Study on Reducing Briquetting El-Baharia Iron Ore by Hydrogen+Nitrogen Gas

N. A. El-Hussiny[1], Hala. H. Abd El-Gawad[2], F. M. Mohamed[1, 3], M. E. H. Shalabi[1*]
[1]Centeral Metallurgical Research and Development Institute, (CMRDI), Cairo, Egypt
[2]Faculty of Science and Arts Mohail Asser King Khalid University, Saudi Arabia
[3]King Khalid University, Faculty of Science and Arts for Girls, Sarat Abida, Saudi Arabia
Email address: mehshalabi@hotmail.com

***Abstract*—*Reduction of El-Baharia iron briquettes was carried out in the temperature range 700 to 950^{o}C. In reduction kinetic study the most satisfactory model was to take the slope of the initial linear region of fractional reduction vs. time curve as a measure of rate constant (k). In k vs. 1/T plots were straight line from which activation energy was calculated.*

***Keywords*—*BriquettingEl-Baharia Iron Ore, Hydrogen, Nitrogen.*

I. Experimental Work

Iron is believed to be the tenth most abundant element in the universe, and the fourth most abundant in the earth's crust. Iron is the most used of all the metals, comprising 95% of all the metal tonnage produced worldwide. Iron is extracted from its ore, and is almost never found in the free elemental state. In order to obtain elemental iron, the impurities must be removed by chemical reduction [1, 2].

The Egyptian iron ores of El-Baharia Oasis is the main feedstock for the blast furnace of Egyptian iron and steel Co.

Hydrogen is best reductant and/or fuel from the environmental and reduction kinetics points of view, but it is currently expensive.

The reduction of iron ores by hydrogen is a gas-solid reaction which occurs in two or three stages. At temperatures higher 570°C, hematite is transformed into magnetite, then into wustite, and finally into metallic iron while at temperatures below 570°C, magnetite is directly transformed into iron since wustite is not thermodynamically stable (Bogdandy and Zngle 1971).

Ezz and Wild [3] indicated that an increase in temperature exerts a major influence on increasing reduction rate, while ore characteristics, such as porosity, shape factor, and surface condition also affected reduction rate also the ore/gas ratio has a major influence on the reduction rate

The reduction of iron ores by hydrogen is a gas-solid reaction which occurs in two or three stages. At temperatures higher 570°C, hematite is transformed into magnetite, then into wustite, and finally into metallic iron while at temperatures below 570°C, magnetite is directly transformed into iron since wustite is not thermodynamically stable (4).

Damien et al. [5] concluded that the reduction of iron ores by hydrogen is a gas-solid reaction which occurs in two or three stages. For temperatures higher than 570°C, hematite (Fe_2O_3) is first transformed into magnetite (Fe_3O_4), then into wustite (Fe_{1-y} O), and finally into metallic iron whereas at temperatures below 570°C, magnetite is directly transformed into iron since wustite is not thermodynamically stable.

Asima and Itishree [6] indicated that the 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].

Moo Eob Choi [7] and Haitao Wang [8] indicated that the kinetics feasibility tests showed that 90 - 99% reduction of iron ore concentrate by hydrogen was obtained within 1 - 7 seconds at 1200 – 1400^{o}C, depending on the amount of excess hydrogen supplied with iron oxide. This reduction rate is fast enough for a flash reduction process. The activation energy of hydrogen reduction of iron ore concentrate was determined to be 463kJ/mol, which demonstrates that this process has greater temperature effect on the reduction rate than most reactions. Also it was found that using pure hydrogen as reducing agent gave a higher extent of reduction than a mixture of CO-H2. Sulphur and phosphorus are partially removed in gaseous from the ore; within the temperature range examined, sulphur removal increased with increase in temperature, whereas phosphorus removal was favor at lower temperature [8].

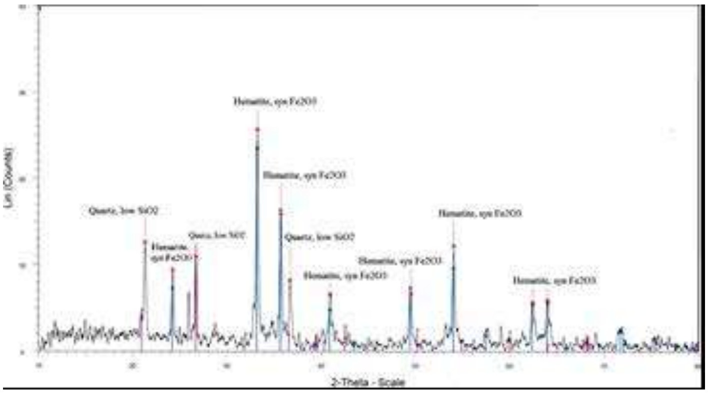
El-Husseiny et al. [9] indicated that: - 1- The reduction of El-Baharia iron ore briquette by hydrogen depends on the flow rate of hydrogen and temperature of the reduction pressure of the briquetting. 2- As the temperature increased the reduction increased. 3- As the flow rate of hydrogen increased the reduction rate increased 4- The reduction of the iron ore briquette is controlled by one of the following models:-a- Diffusion through thin ash layer (Jander equation) b- Diffusion controlled c- Diffusion through ash layer (crank-cinslling-Broushten equation.

