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Hematite Ore Reduction at Particle Scale

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Abstract

It is well established that pure hematite (Fe_2O_3) decomposes to magnetite (Fe_3O_4) in the air (N_2:O_2 = 80:20) at a temperature of 1386°C. In order to find out the thermal stability of hematite ore, thermo-gravimetric analysis (TGA) experiments were conducted in the air. Interestingly the decomposition temperature was found to be 1150°C, 200°C lower than that for the pure Fe_2O_3. The decomposed samples were analyzed using XRD and peaks corresponding to Fe_3O_4, and SiO_2 were found. The decomposed sample was again oxidized at 750°C in the air to obtain the Fe_2O_3 phase back. Interestingly when this oxidized sample was thermally treated again at a high temperature in presence of air, no decomposition was observed till 1350°C.

1. INTRODUCTION

The grades of the iron ore deposits have been deteriorating with time. With the increase in environmental concerns as well as stringent environmental protection laws, fines should be utilized and recycled carefully. Fines are generated mostly from iron ore mining and beneficiation processes, byproducts of iron and steel industries[1]. The fines can be utilized in two ways. One is the recently developed processes (FINEX, HIsarna, etc.) where fines can directly be charged into the reactor[2]. Alternatively, the use of agglomeration techniques where the fines adhere to each other to form bigger-size particles. Out of all the agglomeration techniques, pelletization is the most widely used as of now. Pellet quality depends on the type and nature of raw material used as well as the subsequent thermal treatment given to the pellet. So, the pellet property is a function of bonding phases and their stability during hot metal (iron) production. In order to ascertain the efficient and smooth working of any iron-making process, it is important to have knowledge about the thermal behavior of iron ore[3].

Iron mainly exists in three forms of oxides: hematite, magnetite and wustite. Hematite is the primary source of raw material for iron production in India. While a plethora of literature is available to understand the reduction of hematite ore, only a handful of studies have been done on the thermal decomposition of hematite ore. Few researchers have done the study to find out the decomposition temperature of hematite ore in an inert atmosphere using TGA [2], [4], [5]. A dissociation temperature of 1150°C has been reported for hematite ore in pure nitrogen[4]. Researcher has also tried to find the thermal decomposition of laboratory-grade hematite in the air and inert atmosphere as well. A dissociation temperature of around 1180°C is reported in the nitrogen atmosphere and 1360°C in the air[6].

Theoretical evaluation based upon the thermodynamics calculations of Eq. [1] infers that the hematite becomes less stable with the rise in temperature[2].

$$6Fe_2O_3(s) = 4Fe_3O_4(s) + O_2(g) \qquad \Delta G^\circ = 500600 - 280.7T \qquad [1]$$

Fig. 1 shows a phase diagram of Fe-O_2 at different partial pressure of O_2 for a temperature range of 600-1600°C calculated using FactSage. A dotted line drawn in the diagram for air i.e., a partial pressure of O_2 of 0.20, suggests a decomposition temperature of 1386°C for hematite to magnetite transformation. The weight loss for a complete transformation of hematite to magnetite is 3.34%, when calculated on a molar basis of iron. Reduction degree is the ratio of weight loss of oxygen to the initial weight of oxygen present in iron oxide phase. An equivalent reduction degree is 11.11% for a complete decomposition of hematite to magnetite[2].

