*Physicochem. Probl. Miner. Process. 48(2), 2012, 381−392*

www.minproc.pwr.wroc.pl/journal/

Physicochemical Problems
of Mineral Processing

ISSN 1643-1049 (print)
ISSN 2084-4735 (online)

*Received December 10, 2011; reviewed; accepted February 8, 2012*

# BENEFICIATION OF LOW-GRADE FELDSPAR ORE USING CYCLOJET FLOTATION CELL, CONVENTIONAL CELL AND MAGNETIC SEPARATOR

**Hasan HACIFAZLIOGLU, Ilgin KURSUN, Mert TERZI**

Istanbul University, Engineering Faculty, Mining Engineering Department, Avcılar, Istanbul,
ilginkur@istanbul.edu.tr

Abstract. In order to increase the quality of feldspar ore and to obtain sellable feldspar concentrate, it is necessary to remove coloring impurities such as iron and titanium contained in it. For the removal of coloring minerals from feldspar ore the most widely used method is reverse flotation method. Reverse flotation process is generally carried out in conventional mechanical cells. In this study, it was aimed to enrich low-grade feldspar by using cyclojet flotation cell which was developed as an alternative to conventional cell. Then, experiments were performed by using conventional cell and wet magnetic separator and the results were compared with the flotation results obtained by using cyclojet cell. In experimental studies, 200 micrometer grain sized feldspar (albite) ore obtained from Muğla province at the west side of Turkey was used. It was detected that the sample was containing 0.100% $Fe_2O_3$ and 0.360% $TiO_2$ as coloring minerals. Cyclojet cell, conventional cell and magnetic separator reduced the $Fe_2O_3$ content down to 0.010%, but $TiO_2$ content was different in the concentrates obtained by different devices. There was almost no reduction in $TiO_2$ content by magnetic separation method. Cyclojet cell reduced $TiO_2$ content down to 0.030% and mechanical cell reduced $TiO_2$ content down to 0.020%. The weights of the concentrate were detected as the highest (92.70%) in magnetic separator and as the lowest (75.40%) in cyclojet cell. Therefore, it is possible to say that cyclojet cell can compete with mechanical cell and removal of $TiO_2$ in cyclojet cell is much better than the removal of $TiO_2$ in magnetic separator. Generally, in the flotation process performed by using a reagent of Aero801 and Aero825 mixture in natural pH medium, both $Fe_2O_3$ and $TiO_2$ can be removed at a rate of up to 90%, but magnetic separator can only remove $Fe_2O_3$ mineral.

*keywords: feldspar, separation, flotation*

## 1. Introduction

Feldspar is an important industrial raw material used in ceramic, porcelain and glass industries. Sixty percent of the World feldspar production is used in ceramic industry, 35% is used in glass industry, and 5% is used in welding electrode, rubber, plastic and paint industry as filling material. It is known that total feldspar reserves of the World is $1.740 \cdot 10^6$ Mg and a large part of this reserve is located in Asia. Turkey

http://dx.doi.org/10.5277/ppmp120205

has a reserve of $240 \cdot 10^6$ Mg which is 14% of the World feldspar reserves and it has the largest Na-feldspar reserves among other countries in the World (Bayraktar et al., 1998; Kangal and Guney, 2002; Anonymous, 2010). Commercial and the most important ones of feldspar group minerals are albite ($NaAlSi_3O_8$), orthoclase ($KAISi_3O_8$) and anorthite ($CaAl_2Si_2O_8$) which are named according to the Na, K, and Ca contents in their structures. Since there are not many commercial anorthite deposits in the World, feldspar production mainly depends on albite and orthoclase minerals (Bayraktar et al., 2001; Karaguzel and Çobanoğlu, 2010).

