

# Iron Ore Pellet Reduction Kinetics and the Impact of Binders

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**Abstract:** Iron ore pellet reduction was done at temperatures between 900 and 1100°C. The most accurate model for reduction kinetics was to use the slope of the fractional reduction vs. time curve's initial linear area as a proxy for the rate constant ( $k$ ). Plots of  $k$  vs  $1/T$  showed a straight line, which was used to compute activation energy. To determine the impact of binders, pellets with varying binders percentages were reduced and compared.

**Keywords:** Iron ore

## I. INTRODUCTION

Around the world, blast furnaces are mostly used to produce pig iron. Consequently, it has a very high rate of production and a remarkable degree of heat utilization due to the application of the countercurrent heat exchange concept. The utilization of pellets as a blast furnace raw material has grown significantly over time. It presents numerous opportunities to increase efficiency and reduce the cost of coke usage as blast furnace feed. It is possible to boost production in the current blast furnace by at least 25–30% by employing pre-reduced pellets. Pre-reduced pellets have shown themselves to be a suitable replacement for steel scrap in electric arc furnaces.

In order to free the iron-containing minerals from undesired gangue, naturally occurring iron ores are upgraded by grinding them into fine particles. The iron ore is left in a finely ground form after this beneficiation process, making it difficult to transport or process in steel mills. As a result, the finely powdered material must be combined with different binders to make pellets, which must then be indurated to a strength sufficient to withstand transportation. Examples of industries that use pellets to make iron are JINDAL STEELS, ESSAR STEELS, and others.

Pellets are roughly spherical lumps that are created when crushed iron ore fines aggregate in the presence of moisture and binder after being indurated 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

### IN GENERAL, BINDERS FALL UNDER THE FOLLOWING CATEGORIES:

Natural Binders: Peridur, carboxymethyl cellulose, processed or natural oils, Dextrin, and Thermosetting Resin  
Bentonite, cement, lime, olivine, and other inorganic binder types

**BINDER REQUIREMENTS FOR PELLETIZING IRON ORE:-**

- 1) Mechanical characteristics. It should preserve the good mechanical qualities of green, dry, and fired pellets, such as resistance to abrasion, resistance to fracture from impact and compression, and deformation under load.
- 2) The chemical makeup. It should not introduce components like P, S, As, and others that are detrimental to the environment or metallurgy into product pellets. It shouldn't significantly lower iron grade and raise silica and other contaminants.
- 3) The performance of the metal. It should preserve the pellet's superior metallurgical qualities, such as swelling and reducibility.
- 4) Behavior processing. Green ball preparation, pellet drying, binder addition, mixing, and dispersion shouldn't be very difficult or fundamentally alter the traditional pellet production process.
- 5) The cost component. The cost of producing iron pellets should be reasonable.

**Function of Binders:**

Binders are crucial to the creation of pellets. They boost fire strength and produce robust, wet, and dry balls in green state.

The pace at which oxygen is removed from iron oxide to produce metallic iron is known as reduction kinetics of iron ore reduction. This affects the process's pace of production, which in turn affects the technologies' competitiveness and economic viability.

