Plasma Reduction Process to Minimise Bauxite Residue

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Abstract

Bauxite of Indian origin typically contains 40 – 50 % Al_2O_3, 20 – 28 % Fe_2O_3, 3 – 10 % TiO_2, 4 –10 % SiO_2, 20 –30% LOI and other associated oxides in minor quantities. Due to the higher percentage of Fe_2O_3 in bauxite, generation of Bauxite Residue (or Red Mud), which is costly and problematic to manage, is substantially increased for these bauxites in the Bayer process. In view of this, the recovery of the iron content in bauxite by Plasma Reduction prior to the Bayer process is an interesting option. In this study, laboratory scale simulations have been made to reduce the Fe_2O_3 content in bauxite using the Plasma Reduction process where metallic iron is recovered. The iron produced by this process contains around 85.5% Fe with 85% recovery. The slag rich in alumina and residual iron in the form of FeO can be fed to the Bayer process for the production of alumina.

Key words: Plasma smelting reduction; Arc Plasma smelting reactor; iron from bauxite; Alumina.

1. Introduction

The conventional process for alumina production employing the well-established Bayer Process generates large quantities of Bauxite Residue (or Red Mud) the storage of which is a concern to the alumina industry and the communities in which they operate. So far, outside of some niche applications, no commercial technology has been developed for bulk utilisation of Residue. Utilisation of Bauxite Residue (Red Mud) has been generally limited to either laboratory or pilot scale simulations. However, significant research effort globally is being applied to address this challenge through the application of novel technologies. One such unique and state-of–the-art process is the plasma reduction process which envisages the reduction of iron oxide present in bauxite prior to being fed to the Bayer Process for the extraction of alumina. [1-5]

Bauxite of Indian origin typically contains 40 – 50 % Al_2O_3, 20 – 28 % Fe_2O_3, 3 – 10 % TiO_2, 4 –10 % SiO_2, 20 –30% LOI and other associated oxides in minor quantities. For the production of one tone of alumina, 1 to 2 tonnes of residue is generated out of 2 to 3 tonnes of bauxite. It is now a clear research challenge to reduce to a minimum the percentage of iron oxides present in bauxite prior to bauxite being refined into alumina in the Bayer process. The present work is directed towards this result, and a suitable laboratory scale process has been developed. By employing this process, it has been possible to reduce the bauxite iron oxide content by 85%, and the metallic iron produced contains around 85% Fe. The alumina rich slag produced can be fed to the Bayer process for alumina production.

2. Raw Materials

A Bauxite of Indian origin was the principal raw material for the study. The mineralogical composition and chemical analysis of the bauxite are furnished in Figure 1 and Table 1 respectively. The other raw materials used for the study were aluminium metal (Commercial grade), Hydrogen gas (99.9%) and Argon gas. Figure 1 shows the mineralogical composition of bauxite indicating $Al(OH)_3$ and Fe_2O_3 as major phases as shown in the XRD peaks.