Iron and titanium minerals existing in mineralogical structures of feldspar are known as unwanted impurities because of their coloring properties. Therefore, $Fe_2O_3$ and $TiO_2$ contents of 0.50% or below are required in feldspar. The main impurity minerals observed in feldspar ores are rutile and sphene for titanium, mica minerals and minerals such as garnet, hematite, hornblende, tourmaline, biotite, and muscovite for iron oxides. In case that the amounts of these minerals are higher than the specific values, the quality of glass and ceramic decreases and the color changes accordingly. Therefore, the main goal in enrichment of feldspars is based on removal of the coloring minerals from the ore. Magnetic separation appears to be the most appropriate method for enrichment of feldspars in terms of cost and simplicity. However, flotation method is generally preferred according to the mineralogical property because magnetic susceptibilities of titanium minerals such as sphene and rutile are very low and also magnetic separators used in this area can perform efficient separation down to a specific grain size. Conventional reverse flotation method is still the most widely used method in the World for the removal of the impurities in feldspars. On the other hand, chemical and biological methods also can be used for the removal of impurities. In chemical method, feldspar is leached by organic and inorganic acids and in biological method, microorganisms are used instead of chemicals (Styriakovaa et al., 2006; El-Rehiem and Abd El-Rahman, 2008). Agglomeration or selective flocculation methods are also used for enrichment of feldspar (Doğu and Arol, 2004).

In this study, Na-feldspar ore obtained from Muğla province (Turkey) was enriched by cyclojet cell which is an alternative jet flotation technique, conventional cell and magnetic separator and the results obtained from the devices were compared.

## 2. Experimental studies

### 2.1. Cyclojet flotation cell

Cyclojet cell is a high density jet flotation cell developed in Turkey in 2006 for the enrichment of coal slimes. In the previous studies, outstanding success of cyclojet for the enrichment of coal slime has been proven by many researches. It was observed that clean coals containing ash between 7% and 15% were obtained from coal slime having ash contents of about 45-55% fed into cyclojet cell (Hacıfazlıoğlu, 2009; Hacıfazlıoglu and Toroğlu, 2008). This device, which is effective in enrichment of very fine particles, was used for the flotation of 200 micrometer grain sized Na-feldspar in this experiment.

Cyclojet cell, although it has some structural differences, mainly works with the principle of jet flotation. In this system, jet movement of pulp and centrifugal forces generated within the hydrocyclone and the cell are used. “Jet movement” is created linearly by a nozzle formed by a large number of holes in conventional jet flotation systems, but it is created as cone-shaped by a hydrocyclone apex in a cyclojet cell. In other words, pulp jet created in a cyclojet cell submerges into cell with a cyclonic move and creates a more efficient flotation providing more intensive shearing forces. Furthermore, intense mixing occurring within the cell and hydrocyclone minimizes the coating of particle with slime and it enables an effective flotation process without removing slime from the ore.

Schematic view of pilot-scale cyclojet cell test assembly installed in Istanbul University, Mining Engineering Department Mineral Processing Laboratory is shown in Figure 1. According to Figure 1, pulp conditioned in a 67 $dm^3$ conditioner for 10 minutes with the addition of collector and frother is fed tangentially into a hydrocyclone having a diameter of 16 cm with a pressure of 0.1-0.6 bar (10-60 kPa) by a centrifugal pump driven by a 1.5 kW motor. There are a conical tube with a height of 25 cm just below the hydrocyclone, and a separation cell having a diameter of 30 cm and height of 40 cm below conical tube. Upper flow outlet pipe of hydrocyclone is completely closed in order to prevent the upward movement of the pulp. In this case, high pressure pulp is first mixed thoroughly by swirling in hydrocyclone and then submerges into separation cell by forming a cyclonic jet. Meanwhile, an air gap created by the effect of the jet within the conical tube provides the suction of air from the atmosphere with a vacuum effect. Air from the atmosphere is sucked with a sectional velocity of 0.2 cm/sec through a circular hole with 1 cm diameter on the conical tube. Then, pulp jet mixed with the air sucked quickly submerges into the pulp in the separation cell and allows the formation of a large number of very fine-sized (300-500 microns) air bubbles by action of shear forces. Separation is performed by taking hydrophobic grains (coloring impurities) interfere with the bubbles in the separation cell from the upper part of the cell and taking hydrophilic grains (feldspar) which do not interfere with the air from the lower part of the cell. A by-pass was mounted into the system in order to ensure continuity in the cell and cleaning of feldspar ore over and over again. In other words, the bottom outlet pipe of the separation cell is connected to the conditioner with another pipe. In cyclojet flotation, sulphonate type collectors named as Aero801 and Aero825 manufactured by American CYTEC Company are used with a mixing ratios of 50% and dosages of 1000 and 2000 g/Mg. All experiments were performed by using tap water and at $24^0$C room temperature and at natural pH value of (7-8). Solid content of the pulp and conditioning period were selected as 30% and 8 minutes respectively. Products obtained by reverse flotation were dried in the oven after filtration, and were analyzed by XRD for $Fe_2O_3$ and $TiO_2$ content. Then, $Fe_2O_3$ and $TiO_2$ removal efficiencies were calculated by the following equations:

