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# Pre-beneficiation of Low Grade Diasporic Bauxite Ore by Reduction Roasting

K. Yılmaz, B. Birol, M. N. Sarıdede, E. Yiğit

***Abstract*—**A bauxite ore can be utilized in Bayer Process, if the mass ratio of $Al_2O_3$ to $SiO_2$ is greater than 10. Otherwise, its $Fe_xO_y$ and $SiO_2$ content should be removed. On the other hand, removal of $TiO_2$ from the bauxite ore would be beneficial because of both lowering the red mud residue and obtaining a valuable raw material containing $TiO_2$ mineral. In this study, the low grade diasporic bauxite ore of Yalvaç, Isparta, Turkey was roasted under reducing atmosphere and subjected to magnetic separation. According to the experimental results, 800°C for reduction temperature and 20000 Gauss of magnetic intensity were found to be the optimum parameters for removal of iron oxide and rutile from the non-magnetic ore. On the other hand, 600°C and 5000 Gauss were determined to be the optimum parameters for removal of silica from the non-magnetic ore.

***Keywords*—**Low grade diasporic bauxite, magnetic separation, reduction roasting, separation index.

## I. Introduction

In a bauxite ore, if the mass ratio of $Al_2O_3$ to $SiO_2$ is greater than 10, it can be considered as high-grade bauxite, which can be processed directly by the Bayer process. On the other hand, if this ratio is lower than 8, it is regarded as low-grade bauxite and a pretreatment process should be used before Bayer Process. Although the low grade diasporic bauxite ore of Yalvaç, Isparta in Turkey is a potential raw material for Bayer Process, its high $Fe_xO_y$ and $SiO_2$ content flaws its usability. Additionally $Fe_2O_3$ content should be max. 2-2.5% for refractory purposes. Therefore removal of iron oxides is required to acquire a beneficial raw material [1], [2].

There are an amount of studies that involve the removal of iron oxides by magnetizing the iron bearing compounds by reduction of $Fe_2O_3$ to $Fe_3O_4$, followed by magnetic separation. It was proved to be an effective way to decrease iron content of ores and tailings [2]–[6]. The reduction of hematite is carried out by the following reactions [3];

$$3Fe_2O_3 + C \rightarrow 2Fe_3O_4 + CO_{(g)} \tag{1}$$

$$3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_{2(g)} \tag{2}$$

$$3Fe_2O_3 + H_2 \rightarrow 2Fe_3O_4 + H_2O_{(g)} \tag{3}$$

K.Yılmaz, M.N. Sarıdede, and E. Yiğit are with the Yıldız Technical University, Department of Metallurgical and Materials Engineering, Esenler / İstanbul, 34210, Turkey (e-mail: koksal_1981@yahoo.com, msaridede@gmail.com, erdoganyigit40@yahoo.com)

B.Birol is with the Yıldız Technical University, Department of Metallurgical and Materials Engineering, Esenler / İstanbul, 34210, Turkey (corresponding author to provide phone: +90212-383-4620; fax: +90212-383-4665; e-mail: burak.birol@gmail.com).

Rutile ($TiO_2$), which is a valuable mineral, is also present in the bauxite ores. The separation of rutile also lowers the red mud (Bayer process tailing) amount [7].

Cui et al. investigated the magnetic properties of ilmenite, hematite and LR-rutile after reduction roasting. They have concluded that, reduction roasting of ilmenite at 800°C increased its magnetic susceptibility significantly because of the transformation to maghemite ($\gamma$-$Fe_2O_3$). Same magnetic behavior have been encountered at 800 or 1000 °C, in hematite, which reached that of magnetite after 30min of roasting with a charcoal:hematite ratio of either 1:10 or 1:5. Also in the reduction roasting of the LR Rutile have resulted in an increase in its magnetic susceptibility mainly due to the presence of leucoxene [6]. In another study, the authors investigated the recovery of iron oxide from $SiO_2$, $Fe_2O_3$, CaO and $Al_2O_3$ containing iron ore tailings by reduction roasting. They have asserted that, coal amount, roasting temperature, reduction time, and milling time of roasted samples were the main parameters that affect the recovery of iron minerals. As the result of their experiments, they suggest the optimum conditions of coal: iron ore tailings ratio as 1:100, roasting at 800°C for 30min, and milling 15min of roasted samples. Under these conditions, the grade of magnetic concentrate of 61.3% Fe and recovery rate of iron compounds as 88.2% were obtained [3]. Uwadiale also agrees that the 800°C and high $Fe_2O_3$:C ratio (1:9) give the optimum reduction rates and recovery of iron [8]. On the other hand, a study concerning iron ore refinement by the same process indicates that, best iron recovery results (93%) were obtained from the iron ore samples, which were reduced by $H_2$ at 450°C for 3min, although most MnO removal was achieved from the experiments conducted for 30 min [9].