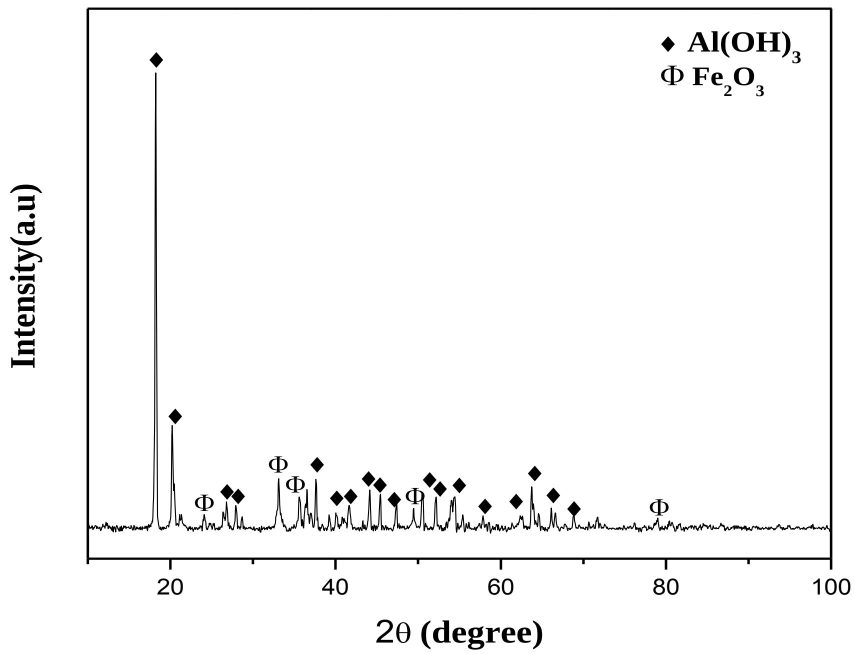

Figure 1. Mineralogical Composition of Bauxite of Indian Origin

Table 1: Typical Chemical Analysis of Indian Bauxite

Input Material	**Al_2O_3**	**Fe_2O_3**	**SiO_2**	**TiO_2**	**LOI**
Indian Bauxite (%)	47.74	13.60	9.81	1.0	27.56

3. Experimental

Smelting studies were carried out in a 35 kW dc extended transferred arc plasma reactor. The reactor is basically a pot type, with zircon coated graphite crucible as the furnace hearth, which is thermally insulated by bubble alumina. Graphite electrodes are arranged in a vertical configuration. The bottom electrode (anode) is kept stationary and the top one (cathode), with an axial hole for feeding the plasma forming Argon gas, is actuated by a rack and pinion mechanism for arc stabilization. The hearth is provided with a graphite spout to tap both metal and slag. A schematic of the reactor is given in Figure 2.

The flow of argon gas was regulated to 1.0 L/minute throughout the experiment. An average arc voltage of 50 V and 250 amperes current were maintained during the experiment. The temperature observed in the plasma reactor was 1400-1600 ^{0}C. Along with the Argon gas, Hydrogen gas was fed at the rate of 5 L/min acting as the reductant for the iron oxide present in bauxite.

Dry bauxite (1 mm size) along with aluminium metal was charged to the reactor. The amount of reductant was kept at 20%, the basicity was varied from 0.25 to 0.5 and the reduction time was varied from 25 to 35 minutes. The plasma power input was maintained at 15 kW throughout the study. It is observed from the experimental data that the maximum iron recovery obtained is 85% from 1 kg of dry bauxite under the following conditions; reductant: 20 %, basicity: 0.25, smelting time: 25 min, and Plasma Power input:15 kW. The aluminium metal used in the study acts as a co-reductant and facilitates the reduction process. The reduction process is also facilitated by the presence of carbon present on the electrode tips and helps to some extent to produce carbonaceous gases in the process. To nullify the effect of these carbonaceous gases, the aluminium metal is used as a co-reductant. It is well known that the alumino-thermic process is highly exothermic and more reactive than carbon. Therefore, in the reduction process, aluminium predominates over carbon and suppresses the production of carbonaceous gases.