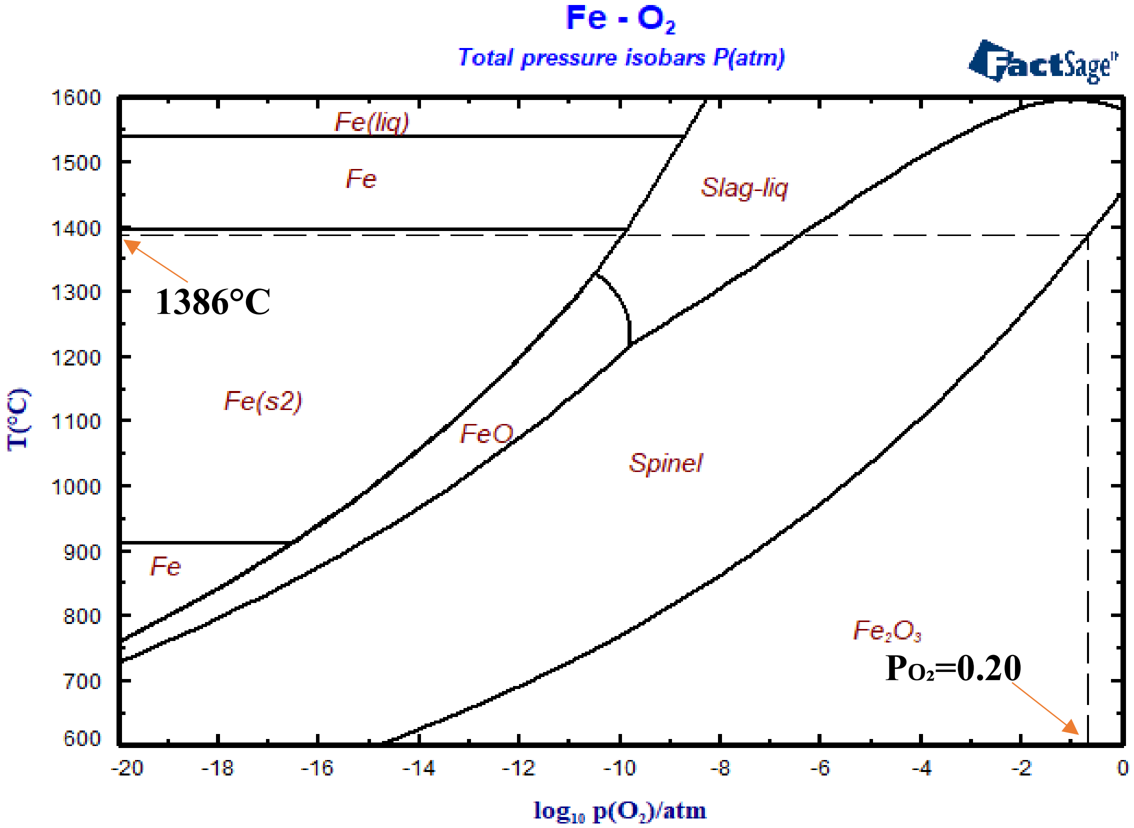

Figure 1. Fe-O_2 phase diagram calculated using FactSage.

2. Materials and methods

Industrial grade hematite ore was procured from Hospet, Karnataka. XRF and wet chemical analysis were performed to determine the composition are shown in Table I and Table II respectively.

Table I. Chemical composition of hematite ore particles in the form of oxides by XRF.

Fe(T)	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	MnO	TiO_2	MgO	P_2O_5	LOI
63.52	4.40	2.30	0.14	0.05	0.01	0.07	0.10	0.15	0.02	1.32

Table II. Chemical composition of hematite ore particles using wet chemical analysis.

Fe(T)	SiO_2	Al_2O_3	CaO	FeO	Fe_2O_3	P_2O_5	Fe_3O_4	TiO_2, K_2O, Na_2O etc.	LOI
63.11	4.56	2.17	0.11	0.98	86.96	0.04	3.16	traces	1.26

Specific gravity of the hematite ore sample was 4.58 when performed using pycnometer glass bottle at room temperature using deionized water as a medium. The specific surface area of the sample was approximately 3000 cm^2/g when performed using Blaine's air permeability apparatus in which the portland cement was used as a standard. A Netzsch STA 449 F1 instrument with a sensitivity of ± 1µg was used to analyzed the thermal decomposition of hematite ore particle in air at a constant flow rate of 60 ml/min. The ore particle was heated 7°C/min to 1150°C and 3°C/min to 1350°C in first thermal cycle. The decomposed sample was heated again 10°C/min to 750°C and held it at this temperature for 45 minutes. Same sample was again studied for thermal decomposition as mentioned in the first cycle. XRD analysis was used for phase identification of hematite ore particle as well as decomposed ore particle after first thermal cycle only.