Sadler and Venkataraman suggest that a reduction at 500°C for 120min is adequate for the bauxite ores containing 2.7% $Fe_2O_3$ transforming into a product containing less than 1.6% $Fe_2O_3$ with a recovery of more than 95% of the iron- free bauxite present in the feed [2].

In this work, the pre-beneficiation of low grade diasporic bauxite ore from Yalvaç, Isparta was investigated by reduction roasting and followed by magnetic separation with various parameters. It was aimed to determine the optimum process parameters for removal of iron oxide and silica in order to obtain a high grade ore to be used in Bayer Process. Additionally, the possibility to recover $TiO_2$, which is a valuable mineral, was investigated.

## II. Experimental

### A. Materials

In order to research the reduction roasting of bauxite ores, a low grade diasporic bauxite ore and coke was used as raw materials. The chemical composition of the raw materials is given in Table I.

TABLE I
CHEMICAL COMPOSITION OF LOW GRADE DIASPORIC BAUXITE ORE AND COKE

| Raw materials | Constituent (wt.%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $Fe_xO_y$ | $SiO_2$ | $Al_2O_3$ | $TiO_2$ | C | Moist. | Ash | V.M. | Other |
| Bauxite | 31.53 | 6.68 | 43.6 | 5.56 | - | - | - | - | 12.63 |
| Coke | - | - | - | - | 79.5 | 14.2 | 17.95 | 2.55 | - |
| Coke Ash | 3.85 | 47.0 | 31.5 | - | - | - | - | - | 4.0 |

### B. Equipment

For comminution of raw materials, laboratory scale crushers, jaw and cone crushers, and ball mill was used and then sieving was performed for classification. The reduction roasting experiments were conducted in a muffle furnace. Wet magnetic separators were used for magnetic separation. The raw materials and products were characterized by ICP-OES analysis.

### C. Experimental Procedure

After the raw materials were crushed and ground under 100 mesh they were dried in a drying oven at 105°C for 2 h. Then, ore and coke were mixed with a coal:ore ratio of 1:100. Following experimental procedure was implied in two stages; Reduction and Magnetic separation.

In the reduction stage, to determine the optimum reduction temperature, samples were reduced at 400, 600 and 800°C for 30 min. In magnetic separation step, the reduced samples were subjected to magnetic separation conducted by magnetic separators with low magnetic intensity (5000 Gauss) and high magnetic intensity (20000 Gauss), respectively. Moreover to investigate the effect of particle size on iron oxide removal, samples under 200 mesh were reduced and separated by a magnetic separator with an intensity of 4000 Gauss.

Products obtained from each process were characterized by ICP-OES analysis.

## III. Results and Discussion

The reduction roasting experiments were conducted by reducing the samples at 400, 600, 800°C for 30 min and the results were compared with the raw ore as given in Fig. 1

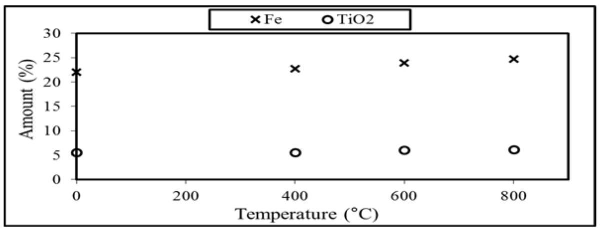


Fig. 1 Fe and $TiO_2$ amounts after reduction of samples at 0, 400, 600, 800°C for 30min

As shown in Fig. 1, Fe and $TiO_2$ contents of the bauxite slightly increase with the increasing reduction temperature. This leads to a consumption of increasing removal of oxygen with the increasing temperature.