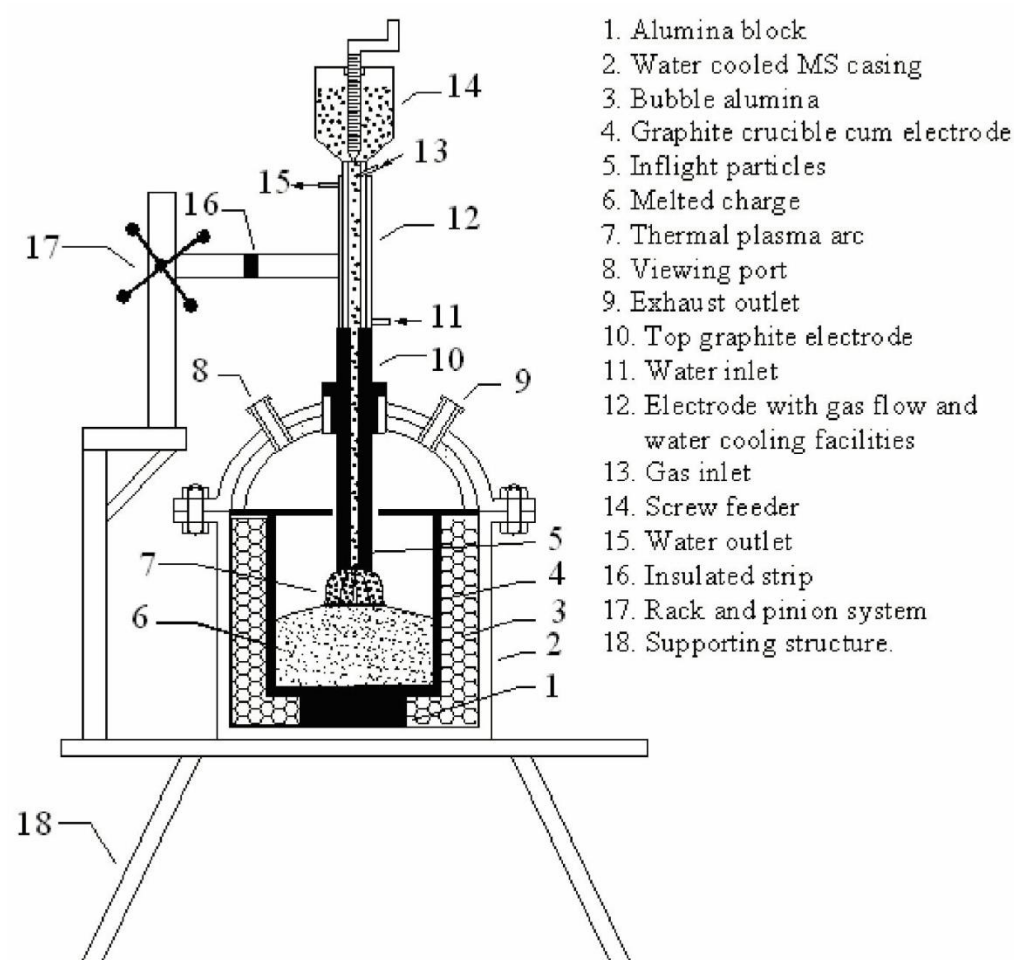

Figure 2. Schematic diagram of extended arc thermal plasma reactor. [6]

3.1 Experimental procedure

Initially bauxite, aluminium metal and dolomite / limestone / fluorspar (flux) powder of required composition were thoroughly mixed and charged inside the graphite crucible. Argon gas was used as plasma gas and was passed through the top electrode at a rate of 1 L/min. The arc was struck and the current of 250 amperes was maintained with an arc voltage of about 60 volts. The plasma arc was continued for 20 to 30 minutes to complete the chemical reaction. The temperature of the molten bath was measured by using a Minolta optical pyrometer. After the molten melt is obtained, the hydrogen gas is fed along with the argon at the rate of 5 L/min. At the end of the smelting, the tap hole was opened and the molten pig iron and slag were allowed to cast in graphite mould. The flow chart of the process is furnished in Figure 3.

FLOW CHART

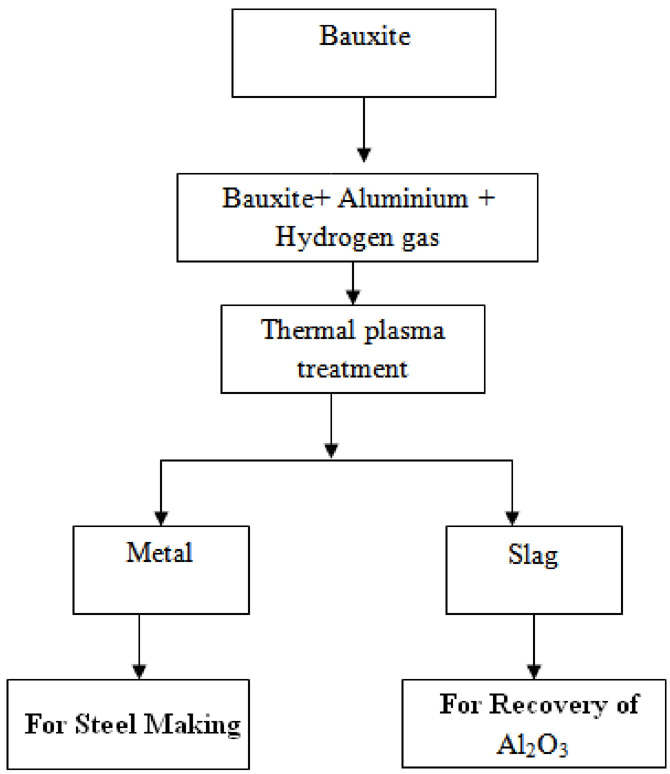

Figure 3. Process Flow Chart.