3. Results and Discussion

The TGA curve of the first thermal cycle for decomposition is plotted as Fig. 2. The decomposition of ore particle was completed in two stages. In the stage one that starts at 390°C, sharp weight loss of approximately 0.5% was observed. This weight loss is due to kaolinite ($Al_2O_3 \cdot 2\, SiO_2 \cdot 2H_2O$) present in the sample[7]. In the stage two that starts at 1150°C, sharp weight loss of approximately 3.3% was observed. This weight loss suggests complete transformation of hematite to magnetite. A similar observation has been made but in inert atmosphere of N_2 which compliments the Fe-O_2 phase diagram shown in Fig. 1 [2] During cooling in air, a weight gain of approximately 0.25% is observed. XRD analysis of the ore particle as well as decomposed ore particle is shown in Figs 3(a) & 3(b) respectively. XRD result of ore particle suggests hematite phase as principal phase. Other phases are very less in amount which cannot be detected using XRD. XRD result of decomposed ore particle at 1350°C suggest magnetite as main phase along with silica.

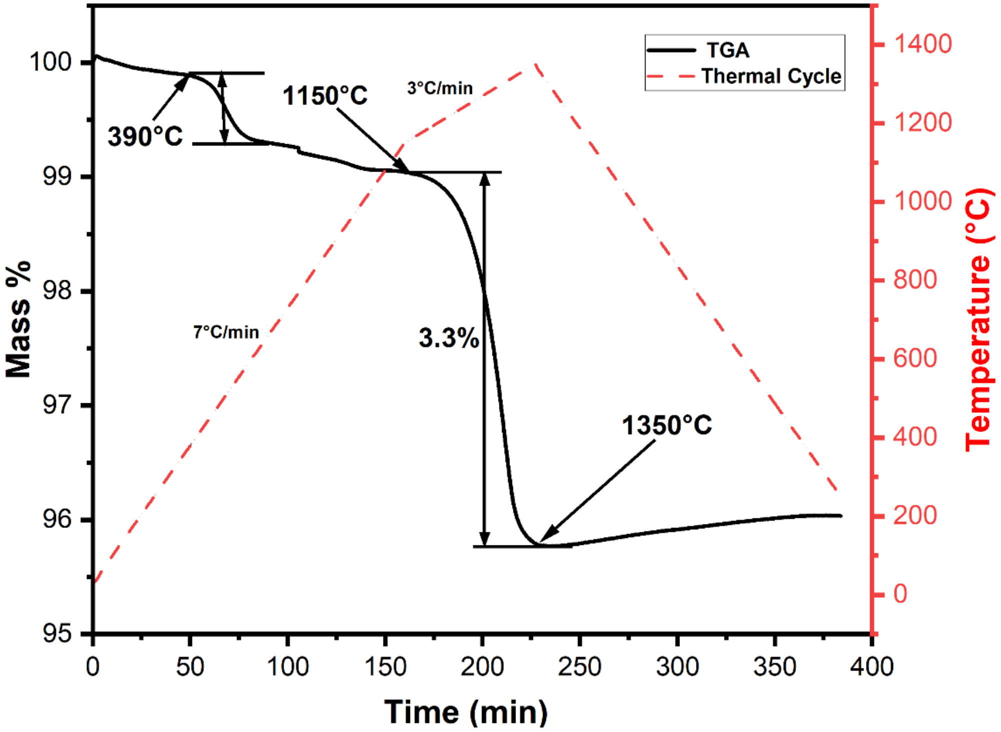

Figure 2. TGA of ore particle till 1350°C.