The samples, under the particle size of 100 mesh, were then subjected to magnetic separation at 5000 and 20000 Gauss field intensity. The products were analyzed and their separation indexes (*SI*) were calculated by;

$$SI = C * MP/100 \quad (4)$$

where C is the amount of the mineral (wt%) and MP is the mineral proportion (wt%) in the concentrate or tailings.

### A. Effect of Reduction Temperature and Magnetic Field Intensity on the $Fe_xO_y$ Distribution

Table II presents the amount, mineral ratio and separation indexes of $Fe_xO_y$ after magnetic separation at 5000 and 20000 Gauss for samples reduced at 400, 600 and 800°C, respectively. Moreover the comparison of the separation indexes of $Fe_xO_y$ versus reduction temperature is given in Fig. 2.

TABLE II
AMOUNT, MINERAL RATIO AND SEPARATION INDEXES OF IRON OXIDE AFTER MAGNETIC SEPARATION

| Reduction Temp. (°C) | Field Intensity (Gauss) | Amount of $Fe_xO_y$ (wt%) | | Ratio of $Fe_xO_y$ (wt%) | | Separation Index of $Fe_xO_y$ (wt%) | |
|---|---|---|---|---|---|---|---|
| | | M | NM | M | NM | M | NM |
| 400 | 5000 | 40.63 | 30.38 | 21.9 | 78.1 | 8.89 | 23.72 |
| 600 | 5000 | 46.07 | 32.81 | 16.9 | 83.1 | 7.78 | 27.26 |
| 800 | 5000 | 40.22 | 33.42 | 32.8 | 67.2 | 13.19 | 22.45 |
| 400 | 20000 | 38.36 | 28.4 | 44.3 | 55.7 | 16.99 | 15.81 |
| 600 | 20000 | 41.72 | 30.96 | 39.3 | 60.7 | 16.39 | 18.79 |
| 800 | 20000 | 39.60 | 31.84 | 47.5 | 52.5 | 18.52 | 16.71 |

M and NM represent the magnetic and non-magnetic fractions of the sample, respectively.

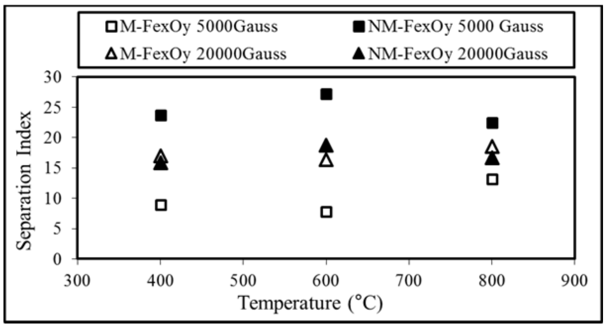


Fig. 2 Separation index changes of $Fe_xO_y$ for magnetic and non-magnetic fractions of samples with the reduction temperature

As given in Table II and Fig. 2, increasing temperature increases the separation index of $Fe_xO_y$ in magnetic fractions, but it decreases after 600°C in non-magnetic fraction. Besides, when high magnetic intensity is used he iron oxide amount in the magnetic fracture of the sample increases. Therefore it is possible to mention that, increasing temperature increases the magnetite formation and higher intensity values can collect the

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iron oxide into the magnetic fracture. So, optimum values to collect iron oxide to magnetic fracture are 800°C for reduction temperature and under magnetic intensity of 20000 Gauss. Also 600°C and 5000 Gauss is proper for collecting iron oxide in non-magnetic fracture.

*B. Effect of Reduction Temperature and Magnetic Field Intensity on the $TiO_2$ Distribution*

The amount, mineral ratio and separation indexes of $TiO_2$ after the experiments and separation indexes of $TiO_2$ are given in Table III and Fig. 3, respectively.