$$Fe_2O_3 \text{ removal efficiency (\%)} = [1 - (Fe_2O_3 \text{ content in concentrate}/Fe_2O_3 \text{ content in feed})]\cdot 100,$$

$$TiO_2 \text{ removal efficiency (\%)} = [1 - (TiO_2 \text{ content in concentrate}/TiO_2 \text{ content in feed})]\cdot 100.$$

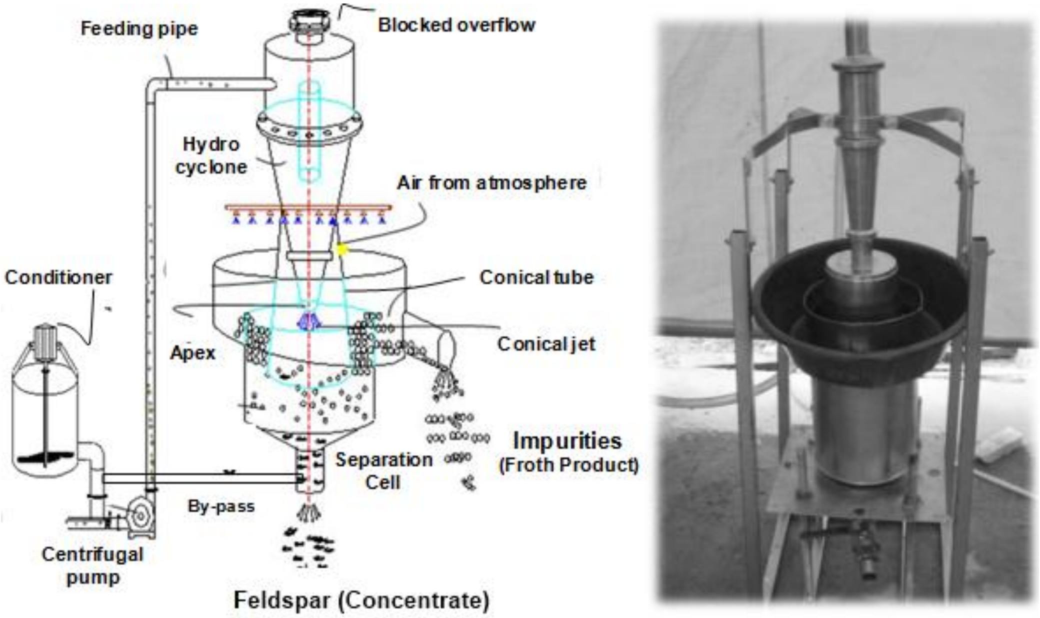

Fig. 1. Cyclojet flotation cell experimental set-up

## 2.2. Na-feldspar sample

A 50 kg Na-feldspar sample was taken from the feldspar enrichment plant owned by Esan Company operating in Muğla province located in the south-west part of Turkey. In this plant, the ore ground to 0.5 mm is enriched by using conventional mechanical mixing flotation cells. Before the enrichment, slime is removed from the Na-feldspar ore by 14 inch hydrocyclones and then feldspar is fed into flotation cell and coloring impurities are removed by reverse flotation. The main coloring impurities in the sample are minerals such as hematite, garnet, anatase, rutile, sphene, biotite and ilmenite containing iron and titanium. It was observed during microscopic observations done that 90% of the colored minerals were liberated from the feldspar grains with size under 200 micrometers. The whole sample was ground gradually by ceramic ball mill down to fine sizes under 200 micrometers in order to allow cyclojet cell to be effective at fine sizes ($<200$ μm) and to obtain high rate of liberation. According to the results of the chemical analysis of the sample used in the experimental studies done by using X-Ray diffractometer (XRD), the following were detected: $SiO_2$ 67.38%; $Al_2O_3$ 19.28%, $Fe_2O_3$ 0.10%, $TiO_2$ 0.36%, MgO 0.25%, CaO 1.08%, $K_2O$ 0.43% and $Na_2O$ 10.07%.

