	0.535	0.527	0.492	0.536
90	0.641	0.659	0.654	0.721

**Figure No.12:- $1-(1-f)^{1/3}$  versus Time for pellets with 2% Bentonite for different temperatures.**



**Mechanism**

The mechanism of reduction of iron ore (lump and pellets) occurs by three methods:

1. Chemical kinetics,
2. Diffusion control and
3. Mixed control (both chemical and diffusion process.)

With the help of the Arrhenius equation we can calculate the activation energy

$$K = A e^{-E/RT}$$

Where,

K = Rate Constant,      A= Arrhenius Constant,      E= Activation Energy,  
 R= Gas Constant,      T= Temperature.

When a graph is plotted between  $\ln A$  and  $1/T$  we get a straight line

where,  $x = (1/T)$ ,       $c = \ln A$

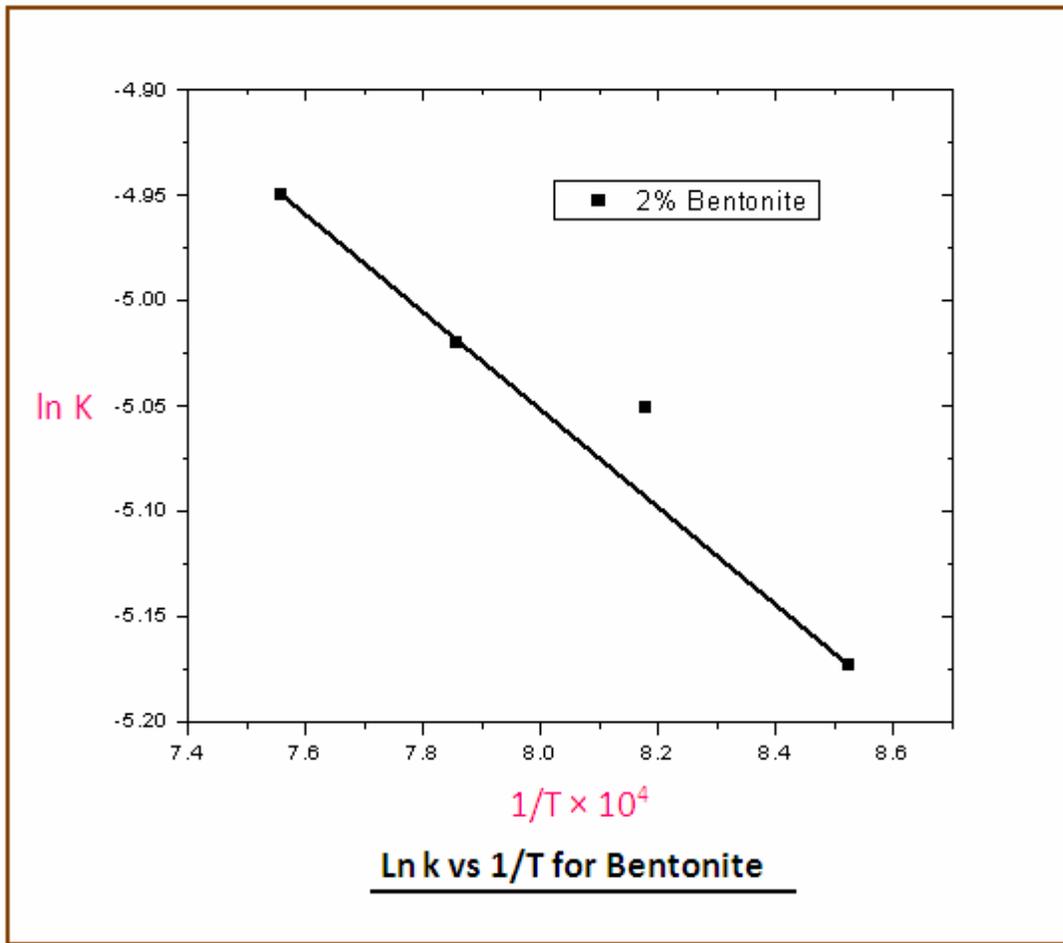
**$\ln(K)$  vs.  $(1/T \times 10^4)$ :**