TABLE III
AMOUNT, MINERAL RATIO AND SEPARATION INDEXES OF RUTILE AFTER MAGNETIC SEPARATION REDUCED

| Reduction Temp. (°C) | Field Intensity (Gauss) | Amount of $TiO_2$ (wt%) | | Ratio of $TiO_2$ (wt%) | | Separation Index of $TiO_2$ (wt%) | |
|---|---|---|---|---|---|---|---|
| | | M | NM | M | NM | M | NM |
| 400 | 5000 | 5.98 | 5.16 | 19.6 | 80.4 | 1.17 | 4.14 |
| 600 | 5000 | 5.95 | 5.62 | 13.2 | 86.8 | 0.78 | 4.87 |
| 800 | 5000 | 6.04 | 5.80 | 29.0 | 71.0 | 1.75 | 4.18 |
| 400 | 20000 | 5.70 | 5.21 | 39.2 | 60.8 | 2.23 | 3.16 |
| 600 | 20000 | 5.84 | 5.63 | 33.2 | 66.8 | 1.93 | 3.76 |
| 800 | 20000 | 5.86 | 5.72 | 43.0 | 57.0 | 2.51 | 3.26 |

M and NM represent the magnetic and non-magnetic fractions of the sample, respectively.

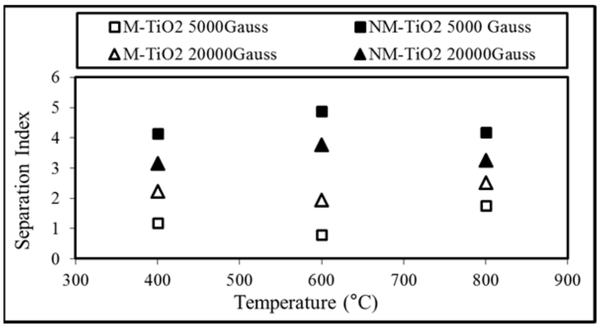


Fig. 3 Separation index changes of $TiO_2$ for magnetic and non-magnetic fractions of samples with the reduction temperature

Both Table III and Fig. 3 exhibit that, $TiO_2$ shows a similar behavior with $Fe_xO_y$ and ideal parameters for $Fe_xO_y$ is also valid for $TiO_2$. This phenomenon can be explained by leucoxene ($xFe_2O_3.yTiO_2$), formation as previously Cui et.al. (2002) indicated. Reduction roasting of ore reduces the iron oxide part by making leucoxene more magnetic and therefore easier to separate from rutile using magnetic separation [6].

*C. Effect of Reduction Temperature and Magnetic Field Intensity on the $Al_2O_3$ and $SiO_2$ Distribution*

$Al_2O_3$ and $SiO_2$ fraction in both magnetic and non-magnetic fractions are given in Table IV, Fig. 4 and Table V and Fig. 5, respectively.

Both $SiO_2$ and $Al_2O_3$ were mostly collected in the non-magnetic fracture, due to their non-magnetic structure. Although with increasing temperature separation index in non-magnetic fracture decreases, this phenomenon may occur due to the inadequate mineral liberalization. Therefore, comminution to lower particle sizes should be investigated.

800°C for reduction temperature and 20000 Gauss magnetic intensity are the optimum parameters for removal of iron oxide and rutile from the non-magnetic ore. However, when these parameters are applied, more $SiO_2$ resides in non-magnetic fracture and more $Al_2O_3$ is spared to the magnetic fracture.

TABLE IV
AMOUNT, MINERAL RATIO AND SEPARATION INDEXES OF ALUMINA AFTER MAGNETIC SEPARATION

| Reduction Temp. (°C) | Field Intensity (Gauss) | Amount of $Al_2O_3$ (wt%) | | Ratio of $Al_2O_3$ (wt%) | | Separation Index of $Al_2O_3$ (wt%) | |
|---|---|---|---|---|---|---|---|
| | | M | NM | M | NM | M | NM |
| 400 | 5000 | 36.20 | 46.88 | 13.90 | 86.1 | 5.05 | 40.30 |
| 600 | 5000 | 34.80 | 49.20 | 9.30 | 90.7 | 3.23 | 44.60 |
| 800 | 5000 | 43.19 | 51.29 | 25.50 | 74.5 | 11.00 | 38.21 |
| 400 | 20000 | 38.93 | 48.79 | 31.90 | 68.1 | 12.41 | 33.32 |
| 600 | 20000 | 40.34 | 51.23 | 27.40 | 72.6 | 11.05 | 37.19 |
| 800 | 20000 | 43.48 | 51.87 | 38.00 | 62.0 | 16.52 | 32.10 |

M and NM represent the magnetic and non-magnetic fractions of the sample, respectively.