## 3. Results and discussion

### 3.1. Optimization of cyclojet operation parameters

Some of the parameters of the study should be optimized in order to allow cyclojet cell to be effective in feldspar flotation. The most important ones are amount of reagent, pulp pressure, conical jet length and conical tube submerging depth. In the experiments performed to find the effect of the amount of reagent (collector), feeding pressure, conical jet height and conical tube submerging depth, solid concentration were set to 40 kPa, 10 cm, 30% respectively. In all experiments, total conditioning time was set to 8 minutes and total flotation time (froth removal time) was set to 10 minutes. Any additional frother or any chemical for pH adjustment were not used in the experiments since the Aero 801 and Aero 825 collectors have frothing characteristics. All experiments were performed by using tap water and at natural pH value of 7-8. The effects of various parameters on concentrate and waste characteristics during cyclojet flotation are given in Table 1. Every optimum parameter obtained was used in the next experiment.

Table 1. The effects of various parameters on concentrate and waste characteristics during cyclojet flotation

| Parameters | Values | Concentrate (Feldspar) | | | Reject (impurities) | | |
|---|---|---|---|---|---|---|---|
| | | $Fe_2O_3$ content(%) | $TiO_2$ content(%) | Wt. (%) | $Fe_2O_3$ content(%) | $TiO_2$ content(%) | Wt. (%) |
| Reagent Aero801+825 (g/Mg) | 750 | 0.070 | 0.230 | 76.600 | 0.198 | 0.786 | 23.400 |
| | 1500 | 0.020 | 0.040 | 67.200 | 0.264 | 1.016 | 32.800 |
| Feed pressure (kPa) | 10 | 0.090 | 0.270 | 82.200 | 0.146 | 0.776 | 17.800 |
| | 40 | 0.010 | 0.040 | 65.400 | 0.270 | 0.965 | 34.600 |
| Conical jet lenght (cm) | 10 | 0.010 | 0.030 | 66.100 | 0.275 | 1.003 | 33.900 |
| | 20 | 0.060 | 0.190 | 70.100 | 0.194 | 0.759 | 29.900 |
| Conical tube submerging depth (cm) | 10 | 0.010 | 0.030 | 67.000 | 0.283 | 91.667 | 33.000 |
| | 20 | 0.050 | 0.150 | 74.000 | 0.242 | 58.333 | 26.000 |

As shown in Table 1, removal of both $Fe_2O_3$ and $TiO_2$ increased with the increase in reagent amount. By increasing the reagent amount from a dosage of 750 g/Mg to a dosage of 1500 g/Mg, the $Fe_2O_3$ content in the concentrate was decreasing from 0.070% to 0.020%, while $TiO_2$ content decreased from 0,230% to 0,040%. Increase in the reagents amount provided flotation of greater amounts of impurities. On the other hand, with a fixed reagents dosage (1500 g/Mg), the $Fe_2O_3$ content in the concentrate was reduced from 0.090% to 0.010% by increasing pulp pressure from 10 kPa to 40 kPa. The $TiO_2$ content in the concentrate was reduced from 0.270% to 0.040% by increasing the feeding pressure. Removal of $Fe_2O_3$ and $TiO_2$ minerals was lower at lower feeding pressure (10 kPa) because sufficient shear forces within the separation cell were not created. In other words, bubbles in cyclojet cell are formed by the pulp jet rapidly flushing from the apex. Here, the larger shear forces are generated as the pulp jet velocity gets higher, and consequently, a large number and relatively small-sized bubbles are formed within the cell.