We plotted the graph of  $\ln(K)$  vs.  $(1/T \times 10^4)$  for pellets with binder, with bentonite and with dextrin. Then calculated the value of Activation Energy from,  $K = A e^{-E/RT}$

**Table No 12:  $\ln K$  vs  $1/T \times 10^4$  for 2% Bentonite.**

Temp.(°C)	Temp.(K)	$1/T \times 10^4$	K	Ln K
900	1173	8.525	$5.67 \times 10^{-3}$	-5.173
950	1223	8.177	$6.40 \times 10^{-3}$	-5.051
1000	1273	7.855	$6.60 \times 10^{-3}$	-5.020
1050	1323	7.559	$7.06 \times 10^{-3}$	-4.950

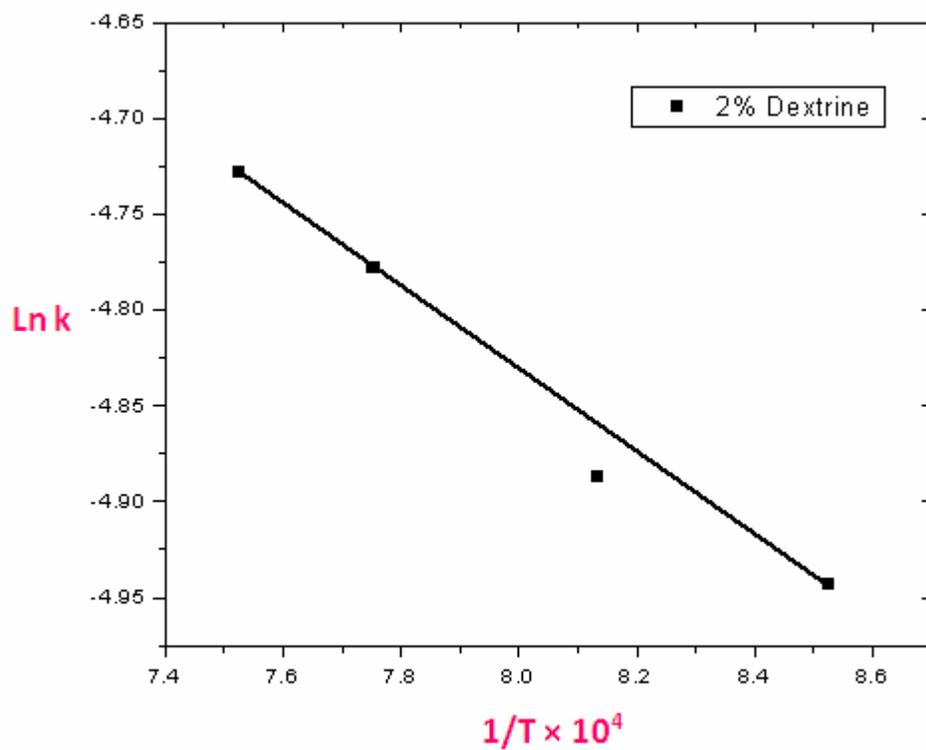
**Figure No 13:  $\ln K$  vs  $1/T \times 10^4$  for 2% Bentonite**



**Table No 13: Ln K vs 1/T x 10<sup>4</sup> for 2% Dextrine.**

Temp.(°C)	Temp.(K)	1/T × 10 <sup>4</sup>	K	Ln K
900	1173	8.525	7.13 × 10 <sup>-3</sup>	-4.943
950	1223	8.177	7.70 × 10 <sup>-3</sup>	-4.866
1000	1273	7.855	8.56 × 10 <sup>-3</sup>	-4.760
1050	1323	7.559	9.30 × 10 <sup>-3</sup>	-4.677

**Figure No 14: Ln K vs 1/T x 10<sup>4</sup> for 2% Dextrine**



Ln k vs 1/T for Dextrine

## RESULTS AND DISCUSSIONS

1. With Increase in temperature for a pellet the percentage reduction increases with the increase in time.
2. The percentage reduction in case of pellet with Dextrin was found more. This may be because of the lower activation energy of the pellets with dextrin as a binder.
3. A number of Models were considered out of which the model  $1-(1-R)^{1/3}=kT$  exactly fits to our experimental values.
4. Activation Energy E was found to be 18.86 kJ/K/mole for 2% dextrine & 22.85 kJ/K/mole for 2% Bentonite. Slope of this graph x (universal gas constant) = activation energy (E)
5. So the rate of reaction in case of pellets with Dextrin is faster than the rate of reaction of pellets with Bentonite.