4. Results and Discussion

About 200 g of Indian Bauxite was taken for Hydrogen Plasma Smelting studies. The bauxite was crushed and ground to -100 mesh and mixed with 20 g of metallic aluminium powder. Then granules of 1 - 6 mm size were prepared by adding 10% water to the powder sample. Granules were dried in an Oven at 120 ^{o}C for 6 hrs. Then the dried granules were reduced by Hydrogen Plasma with a flow rate of 8 L / min of Hydrogen gas for a period of 25 min. After the experiment was over, the reduced samples were cooled and collected separately for metal and slag. The samples were then analyzed by XRD and for Chemical Composition. The chemical composition of metal and slag are given in Tables 2 and 3 respectively. The XRD results for both metal and slag are given in Figures 4 and 5 respectively.

The smelting reduction process takes place by Hydrogen plasma at a higher temperature of 1600°C in Hydrogen Plasma Smelting Reactor. The metallic aluminium powder used in the process acts as an initiator. It is observed that the rate of reaction is increased substantially by using metallic aluminium powder. It may be due to the metallic aluminium powder acting as a better reductant in association with Hydrogen Plasma and facilitates the reaction kinetics. In the process, iron oxide present in bauxite is reduced to metallic iron. At the higher temperature of 1600°C, both metal and slag gets separated.

Table 2. Chemical Composition of Metal.

Sample	Fe	Al	Si	Ti
Metal (%)	85.5	1.25	3.00	1.58

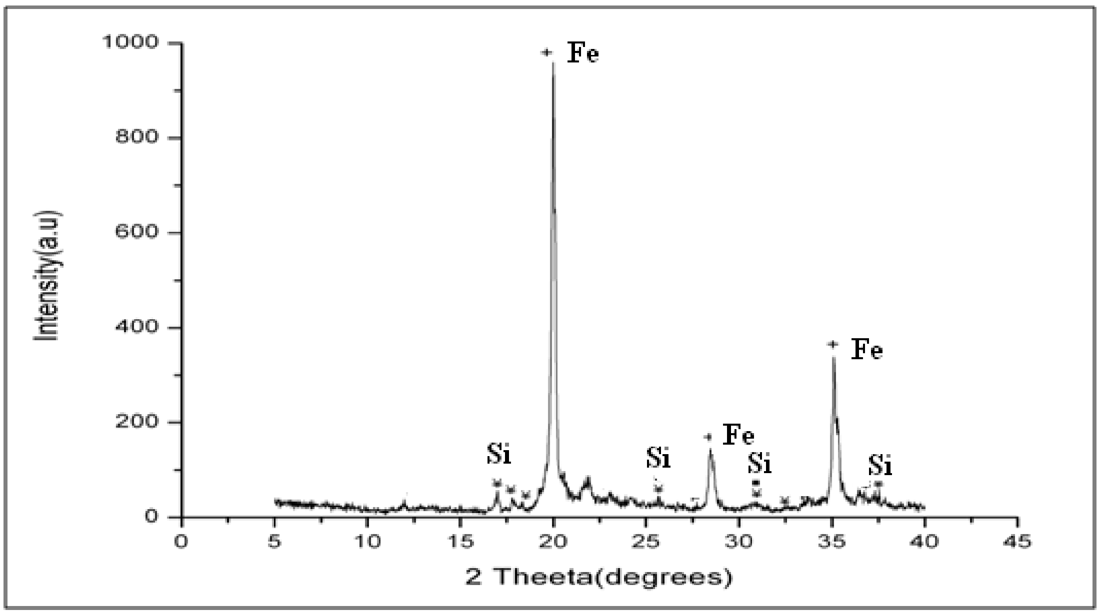

Figure 4. XRD Analysis of Metal.