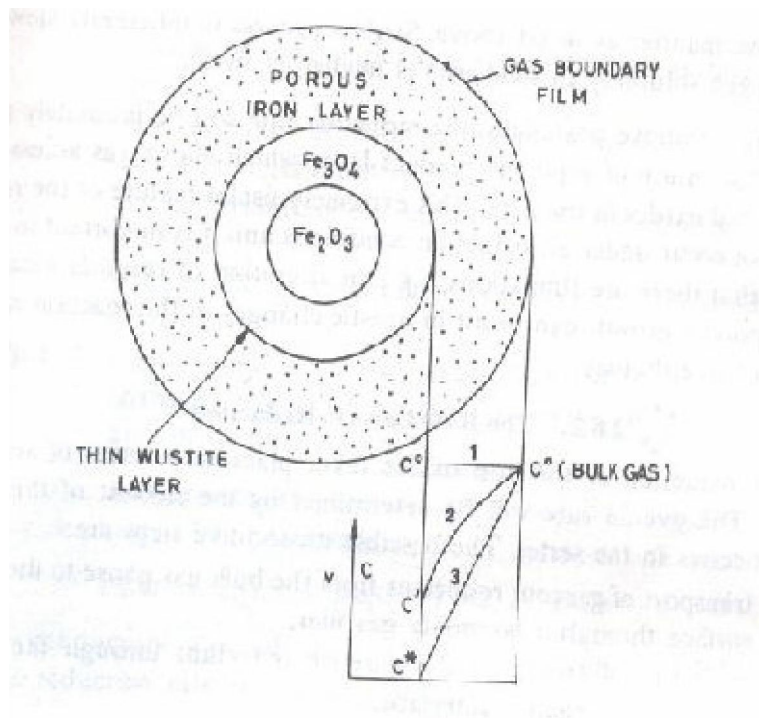


Fig: 1.1 Layer of Pellet

As seen in the illustration, a shell or layer of metallic iron will form when it comes into contact with a layer of wustite. The responding interface between the solid reactants and the solid products moves parallel to the initial solid surface in topochemical reactions, which is typical of this structure.

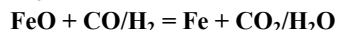
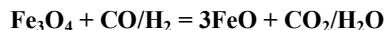
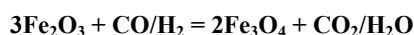
**The Rate Laws in Reduction**

There are several sequential phases involved in the reduction of the iron oxides. The slowest process or processes in the series will decide the overall rate. The actions that could be taken in succession are:

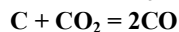
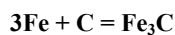
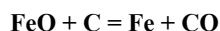
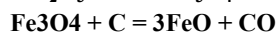
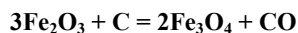
- Gaseous reductant transport via a boundary gas film from the bulk gas phase to the particle surface.
- Gaseous reductant molecular diffusion to the reaction interface via the product layer
- Gaseous reductant adsorption at the contact
- reaction at the interface (between the lattice's oxygen and the adsorbed reductant)
- The gaseous products' desorption from the interface
- Iron and oxygen ion mass transit, solid phase changes, and the development and expansion of reaction products, such as magnetite, wustite, and iron
- Gaseous products diffuse molecularly to the particle surface via the product layer.
- movement of the gaseous products into the bulk gas phase from the particle surface via the boundary gas film. Chemical control (steps iii to vi) and diffusion control (steps I & viii; ii; vi & vii) are the rate-limiting scenarios.

### Reduction Reactions:-

Indirect Reduction:-



Direct Reduction:-



## II. EXPERIMENTAL DETAILS

### EXPERIMENTAL PROCEDURE

- Mohanty, M. G. Charcoal and iron ore were extracted.
- Charcoal and iron ore underwent chemical examination.
- The ore is ground to a size of -100#.
- Charcoal is crushed to a size of -72#.
- Pellets are made by hand rolling a variety of binder kinds and amounts (0.5 to 2%) with water.
- Pellets are air-dried, then oven-dried at 110 °C to eliminate moisture.
- Firing was carried out in a muffle furnace at 1300°C in order to get the right strength in the pellet through heat hardening, which is achieved by recrystallization or gangue particles fusing to create slag phase.
- The resulting pellet is placed inside a metal crucible. Charcoal is then placed around the pellet, and it is subsequently decreased.
- In the first instance, every crucible holding iron ore pellets was put in a furnace, and reduction was done using charcoal at temperatures ranging from 900 to 1100°C.
- In the second case, six crucibles containing pellets of varying binder percentages (.5%, 1%, and 2%), were removed and reduction was performed at 950°C. The pellets were removed at intervals of 10, 20, 30, 40, 50, and 60 minutes.
- Following that, the iron oxide pellet's initial and final weights are measured, and the % reduction is computed. Plotting of the weight loss between percentage reduction and time was done in both cases. Next, a plot of a straight line between  $1 - (1-R)^{1/3}$  was plotted against time. The graph's slope provides the rate constant, or K.
- Graphs for  $\ln(K)$  vs.  $1/T \times 10^4$  were then created. The graph's slope indicates the activation energy, which was determined using the Arrhenius Equation:  $K = Ae^{-E/RT}$ .