## **CONCLUSION**

With increase in temperature, % reduction of pellets increases . With increase in time, % reduction of pellets increases  
Lower the binder percentage, greater the reducibility (2% >5% >8%) of pellets  
Reduction of pellets with Dextrine binder is faster as compared to Bentonite Iron ore  
reduction kinetics follow Topochemical reaction nature  
Reduction reaction is temperature dependant.

## **REFERENCES**

1. Forsmo S. P. E, Apelqvist A. J., Bjorkman B. M. T, Samskog P.O, "Binding Mechanisms in wet iron ore green pellets with a bentonite binder" - Powder Technology 169 ((2006)147-158
2. Coetsee T., Pistorius P.C, Villiers E.E D. "Rate determining steps for reduction in magnetite-coal pellets" -, Minerals Engineering 15 (2002) 919-929
3. Guanzhou Qiu, Tao Jiang, Hongxu Li, Dianzou Wang "Functions and molecular structure of organic binders for iron ore pelletisation" Colloids and surfaces A : Physiochem.Eng.Aspects 224 (2003) 11-22
4. Fenwei Su, Lampiene, Hans-Olof, Robinson Ryan; "Recycling of sludge and dust to the BOF converter by cold bonded pelletizing " International Journal of Mineral Processing, v 44, n 4, 2004, p 770-776
5. Mohamed O.A., Shalabi M.E.H, El-Hussiny N.A., Khedr M.H, Mostafa F. "The role of normal and activated bentonite on the pelletization of barite iron ore concentrate and the quality of pellets" Agglomerating iron ore concentrates, Chem. Eng. Prog. 130(2003) 277-282
6. Kawatra S.K., Eisele T.C., Ripke S.J., Ramirez G., "High-Carbon Fly-Ash as a Binder for Iron Ore Pellets", Vol. No24 (2000) Mineral Processing and Extractive Metallurgy Review
7. Robinson R , "High Temperature properties of by-product cold bonded pellets containing blast furnace flue gas" -, Thermochimica Acta 432 (2005) 112 – 123
8. Ripke S.J., Kawatra S. K. "Can fly-ash extend Bentonite binder for iron ore agglomeration" Int. J. of Mineral Process. 60 (2000) 181-198
9. Dutta S.K., Ghosh A., "Kinetics of gaseous reduction of Iron ore fines" ISIJ Intenational , Vol.33 (1993), No-11, 1168-1173
10. Eisele, T.C., and Kawatra, S.K., "A review of binders in iron ore pelletization," Mineral Processing and Extractive Metallurgy Review, Vol.24, No. 1, 2003, pp.1-90.
11. Kawatra, S. K., and Ripke, S. J. "Laboratory studies for improving green ball strength in bentonite bonded magnetite concentrate pellets," International Journal of Mineral Processing, Vol.72 No.1-4, 2003. pp. 429-441.
12. Kawatra, S.K. and Ripke S.J. , "Effects of Bentonite Fiber Formation in Iron Ore

Pelletization“ International Journal of Mineral Processing, Elsevier Press, Amsterdam, Vol. 65, , 2002, No. 3-4

**Books:**

- Biswas A.K. – Principles of Blast furnace iron making.
- Dr. Tupkary R.H. – Introduction to Iron making.

**Sites Visited:**

[www.sciencedirect.com](http://www.sciencedirect.com)

[www.freshpatent.com](http://www.freshpatent.com)

[www.google.com](http://www.google.com)

[www.engineeringvillage.com](http://www.engineeringvillage.com)

[www.scopus.com](http://www.scopus.com)

[www.OAster.com](http://www.OAster.com)