The aim of this work is study the reduction of The El-Baharia Egypt iron ore briquette by hydrogen + nitrogen.

II. Experimental Work

2.1 Raw Materials

Iron ore sample was obtained from the Egyptian Iron and Steel Company, The phase identification illustrated in figures 1 was performed using Philips type 1373 x-ray diffractometer; it is clear that El-Baharia iron ore is rich in hematite and quartz. [10]



2.2. Preparation of the Briquetting and Its Physical Properties

El-Bahaeia iron ore were grinding in vibrating mill to powder with size less than 75 micrometers. The fine of iron ore powder (10g) are mixed with 2.5% molasses and then pressed in the mould (12mm diameter and height 22mm using MEGA.KSC-10 hydraulic press) Fig. 1. under different pressure (the pressure range from 75 MPa up to 275 MPa).

Fig. 1. MEGA.KSC-10 hydraulic press

The briquette subjected to drop number test and crushing strength tests. The drop number indicates how often green briquette can be dropped from a height 46 cm before they show perceptible cracks or crumble. Ten green briquettes are individually dropped on to a steel plate. The number of drops is determined for each briquette. The arithmetical average values of the crumbing behavior of the ten briquettes yield the drop number .The average crushing strength is done by compressed 10 briquettes between parallel steel plates up to their breaking [11].

2.3. Reduction Procedures

The reduction of El-Baharia brequttte by hydrogen and nitrogen were done on thermo gravimetric apparatus (A schematic diagram of thermo gravimetric apparatus is shown in Fig 2. Which consisted of a vertical furnace, electronic balance for monitoring the weight change of reacting sample and temperature controller. The sample was placed in a Ni-Cr basket which was suspended under the electronic balance by Ni-Cr wire. The furnace temperature was raised to the required temperature (700-950 ^{o}C) and maintained constant to ± 5 ºC. Then samples were placed in hot zone. The nitrogen flow rate was 0.5 l/min on all the experiments. At initial time and after the end of reduction only the weight of the sample was continuously recorded at the end of the run, the samples were withdrawn from the furnace and putted in the desiccators. The amount of removable oxygen was determined by the weight loss in the sample (Wo-W) during the experiment of reduction with H_2 in the furnace. The percentage of reduction was calculated according to the following equations [10]:-

Percentage of reduction = [(Wo-Wt) / Wo] *100

Where Wo the initial mass of sample.

Wt mass of sample after each time, t.

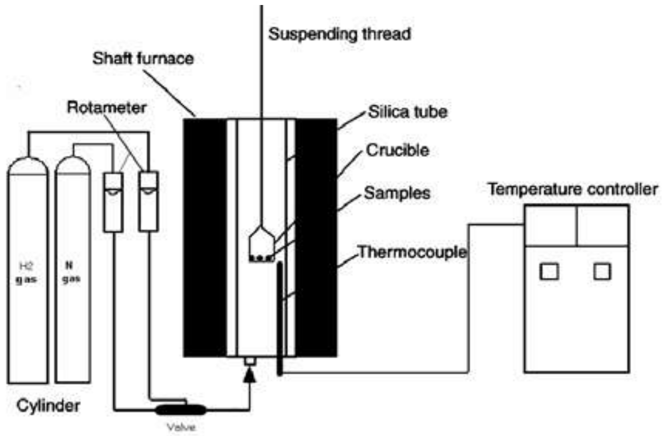


Fig. 2. Schematic diagram of the apparatus

III. Results and Discussion

3.1. Effect of Pressing Load on the Quality of the Produced Briquettes

The drop damage resistance and compressive strength of the produced briquettes with respect to different pressing load and at constant amount of molasses (2%) are shown in Figures 3-6. From these figures, it was found that as the pressing load increased from 87 to 241 MPa. The drop damage resistance and the compressive strength for both green and dried briquettes (drying time 3 days) increased and reached to its maximum values at 241 MPa. This could be attributed to the fact that increasing pressing load leads to increase the number of contact points between particles and subsequently the Vander Waals force increased [12-14].