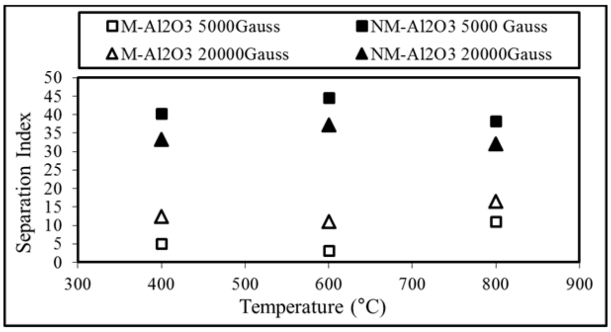


Fig. 4 Separation index changes of $Al_2O_3$ in magnetic and non-magnetic fractions of samples with the reduction temperature

TABLE V
AMOUNT, MINERAL RATIO AND SEPARATION INDEXES OF SILICA AFTER MAGNETIC SEPARATION REDUCED

| Reduction Temp. (°C) | Field Intensity (Gauss) | Amount of $SiO_2$ (wt%) | | Ratio of $SiO_2$ (wt%) | | Separation Index of $SiO_2$ (wt%) | |
|---|---|---|---|---|---|---|---|
| | | M | NM | M | NM | M | NM |
| 400 | 5000 | 7.48 | 6.30 | 20.00 | 80.0 | 1.49 | 5.04 |
| 600 | 5000 | 8.01 | 6.94 | 14.30 | 85.7 | 1.14 | 5.94 |
| 800 | 5000 | 7.76 | 6.69 | 32.00 | 68.0 | 2.48 | 4.54 |
| 400 | 20000 | 6.63 | 6.23 | 38.60 | 61.4 | 2.55 | 3.82 |
| 600 | 20000 | 7.32 | 7.07 | 33.20 | 66.8 | 2.43 | 4.72 |
| 800 | 20000 | 8.08 | 7.58 | 43.90 | 56.1 | 3.54 | 4.20 |

M and NM represent the magnetic and non-magnetic fractions of the sample, respectively.

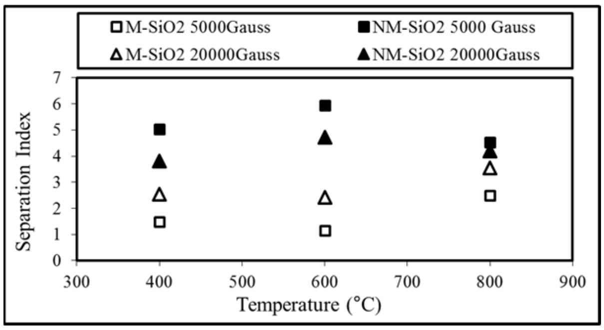


Fig. 5 Separation index changes of $SiO_2$ in magnetic and non-magnetic fractions of samples with the reduction temperature

## IV. Conclusions

To be able to use a low grade bauxite ore in Bayer Process, its high $Fe_xO_y$ and $SiO_2$ content should be removed. Additionally if the $TiO_2$ content of the ore can be removed, it would be beneficial because of both lowering the red mud residue and obtaining a valuable raw material containing $TiO_2$ mineral.

In this study, the low grade diasporic bauxite ore was roasted under reducing conditions, in order to obtain more suitable form of iron oxide and rutile for magnetic separation. According to the experimental outputs the following results were concluded;

- Increasing temperature increases the magnetic properties of almost all the minerals investigated.
- Higher magnetic intensity in magnetic separation, increases the mineral proportion in the magnetic fracture.
- 800°C for reduction temperature and 20000 Gauss magnetic intensity were found to be the optimum parameters for removal of iron oxide and rutile from the non-magnetic ore.
- 600°C for reduction temperature and 5000 Gauss magnetic intensity were determined to be the optimum parameters for removal of silica from the non-magnetic ore.
- After this pre-investigation, further researches should be performed in order to determine more effective conditions of reduction roasting and detect the phases in magnetic and non-magnetic fractions.

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