

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

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

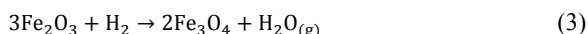
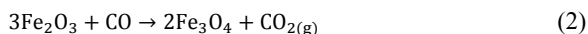
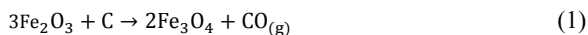
Abstract—A bauxite ore can be utilized in Bayer Process, if the mass ratio of Al_2O_3 to SiO_2 is greater than 10. Otherwise, its Fe_xO_y and SiO_2 content should be removed. On the other hand, removal of TiO_2 from the bauxite ore would be beneficial because of both lowering the red mud residue and 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];



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: koksalsal_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 ($\gamma\text{-Fe}_2\text{O}_3$). 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 leucosene [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]. Uwadike 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 ₂ O ₃	SiO ₂	Al ₂ O 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

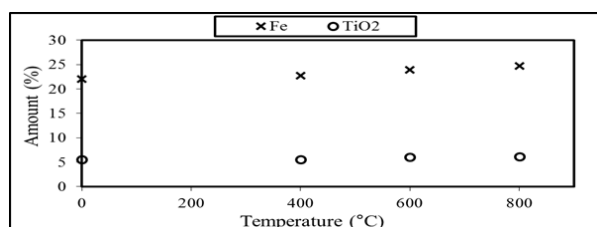


Fig. 1 Fe and TiO₂ amounts after reduction of samples at 0, 400, 600, 800°C for 30min

As shown in Fig. 1, Fe and TiO₂ 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 _x O _y (wt%)		Ratio of Fe _x O _y (wt%)		Separation Index of Fe _x O _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.

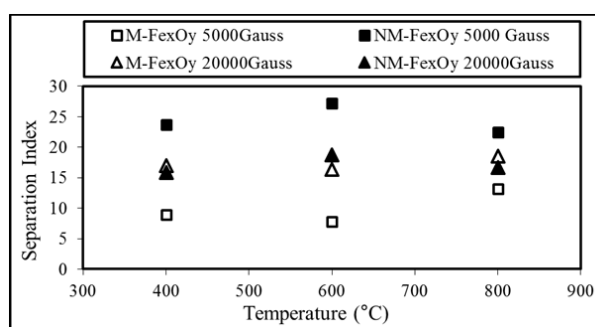


Fig. 2 Separation index changes of Fe_xO_y for magnetic and non-magnetic fractions of samples with the reduction temperature

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 the 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

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.

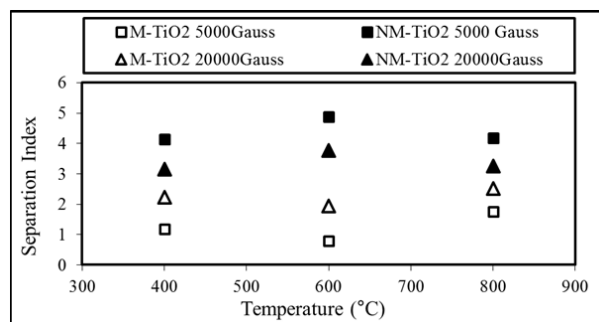


Fig. 3 Separation index changes of TiO_2 for magnetic and non-magnetic fractions of samples with the reduction temperature

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 leucosene ($x\text{Fe}_2\text{O}_3.y\text{TiO}_2$), formation as previously Cui et.al. (2002) indicated. Reduction roasting of ore reduces the iron oxide part by making leucosene 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.

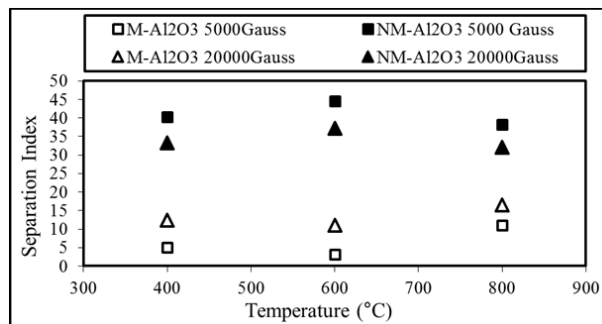


Fig. 4 Separation index changes of Al_2O_3 in magnetic and non-magnetic fractions of samples with the reduction temperature

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.

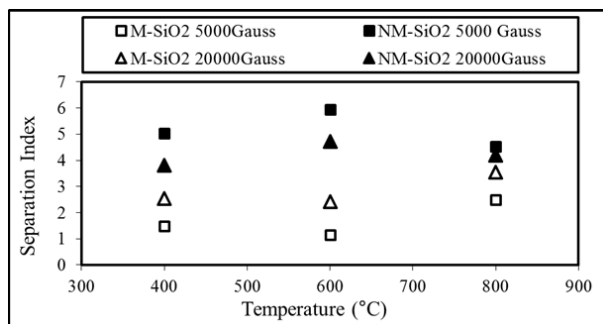


Fig. 5 Separation index changes of SiO₂ in magnetic and non-magnetic fractions of samples with the reduction temperature

IV. CONCLUSIONS

To be able to use a low grade bauxite ore in Bayer Process, its high Fe_xO_y and SiO₂ content should be removed. Additionally if the TiO₂ 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 TiO₂ 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.

REFERENCES

- [1] A. Pehlivan, A. O. Aydin, and A. Alp, "Alumina Extraction From Low - Grade Diasporic Bauxite By Pyro - Hydro Metallurgical Process," *Sak. Univ. J. Sci.*, vol. 16, no. 2, pp. 92–98, 2012.
- [2] L. Y. Sadler and C. Venkataraman, "A process for enhanced removal of iron from bauxite ores," *Int. J. Miner. Process.*, vol. 31, no. 3–4, pp. 233–246, 1991.
- [3] C. Li, H. Sun, J. Bai, and L. Li, "Innovative methodology for comprehensive utilization of iron ore tailings. Part 1. The recovery of iron from iron ore tailings using magnetic separation after magnetizing roasting," *J. Hazard. Mater.*, vol. 174, pp. 71–77, 2010.
- [4] J. Pesi and R. H. Eric, "High temperature carbothermic reduction of Fe₂O₃-TiO₂-M_xO_y oxide mixtures," in *Minerals Engineering*, 2002, vol. 15, no. 11, pp. 971–984.
- [5] H. Yang, L. Jing, and B. Zhang, "Recovery of iron from vanadium tailings with coal-based direct reduction followed by magnetic separation," *J. Hazard. Mater.*, vol. 185, no. 2–3, pp. 1405–1411, 2011.

- [6] Z. Cui, Q. Liu, and T. Etsell, "Magnetic properties of ilmenite, hematite and oilsand minerals after roasting," *Miner. Eng.*, vol. 15, no. 12, pp. 1121–1129, Dec. 2002.
- [7] R. Kumar and J. Srivastava, and Premchand "Utilization of iron values of red mud for metallurgical applications," in *Proc. Environmental and Waste Management in Nonferrous Metallurgical Industries*, Jamshedpur, pp. 108–119, 1998.
- [8] G. G. O. O. Uwadiale, "Magnetizing Reduction of Iron Ores," *Miner. Process. Extr. Metall. Rev.*, vol. 11, no. October 2013, pp. 1–19, 1992.
- [9] M. I. Nasr and M. a. Youssef, "Optimization of Magnetizing Reduction and Magnetic Separation of Iron Ores by Experimental Design.," *ISIJ Int.*, vol. 36, no. 1 1996, pp. 631–639, 1996.