Recover Iron from Bauxite Residue (Red Mud)

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Abstract. Red mud is a hazardous waste generated from alumina refining industries. Unless managed properly, red mud poses significant risks to the local safety and environment. The Bayer Red Mud was considered as a low-grade iron ore with a grade of 5wt% to 20wt% iron. We adopted the reduction roasting-magnetic separation process to recover ferric from red mud by electromagnetic induction furnace. The effects of different parameters on the recovery rate of iron were studied in-depth. The optimum reduction reaction conditions were obtained that is 1wt% of carbon in red mud at 1450 ℃ roasting for 60 min and the magnetic field intensity is about 0.19T. The experimental results indicated that the grade of total iron and the iron recovery were 66.50% and 65.4%, respectively. The prove the electromagnetic induction furnace is more beneficial to iron recovery.

1. Introduction
Red mud is a kind of alkaline solid waste generated from the alumina refining of bauxite ore, which containing a certain amount of alumina, caustic soda, ferrotitanium oxide and a small amount of rare metals. The output, composition and characteristics of red mud vary with the type of bauxite and the production process, and are generally divided into two types: bayer red mud and sintering red mud. The production of 1 tonne of alumina generates about 1.5 tonnes of red mud [1]. With the increasing demand for alumina worldwide, it’s no doubt that the generation of red mud is estimated to be over 4 billion tons [2]. At present, the comprehensive utilization and management of red mud is still a worldwide problem. In the past, large amounts of red mud are discharged into the sea [3]. Today, the disposal of red mud was mainly by stockpiling [4]. We have to recognize that this method not only makes the alkaline material of red mud infiltrate the soil and groundwater, but also occupies a large amount of land resources. On the one hand, it pollutes the environment. On the other hand, it has a big security risk [5]. However, we hope to find a better way to efficiently recycle the valuable metals in red mud to provide options for its management after disposal. Many attempts have been made to find an environmentally friendly and cost-effective method to dispose of or utilize red mud. Red mud can be used in building materials, valuable metals recovery and fillers. [6, 7, 8]
Red mud can be considered as a secondary raw material for the recovery of valuable substances. For instance, the metals in red mud have recently attracted research interest due to increasing demand and value for iron, aluminum, titanium, rare earth elements and other materials [9]. Recently, iron recovery has attracted major attention. However, it is difficult to recover metals from red mud because they are locked in complex mineral phases. Minerals in red mud include boehmte, hematite, aluminosilicate, sodalite, quartz, perovskite, cancrinite [10]. In spite of these issues, many researchers have carried out a lot of studies on the recovery of valuable materials in red mud. Although high pressure hydro-chemistry method is one of the most effective methods to recover caustic soda and alumina, ferric in red mud can not be recovered [11]. Two main methods of recovering iron from red mud are based on: reduction roasting-magnetic separation process, and smelting in an electric shaft furnace to produce pig iron. Development of suitable metallurgical processes for ferric oxide recovery from red mud is important.

In this study, recover ferric values by using reduction roasting process (Electromagnetic induction furnace) followed by magnetic separation. In this paper, the effects of different parameters on recovery rate of iron were studied and optimized. Under the same conditions, the experiments were carried out respectively in the electric resistance furnace and the electromagnetic induction furnace. It is further explained whether the electromagnetic induction furnace is beneficial to the recovery of iron from the red mud.

2. Experimental

2.1. Materials

Bayer red mud used in the experiments was obtained from an aluminum company in Henan Province, China. The sample was analyzed by using XRF(X Ray Fluorescence), and the result is listed in Table 1. The X-ray diffraction pattern (XRD) of the Bayer red mud is shown in Fig.1. It is shown from Table 1 that the chemical composition of sample, showing 27.36% Al₂O₃, 23.21% SiO₂, 14.90% CaO, 11.08% Fe₂O₃, 8.63% Na₂O, 6.25% TiO₂. According to the XRD pattern shown in Fig.1, the main phases of red mud are katoite (Ca₃Al₂(SiO₄)(OH)₈), andradite (Ca₃(Fe₀.₈₇Al₀.₁₃)₂(SiO₄)₁.₆₅(OH)₅.₄), calcite (CaCO₃), hematite (Fe₂O₃), muscovite (KAl₂Si₃AlO₁₀(OH)₂), diaspore (AlO(OH)).