Another important parameter affecting flotation efficiency in cyclojet cell is the conical jet length. As it can be seen clearly from the results indicated in Table 1 that concentrates having lower $Fe_2O_3$ and $TiO_2$ contents are obtained. The $Fe_2O_3$ content in the concentrate decreased from 0.060% to 0.010% by decreasing the jet length from 20 cm to 10 cm. The $TiO_2$ content in the concentrate decreased from 0.190% to 0.030%. The reason of this situation is related with the formation of sufficient number of bubbles as in the case of pressure effect. With the high jet length (20 cm), shear force was reduced due to jet activity and a smaller number of bubbles were formed in the cell. When the jet length was decreased to 10 cm, more bubbles were formed and more impurities were moved into froth product.

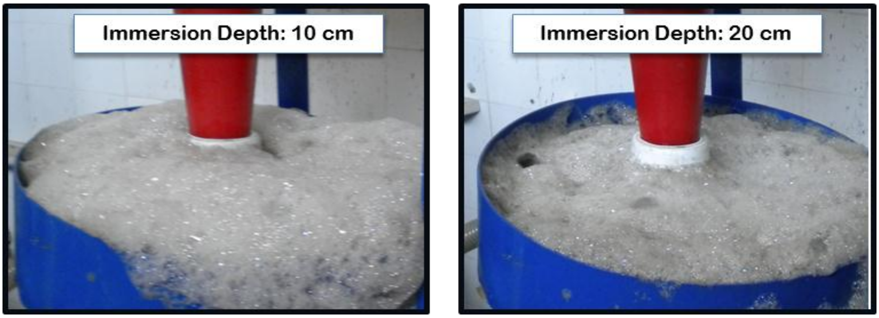

Fig. 2. Pictures of the froth at low and high conical tube submerging depths

In jet flotation systems, hydraulic pressure applied on the unit surface area at the outlet point of the tube increases as the depth of the sublance increases. Therefore, velocity of the pulp leaving the discharge point and the velocity of formation of the bubbles decrease. Furthermore, the sizes of the bubbles decrease because of high pressure (Güney et al., 2002; Cowburn et al., 2006; Çınar et al., 2007). A similar situation is also valid for the cyclojet cell, the sizes of the bubbles formed decrease as the depth of the sublance increases. However, the number of the bubbles formed decreases because of the changing medium conditions and high pressure. The pictures of the bubbles (froth) obtained at conical tube submerging depths of 10 and 20 cm are given in Fig. 2. It can be seen clearly in Figure 2 that a more intense layer of froth and therefore more number of bubbles were formed at an immersion depth of 10 cm and a thinner layer of froth was formed at an immersion depth of 20 cm. While $Fe_2O_3$

content was 0.010% at the immersion depth of 10 cm, the $Fe_2O_3$ content increased to 0.050% at the immersion depth of 20 cm. A possible reason is that grains cannot spread into the cell completely at higher immersion depths and they by-pass and mix with feldspar product. In other words, the impurities that must be moved with the froth could not pass over the conical tube and by going down to the bottom of the cell they entered the channel from which the feldspar concentrate is taken. Furthermore, as a result of formation of bubbles in insufficient number, less amount of impurity moved into froth product and a part of the impurities remained in the feldspar concentrate.

## 3.2. Cyclojet flotation tests performed under optimum conditions

Several flotation tests were performed in the cyclojet cell with a reagent amount of 1500 g/Mg at a feeding pressure of 40 kPa conical jet lenght and immersion depth of 10 cm, with solid concentration of 30%. Flotation tests were performed at 5 different foam skimming times such as 2, 4, 6, 8, and 10 minutes. In other words, the concentrate and the reject were taken separately at the end of 2, 4, 6, 8 and 10 minutes and they were dried and then analyzed. Characteristics of the concentrates obtained for different flotation times are shown in Fig. 3.