Percentage reduction can be calculated as

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

**OBSERVATIONS:**

Table No-2.1: Charcoal Proximate Analysis Results

%Moisture	8.65%
%Volatile Matter	9.32%
%Fixed Carbon	73.66%
%Ash	8.35%

Table No-2.2 :Iron ore Chemical Analysis Results

Fe	63.69%
MnO	0.08%
SiO <sub>2</sub>	1.5%
Al <sub>2</sub> O <sub>3</sub>	1.3%

**GRAPHICAL ANALYSIS:-**

A graph of reduction versus time was plotted as part of the graphical study, and the impact of various binders on reduction time will be examined. Pellets become less reducible as the amount of binder increases. This is because the porosity has decreased.

Table No-2.3: Percentage Reduction versus time for Pellet with Dextrine

Time( in minutes)	0.5%Dextrine (in %)	1%Dextrine (in%)	2%Dextrine (in%)
10	27.3	19.2	16.7
20	46.8	39.7	32.5
30	65.1	58.2	53.4
40	84.5	77.2	69.8
50	92.6	85.9	79.8
60	93.0	87.1	80.7

Figure No 2.1- Percentage Reduction versus time for Pellet with Dextrine

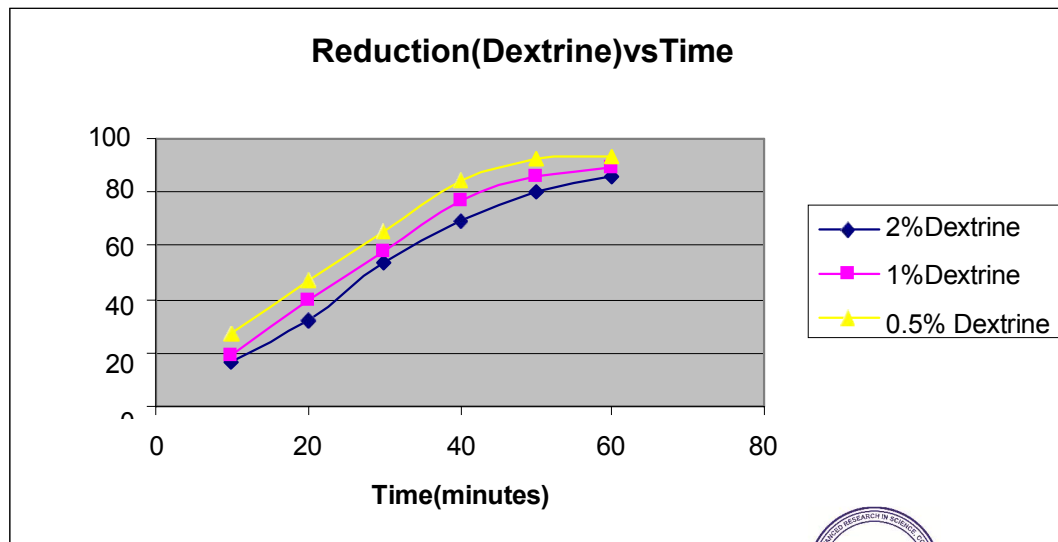
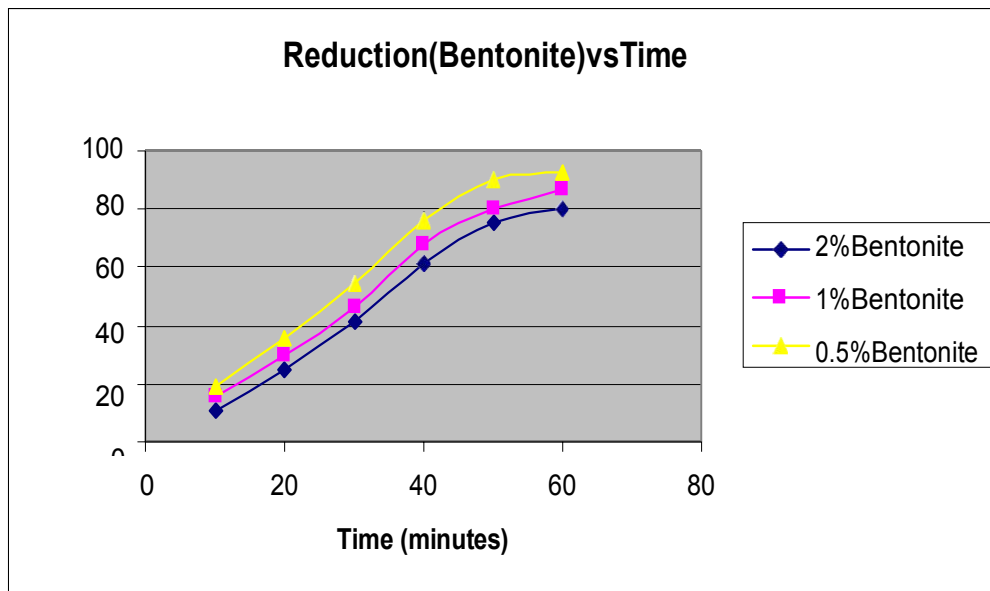