Table 1. The main chemical composition of red mud/wt%

| Element | Al₂O₃ | SiO₂ | CaO | Fe₂O₃ | Na₂O | TiO₂ | Others |
|---------|-------|------|-----|-------|------|------|--------|
| Content | 27.36 | 23.21| 14.90| 11.08 | 8.63 | 6.25 | 8.57    |

Figure 1. XRD pattern of the Red mud
2.2. Experimental method
Five group experiments were designed to investigate the effects of different parameters on iron recovery from the red mud, such as magnetic intensity, roasting time, roasting temperature, the ratio of carbon to red mud, and furnace. The red mud was mixed with carbon and additive according to specific proportions. The mixtures were pressed into pellets with 20 mm diameter and 20 mm thickness under 6MPa pressure. The pellets were put in crucibles to roast at high temperature in an electromagnetic induction furnace. After a given time, the roasted samples cooling to the room temperature. Products were ground and separated by a magnetic separator at a given magnetic field intensity. The experimental process is shown in Fig.2. The grade of total iron ($T_{Fe}$) was analyzed by chemical method. Then the recovery rate of iron was calculated according to mass balance in magnetic separation operation.

![Figure 2. Experimental flow chart of reducing iron from red mud](image)

2.3. Experimental facilities
While most of the researcher performed experiments in a resistive furnace, the roasting process was performed in an electromagnetic induction furnace in this paper. The equipment is shown in Fig.3.

![Figure 3. Electromagnetic induction furnace](image)

3. Results and discussions
3.1. Effect of magnetic field intensity on the recovery of iron
The magnetic field intensity has an important influence on the recovery rate of the iron during separated by a magnetic separator. Samples consisted of red mud, active carbon and additive at a proportion of 100:18.6, roasting temperature of 1250 °C for 120 min, and Products were ground and separated by a
magnetic separator at a magnetic field intensity of 0.1, 0.13, 0.16, 0.19, 0.22, 0.25 T, respectively. Fig.4 illustrates the effect of magnetic field intensity on $T_{Fe}$ and recovery rate of iron.

![Figure 4](image.png)

**Figure 4.** Effect of the magnetic field intensity on iron recovery and $T_{Fe}$ grade of concentrate

From Fig.4, the parameters of iron recovery rise rapidly with the increase of magnetic field intensity. But, the $T_{Fe}$ in concentrate drop with the increase of magnetic field intensity. Some of the less magnetic iron minerals and impurity minerals in the materials are also separated together with magnetic field intensity increasing. As a result, the recovery rate of iron increases and the $T_{Fe}$ in concentrate decreases. In the case of high recovery rate, the $T_{Fe}$ in concentrate is better at the same time. Generally the magnetic field intensity was about 0.19T.

3.2. **Effect of temperature on the recovery of iron**

The roasting temperature has an important influence on the recovery rate of the iron during reduction roasting process. Samples consisted of red mud, carbon and additive at a proportion of 100:18:6, and were roasted for 120 min at 1050, 1150, 1250, 1350 and 1450°C, respectively. Experimental results are shown in Fig.5.

![Figure 5](image.png)

**Figure 5.** Effect of the roasting temperature on iron recovery and $T_{Fe}$ grade of concentrate
It is shown from Fig.5 that effect of roasting temperature on the recovery rate of the iron was apparent. The parameters of iron recovery rose with the increase of sintering temperature. However, the $T_{Fe}$ in concentrate is no obvious change with the increase of sintering temperature. Although higher roast temperature is beneficial to iron recovery, for industrial applications, generally the optimum roasting temperature was about 1450℃.

3.3. Effect of roasting time on the recovery of iron
The effect of roasting time on the recovery of iron is indicated in Fig.6. The materials consisted of red mud, carbon and additive at a proportion of 100:18:6, and were smelted in an electromagnetic induction furnace, and the roasting time varied from 40 to 140 min.

It can be seen from Fig.6 that the $T_{Fe}$ in concentrate and recovery rate is no obvious relationship with the increase of roasting time. Due to the low iron content in the raw material, it doesn't take much reaction time. Therefore, for industrial applications, it was inferred that the optimum roasting time was about 60 min, during which deoxidization reaction of ferrous oxides was mostly completed.

![Figure 6. Effect of the roasting time on iron recovery and $T_{Fe}$ grade of concentrate](image)

3.4. Effect of ratio of carbon to red mud on the recovery of iron

![Figure 7. Effect of the ratio of carbon on iron recovery and $T_{Fe}$ grade of concentrate](image)
From current research, carbon is a good reducing agent. In order to determine the optimum dosage of carbon, different carbon additions were studied, respectively, with the other experimental parameters under the same amount of addition. Samples consisted of red mud and additive at a proportion of 100:6, and were roasted for 60 min at 1450 °C. The results are shown in Fig.7.