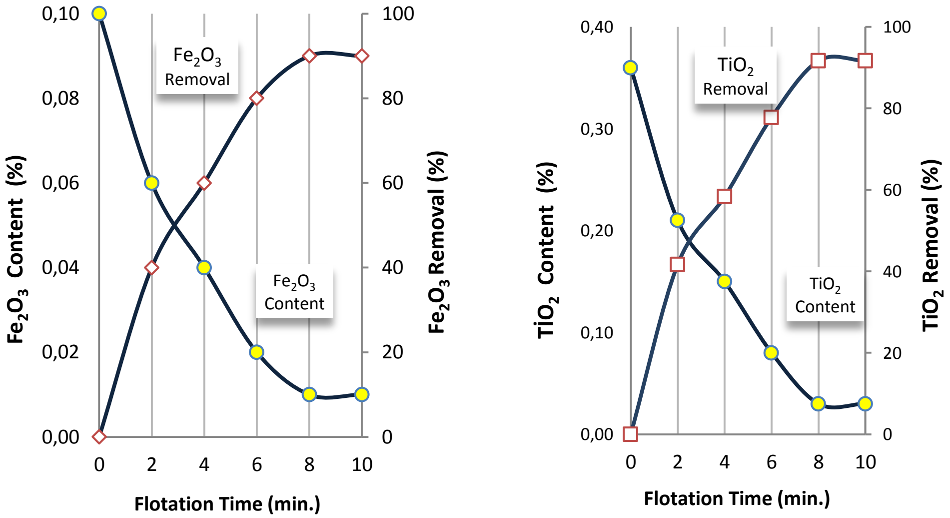

Fig. 3. $Fe_2O_3$ and $TiO_2$ content in concentrate and removal efficiency versus flotation time

As it was stated before, a by-pass was connected to the concentrate (feldspar) outlet pipe in the cyclojet cell. Feldspar concentrate obtained was transferred to the conditioner again through this by-pass pipe. Then, it was fed back to cyclojet cell by a centrifugal pump. Therefore, continuous flotation conditions are obtained in the cyclojet cell and products with different characteristics can be obtained with to the flotation time. As it can be seen in Fig. 3, the removal of both $Fe_2O_3$ and $TiO_2$

increased with increasing flotation time. While the $Fe_2O_3$ removal was 40% at the end of a flotation time of 2 minutes, it increased to 90% at the end of a flotation time of 10 minutes. A similar situation is also valid for $TiO_2$ because that the removal of $TiO_2$ at the end of flotation times of 2 and 10 minutes were 41.66% and 91.66%, respectively. Impurities which could not interfere with froth in the first stage interfere with froth in the second stage and then in the third stage and they were efficiently removed from the feldspar concentrate with increasing time of flotation. This situation has been clearly established in all the experiments. However, the contents of $Fe_2O_3$ and $TiO_2$ in the concentrates obtained at and after 8 minutes of flotation were similar. The amounts of the concentrate detected at the end of flotation times of 8 and 10 minutes were 75.40% and 66.10%, respectively. A further increase in the flotation time caused floating the feldspar grains and consequently a decrease in the weight of the concentrate. Therefore, the optimum flotation time for flotation of feldspar in cyclojet cell has been determined to be 8 minutes. At the end of this flotation time, the contents of $Fe_2O_3$ and $TiO_2$ have been detected as 0.010% and 0.030% respectively. The weights of the concentrate and the residue have been determined as 75.40% and 24.60%, respectively.

### 3.3. Comparison of the results obtained by cyclojet cell with the results obtained by mechanical cell and magnetic separator

Conventional flotation experiments were performed in Denver Model D-12 laboratory flotation cell having a volume of 3 $dm^3$. Following optimization studies, flotation was carried out under similar conditions with cyclojet cell. As reagent, a mixture of Aero 801 and Aero 825 with 50% mixing ratios and 1500 g/Mg dosage was used. Experiments were performed by using tap water and at natural pH (7-8). Mixer rotations and froth skimming time were chosen as 800 rpm and 10 minutes, respectively. Magnetic separation experiments were performed by using Boxmag Rapid LWHL type high field strength wet magnetic separator having maximum magnetic field strength of 1.9 T. This magnetic separator has a metal grade type matrix which can be moved between two fixed bobbin terminals. While the pulp was passing through the matrix, iron compounds are caught by the matrix. During preliminary experiments performed, pulp flow was too high because feeding size was too fine (-200 micrometers) and the hole between grade matrix was large (3000 micron meters). In this case, iron compounds could not be caught efficiently by the matrix. Therefore, periphery of grade matrix was surrounded with a wire matrix (Fig. 4) and the retention time of the grains in the matrix was increased. Then, the experiments have been carried out with a feeding velocity of 15 g/sec and at a solid rate of 30%. Obtained samples were passed through the magnetic separator 3 times. In other words, 3 stage cleaning process was performed.