3.2 Effect of Change Amount of Nitrogen Gas Added to Hydrogen

Fig. 7 illustrate the effect of change the amount of nitrogen added to hydrogen on the reduction of iron ore. From which it is clear that as the amount of nitrogen increase the reduction decreased.

3.3 Effect of Temperature Change on the Reduction Percentage

In order to examine the effect of temperature on the reduction of El-Baharia iron ore briquette by one L/min

N. A. El-Hussiny, Hala. H. Abd El-Gawad, F. M. Mohamed, and M. E. H. Shalabi, "Study on Reducing Briquetting El-Baharia Iron Ore by Hydrogen+Nitrogen Gas," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 1, Issue 3, pp. 12-15, 2018.

hydrogen and one L /min nitrogen flow rate, experiments were carried out at 700 – 1000^{o}C. Plots of the reduction percentage as function of time are shown in Fig. 8. From this figure it is observed that the reduction temperature influences significantly the reduction percentage.

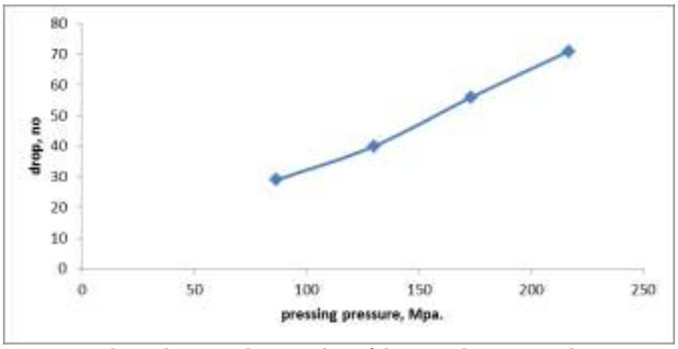


Fig. 3. Relation between drop number of the green briquette and pressing load.

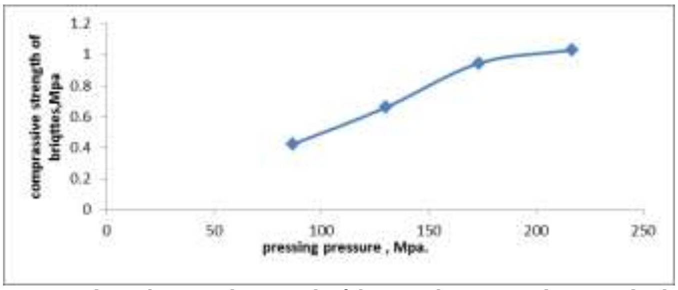


Fig. 4. Relation between the strength of the green briquette and pressing load

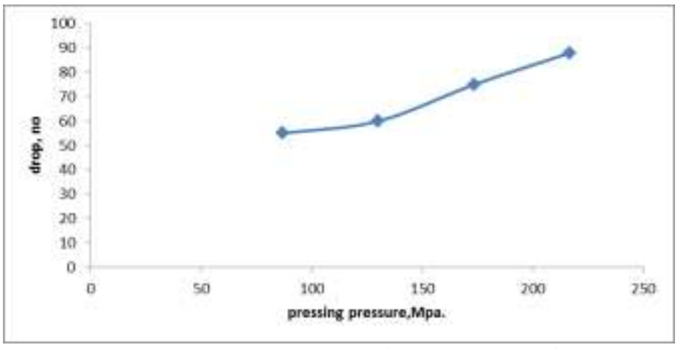


Fig. 5. Relation between the drop number of the dry briquette after 3 day and pressing load

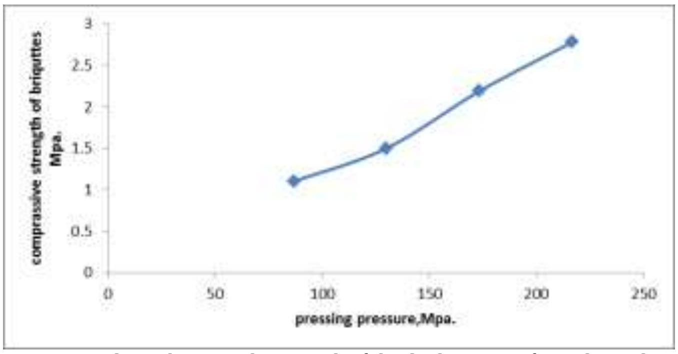


Fig. 6. Relation between the strength of the dry briquette after 3 day and pressing load