As shown in Fig.7, the parameters of iron recovery and $T_{Fe}$ in concentrate decreased rapidly with the increase of the ratio of carbon to red mud. When the ratio of carbon to red mud was over 12.5wt%, $T_{Fe}$ and recovery of iron kept stable. It is indicated that increasing amount of carbon added can’t promote iron recovery and $T_{Fe}$ in concentrate. Due to the low iron content in the raw material, too much carbon is bad for iron reduction. Based on an overall consideration of various factors, the optimum percentage of carbon in red mud was 1wt%.

3.5. Effect of furnace on the recovery of iron

In order to prove the electromagnetic induction furnace is more beneficial to iron recovery, different furnace were studied, respectively, with the other experimental parameters kept at the same amount of addition. The effect of furnace on the recovery of iron is indicated in Table 2 under the condition of roasting temperature of 1450 °C, reaction time of 1h and red mud, carbon and additive at a proportion of 100:1:6.

| Furnace                        | Recovery ratio of iron | $T_{Fe}$ in concentrate |
|-------------------------------|------------------------|-------------------------|
| resistance furnace            | 17.97                  | 17.24                   |
| electromagnetic induction furnace | 66.50                | 65.40                   |

It is shown from Table 2 that effect of furnace on the recovery rate of the iron was apparent. The experiment result of electromagnetic induction furnace is better than that of resistance furnace. It is preliminarily determined that magnetic field stirring is conducive to iron accumulation.

4. Conclusion

1) Major chemical composition of red mud was Al$_2$O$_3$, SiO$_2$, CaO, Fe$_2$O$_3$, Na$_2$O and TiO$_2$. Katoite, andradite, calcite, hematite, muscovite, and diaspore existed in red mud as the main mineral phases, and most of iron existed in hematite ore, accompanied by some andradite.

2) These main factors all play an important role in the recovery of iron which are the magnetic field intensity, roasting temperature and time, the ratio of carbon to red mud and furnace. The optimum reduction reaction conditions were obtained that is 1wt% of carbon in red mud at 1450 °C roasting for 60 min and the magnetic field intensity is about 0.19T. Based on the above optimum reaction conditions, magnetic separation concentrate can be obtained with the grade of 65.4% $T_{Fe}$ and 66.50% recovery of iron.

3) Compared with the resistance furnace, the electromagnetic induction furnace is more beneficial to iron recovery.

Acknowledgments

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References

[1] S. Zhu, D. Zhu, X. Wang, Removal of fluorine from red mud (bauxite residue) by electrokinetics, Electrochim. Acta. 242 (2017) 300-306.

[2] X. Zhu, W. Li, X. Guan, An active dealkalization of red mud with roasting and water leaching, J. Hazard. Mater. 286 (2015) 85-91.
[3] G. Power, M. Gräfe, C. Klauber, Bauxite residue issues: I. Current management, disposal and storage practices, Hydrometallurgy. 108 (2011) 33-45.

[4] K. Evans, The History, Challenges, and New Developments in the Management and Use of Bauxite Residue, J. Sustain. Metall. 2 (2016) 316-331.

[5] B.E.H. Jones, R.J. Haynes, I.R. Phillips, Addition of an organic amendment and/or residue mud to bauxite residue sand in order to improve its properties as a growth medium, J. Environ. Manag. 95 (2012) 29-38.

[6] C. Klauber, M. Gräfe, G. Power, Bauxite residue issues: II. options for residue utilization, Hydrometallurgy. 108 (2011) 11-32.

[7] S. Ordonez, Catalytic Applications of Red Mud, an Aluminum Industry Waste: A Review, Appl. Catal. B-Environ. 84 (2008) 732-733.

[8] K. Snars, R.J. Gilkes, Evaluation of bauxite residues (red muds) of different origins for environmental applications, Appl. Clay. Sci. 46 (2009) 0-20.

[9] S. Kumar, R. Kumar, A. Bandopadhyay, Innovative methodologies for the utilisation of wastes from metallurgical and allied industries, Resour. Conserv. Recy. 48 (2006) 301-314.

[10] S. Wang, H.M. Ang, M.O. Tadé, Novel applications of red mud as coagulant, adsorbent and catalyst for environmentally benign processes, Chemosphere. 72 (2008) 1621-1635.

[11] W. Liu, J. Yang, B. Xiao, Application of bayer red Mud for iron Recovery and Building Material Production from Alumosilicate Residues, J. Hazard. Mater. 161 (2009) 474-478.