Table No-2.4: Percentage Reduction versus time for Pellet with Bentonite

Time(in minutes)	0.5%Bentonite (in%)	1% Bentonite (in%)	2% Bentonite (in%)
10	18.6	15.3	10.9
20	35.4	29.6	25.1
30	54.2	46	41.2
40	76	67.5	61.3
50	89.7	80.4	75.6
60	92.8	86.8	80.2

Figure No 2.2: Percentage Reduction versus time for Pellet with Bentonite



**1-(1-R) 1/3 versus Time (minutes):-**

Several models were examined, however the model  $1-(1-R)^{1/3} = KT$  provides a straight line that precisely matches our experimental findings, allowing us to calculate the value of K.

Table No 2.5:  $1-(1-R)^{1/3}$  versus Time for Pellets with Dextrine

Time (in minutes)	0.5%dextrine	1%dextrine	2%dextrine
10	0.1008	0.0686	0.0591
20	0.1897	0.1552	0.1228
30	0.2959	0.2523	0.2247
40	0.4628	0.3891	0.3291
50	0.5802	0.4795	0.4133

**Mechanism:-**

Three mechanisms underlie the reduction of iron ore (lump and pellets):

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

The activation energy

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

can be computed using the Arrhenius equation.

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,

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

Table No 2.6 :  $\ln K$  vs  $1/T \times 10^4$  for 0.5 % Bentonite

Temperature(°C)	Temperature(K)	$1/T \times 10^4$	K	$\ln K$
900	1172	8.52	0.00359	-5.62
950	1222	8.17	0.00362	-5.34
1000	1001	7.85	0.00364	-5.04
1050	1322	7.558	0.0062	-5.09
1100	1372	7.282	0.0075	-4.89

Table No 2.7 :  $\ln K$  vs  $1/T \times 10^4$  for 0.5% Dextrine

Temperature(°C)	Temperature(K)	$1/T \times 10^4$	K	$\ln K$
900	1172	8.524	.0077	-4.87
950	1222	8.176	.0099	-4.62
1000	1272	7.854	.0128	-4.36
1050	1322	7.558	.0164	-4.11
1100	1372	7.282	.020	-3.89

### III. RESULTS AND CONCLUSION

The percentage reduction for a pellet increases as the temperature rises over time.

There was a greater percentage decrease in the pellet containing dextrin. This might be as a result of the pellets' decreased activation energy when dextrin is used as a binder.

Several models were examined, and the model  $1-(1-R)^{1/3} = kT$  best matched our experimental values.

For 0.5% dextrin and 0.5% bentonite, the activation energy E was 17.423 kcal/°C/mole and 20.701 kcal/°C/mole, respectively. This graph's slope is equal to activation energy (E) x (universal gas constant).

As a result, the rate of reaction for pellets containing Dextrin is higher than the rate for pellets containing Bentonite.

### CONCLUSION

1. The percentage of pellets reduced rises as the temperature rises.
2. As time passes, the percentage of pellets reduced rises.
3. The more reducible the pellets are (.5% > 1% > 2%), the lower the binder %.
4. Compared to Bentonite, Dextrine binder reduces pellets more quickly.
5. The kinetics of iron ore reduction follow the nature of topochemical reactions.
6. The temperature affects the reduction reaction.

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