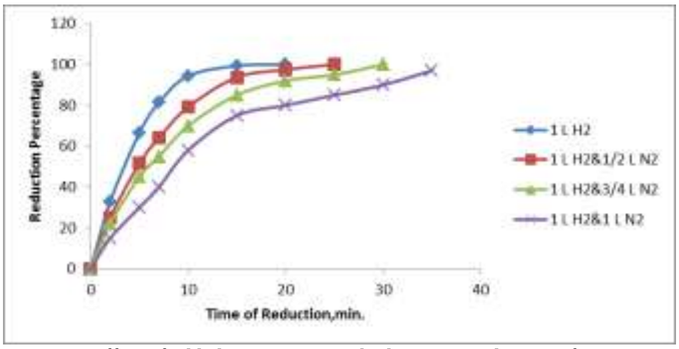


Fig. 7. Effect of added nitrogen gas to hydrogen on reduction of iron ore

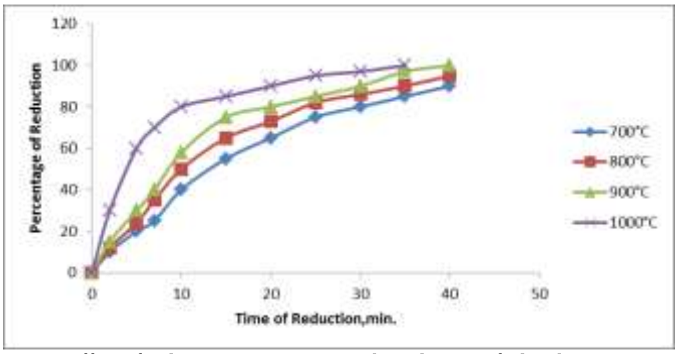


Fig. 9. Effect of reduction temperature on the reduction of El-Baharia iron ore briquette (one liter hydrogen and one liter nitrogen

3.4. Kinetics Reduction of Briquette

Kinetic studies for estimation the apparent activation energies were carried out for the briquettes at different temperatures range from 700˚C up to 950˚C for different time intervals in the range of 0 - 60 min.

Using equation (R+(1-R)ln(1-R)

Where R is fractional reduction, t is time of reduction, k is the rate constant.

Fig. 10 illustrate the relation between (R+(1-R)ln(1-R)against time of reduction for different reduction temperature. From which it is clear that the straight line was observed.

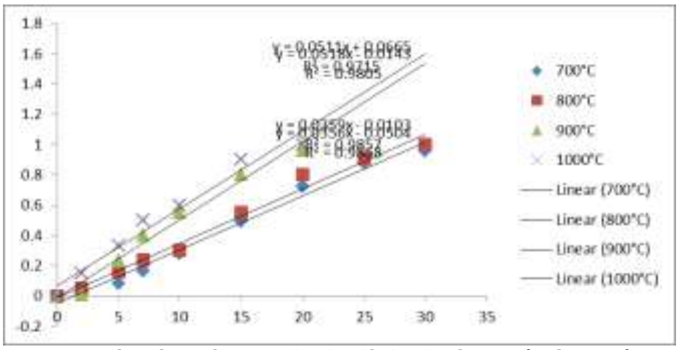


Fig. 10. The relation between (R+(1-R)ln(1-R)and time of reduction for different reduction temperature.

3.5 Calculation of the Reaction Activation Energy

The natural logarithmic values of these reaction rate constants (k) were plotted against the reciprocal of the absolute reduction temperatures (T) according to Arrhenius equation as shown in Figure 11. The activation energy of the

N. A. El-Hussiny, Hala. H. Abd El-Gawad, F. M. Mohamed, and M. E. H. Shalabi, “Study on Reducing Briquetting El-Baharia Iron Ore by Hydrogen+Nitrogen Gas,” *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 1, Issue 3, pp. 12-15, 2018.

reaction is calculated from the slope of the straight line and found to be 8.27 kJ. $mol.^{-1}$ (1.98 kCal/mol.).