Table 3. Chemical Composition of Slag.

Sample	Al_2O_3	FeO	CaO	SiO_2	TiO_2
Slag (%)	65.12	2.75	1.09	4.34	2.19

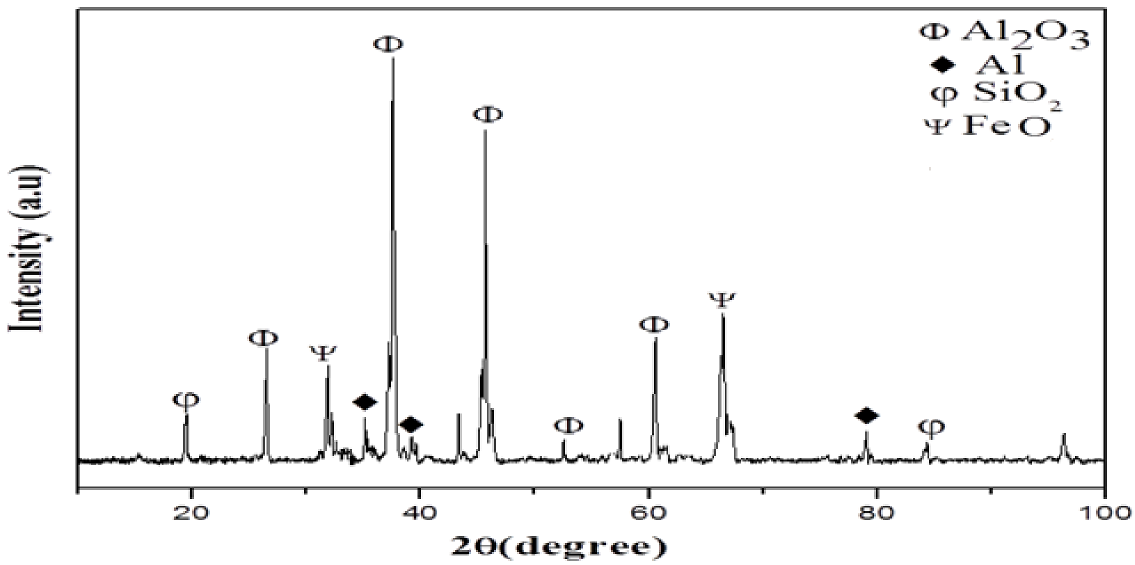

Figure 5. XRD Analysis of Slag.

From the above experimental findings it is observed that the iron produced by this process contains around 85.5% Fe with around 85% recovery.

5. Reaction Mechanism

There is no doubt that hydrogen can be used as a reducing gas in smelting reduction processes. A careful analysis of the literature shows that iron oxides can be reduced by hydrogen gas and in this context, a series of relevant reactions taking place in the process are given below [7-8].

$3Fe_2O_3 + 3\ H_2 = 2\ Fe_3O_4 + 3\ H_2O$ ---------- (1)

$w/(4w-3)\ Fe_3O_4 + H_2 = 3/(4w-3)Fe_wO + H_2O$ ---------- (2)

$Fe_wO + H_2 = w\ Fe + H_2O$ ---------- (3)

$Fe_3O_4 + 4\ H_2 = 3Fe + 4\ H_2O$ ---------- (4)

$2H_2 + O_2 = 2H_2O$ ---------- (5)

$2Fe + O_2 = 2FeO$ ---------- (6)

$4H + O_2 = 2H_2O$ ---------- (7)

$4H^+ + 2O^{2-} = 2H_2O$ ---------- (8)

6. Conclusion

From the above experimental findings it can be concluded that it is possible to produce pig iron containing 85.5% Fe with 85% recovery from bauxite of Indian origin by employing the Hydrogen

Plasma Smelting process. The result obtained in the present investigation seems promising, and may be an option to minimize Bauxite Residue generation in Alumina Refineries.

Further studies are needed to establish higher reduction efficiencies for the iron oxide present in bauxite.

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