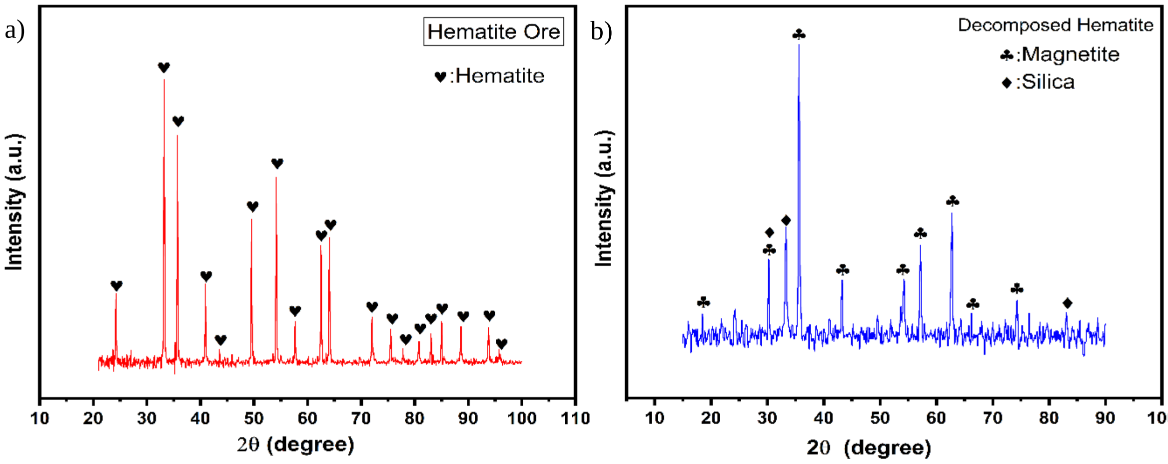

Figure 3. XRD pattern of a) Ore particle b) decomposed sample at 1350°C.

The decomposed ore particle containing magnetite as the main phase was again oxidised in TGA at 750°C to get hematite phase back. A weight gain of 2.36% is observed. The weight gain for a complete oxidation of magnetite to hematite is 3.45%. Not all the magnetite has transformed to hematite during oxidation at 750°C even after 45 minutes of holding time. This partially oxidised hematite phase containing ore particle was again studied for decomposition till 1350°C and no weight loss has been observed. On the other hand, a weight gain of 0.85% is observed. The TGA results of the oxidation and second cycle of decomposition is shown in Figs 4(a) & 4(b) respectively. The sum of all the weight gains (0.25% + 2.36% + 0.85%) is 3.46% which suggest a complete oxidation of magnetite phase formed during first cycle of decomposition to hematite.

The thermal decomposition of hematite in air at 1150°C is a deviation from the already established literature. Literature suggests the early decomposition can only happen because of the presence of MgO in the system [8], [9]. But this is quite unlikely in this case, as the amount of MgO is quite low. We are yet to ascertain any other reason or mechanism of decomposition at 1150°C.

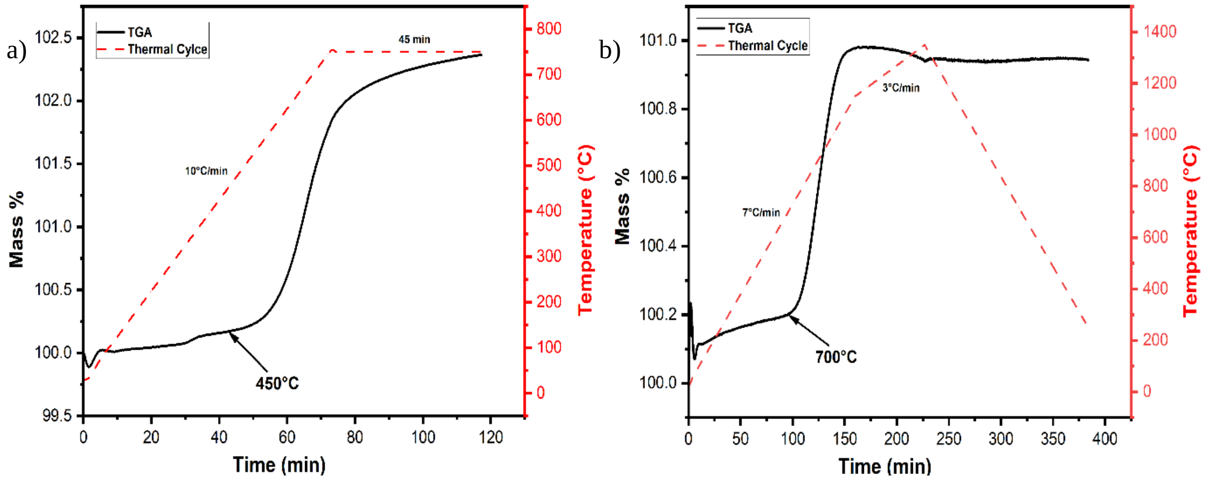

Figure 4. TGA results of ore particle a) Oxidation at 750°C b) second cycle of decomposition at1350°C.

4. Acknowledgment

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