The results of activation energy indicated that, the reaction which carried between one liter hydrogen gas +one liter nitrogen gas and it is diffusion controlled

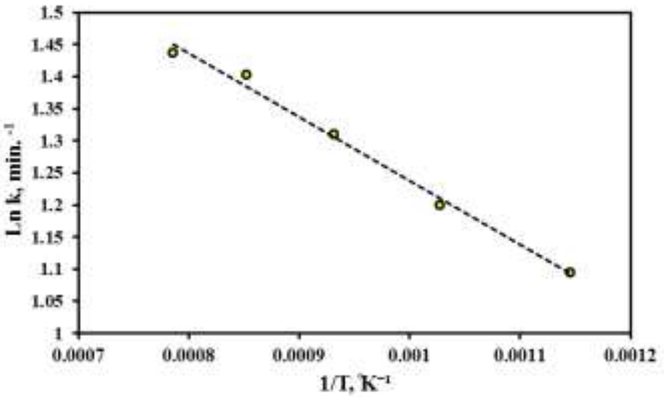


Fig. 11. The relation between the reciprocal of absolute temperature 1/*T* and ln*K*

IV. Conclusions

1) The compressive strength and the drop damage resistances of briquettes increased with increasing the pressing pressure up to 241 MPa. at 2% molasses.
2) The reduction rates increased with increasing temperature of the reduction from 700 up to 1000°C.
3) The reduction rate decreased with increased nitrogen added to hydrogen flow at constant temperature.
5) The diffusion processes through the produced briquettes is the reduction control step and the briquettes have activation energy = 8.27 kJ/ mole.

References

[1] Sandeep Kumar Baliarsingh and Barun Mishra, "Kinetics of iron ore reduction by coal and charcoal," A thesis submitted inpartial fulfill-ment of the requirements for the degree of Bachelor of technology in metallurgical and materials engineering, department of metallurgical and materials engineering. National Institute of Technology, 769008, 2008
[2] Nagwa Mohamed Hashem, Bahaa Ahmed Salah, Naglaa Ah-med El-hussiny, Said Anwar Sayed, Mohamed GamalKhalifa, and Mohamed El-Menshawi Hussein Shalabi, "Reduction kinetics of Egyptian iron ore by non coking coal," *International Journal of Scientific & Engineering Research*, vol. 6, issue 3, pp. 846-852, 2015.
[3] S. Y. M. Ezz and R. Wild, "The gaseous reduction of fine iron ores," *Journal of Iron and Steel Institute*, vol. 194, pp. 211-21, 1960.
[4] L. F. Bogdandy and G. Y. Zngle, *Production of Iron Ores*, Metalluriga Moscow, 1971.
[5] D. Wagner, O. Devisme, F. Patisson, and D. Ablitzer, "A Laboratory study of the reduction of iron oxides by hydrogen," *Sohn International Symposium*, San Diego, Proceedings edited by F. Kongoli and R.G. Reddy, TMS, vol. 2, pp. 111-120, 27-31 Aug. 2006.
[6] A. Priyadarsini and I. Mishra, "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, Department of Metallu Department of Metallurgical and Materials Engineer in National Institute of Technology, Rourkela, 2007.
[7] M. E. Choi, "Suspension hydrogen reduction of iron ore concentrate," in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Department of Metallurgical Engineering ,The University of Utah August 2010 The University of Utah August 2010.
[8] Haitao Wang, "Reduction kinetics of iron ore concentrate particles relevant to Novel green iron making process," in partial fulfillment of the requirements for the degree of Doctor of Philosophy , Depart-ment of Metallurgical Engineering, The University of Utah , August 2011
[9] N. A. El-Husseiny, A. El-Amir, F. M. Mohamed, S. Th. Abdel-Rahim, and M. E. H. Shalabi, "Kinetics of direct reduction of El-Baharia Iron ore (El-Gedida) Oasis Egypt, briquette via Hydrogen," *International Journal of Scientific & Engineering Research*, vol. 6, issue 7, pp. 1018-1027, July-2015.
[10] N. M. Hashem, B. A. Salah, N. A. El-Hussiny, S. A. Sayed, M. G. Khalifa, and M. El-Menshawi Hussein Shalabi, "Reduction kinetics of egyptian iron ore by non coking coal," *International Journal of Scientific & Engineering Research*, vol. 6, issue 3, pp. 846-852, March-2015.
[11] K. Mayer, *Pelletization of Iron Ores*, Springer-Verlag Berlin Heidelberg, 1980.
[12] W. K. Lu and D. F. Huang, "Mechanisms of reduction of iron ore/ coal agglomerates," *Mineral Processing and Extractive Metallurgy*, vol. 24, issue 3-4, pp. 293–324, 2003.
[13] J. Sterneland, M. A. Andersson, and P. G. Jöussn, "Comparison of iron ore reduction in experimental blast furnace and laboratory scale simulation of blast furnace process," *Journal Iron Making and Steelmaking*, vol. 30, issue 4, pp. 313–327, 2003.
[14] S. J. Mangena and V. M. du Cann, "Binderless briquetting of some selected South African prime coking, blend coking and weathered bituminous coals and the effect of coal properties on binderless briquetting," *International Journal of Coal Geology*, vol. 71, issue 2-3, pp. 303–312, 2007.