Under similar conditions, the results obtained by cyclojet cell and mechanical cell are given together with the results obtained by magnetic separator in Table 2. Percentages of $Fe_2O_3$ and $TiO_2$ removal are shown in Fig. 5 comparatively. According to Table 1, while cyclojet cell was producing a feldspar concentrate containing 0.010% $Fe_2O_3$ and 0.030% $TiO_2$, mechanical cell produced a concentrate containing 0.010% $Fe_2O_3$ and 0.020% $TiO_2$. The $Fe_2O_3$ contents of both types of cell are the same, but $TiO_2$ contents are different. $TiO_2$ content of the concentrate obtained from the mechanical cell is lower. Possible reason for this situation is that the mechanical cell has smaller sizes and more favorable conditions for the removal of $TiO_2$ were present. On the other hand, the magnetic separator showed a similar performance with the cyclojet cell and mechanical cell in respect to $Fe_2O_3$ removal. The $Fe_2O_3$ content of the concentrate was detected as 0.01% with 90% removal efficiency. However, the magnetic separator showed poor performance for the removal of $TiO_2$. Since the minerals such as rutile and sphene forming the $TiO_2$ content have no magnetic sensitivity or too low sensitivity, these minerals were not caught by magnetic separator and merged into the concentrate.

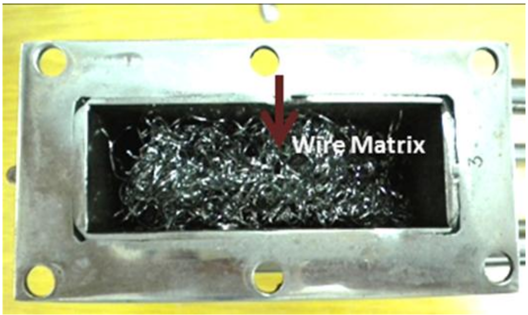

Fig. 4. View of wire matrix in wet magnetic separator

Table 2. Characteristics of the products obtained by cyclojet, mechanical cell and magnetic separator

| Devices | Concentrate (feldspar) | | | Reject (impurities) | | |
|---|---|---|---|---|---|---|
| | $Fe_2O_3$ content(%) | $TiO_2$ content(%) | Wt. (%) | $Fe_2O_3$ content(%) | $TiO_2$ content(%) | Wt. (%) |
| Cyclojet Flotation Cell | 0.010 | 0.030 | 75.400 | 0.376 | 1.371 | 24.600 |
| Mechanical Cell | 0.010 | 0.020 | 78.500 | 0.429 | 1.601 | 21.500 |
| Wet Magnetic Separator | 0.010 | 0.340 | 92.700 | 1.243 | 0.614 | 7.300 |

When examining the weights of concentrate, it is observed that the highest efficiency was obtained by magnetic separator and the lowest efficiency was obtained by cyclojet cell. The amounts of the concentrates obtained by magnetic separator, mechanical cell and cyclojet cell were detected as 92.70%, 78.50% and 75.4% respectively. During flotation process, at normal pH (7-8) feldspars can float in the froth and emerge into froth product (impurities) in the course of time, but the lack of this problem in magnetic separation is the main cause for the high gravimetric efficiency. The complete chemical analyses of the final concentrates obtained by 3 different devices are shown in Table 3 together with the analysis of the feldspar sample feed. As it can be seen from Table 3, the contents of the minerals such as $SiO_2$, $Al_2O_3$, CaO, MgO, $Na_2O$ did not changed drastically as a result of the enrichment of feldspar ore by flotation and magnetic separation. While the flotation reagent was floating $Fe_2O_3$ and $TiO_2$ minerals, magnetic field in the magnetic separator affected only $Fe_2O_3$ mineral in feldspar which has magnetic sensitivity.

Because of this situation, as it can be seen clearly in Table 3 (foam products) that the $Fe_2O_3$ content in the residue was 0.146% at a feeding pressure of 10 kPa and it increased to 0.270% at a feeding pressure of 40 kPa. Similarly, $TiO_2$ content in the residue was 0.776% and 0.965% at feeding pressures of 10 and 40 kPa respectively.

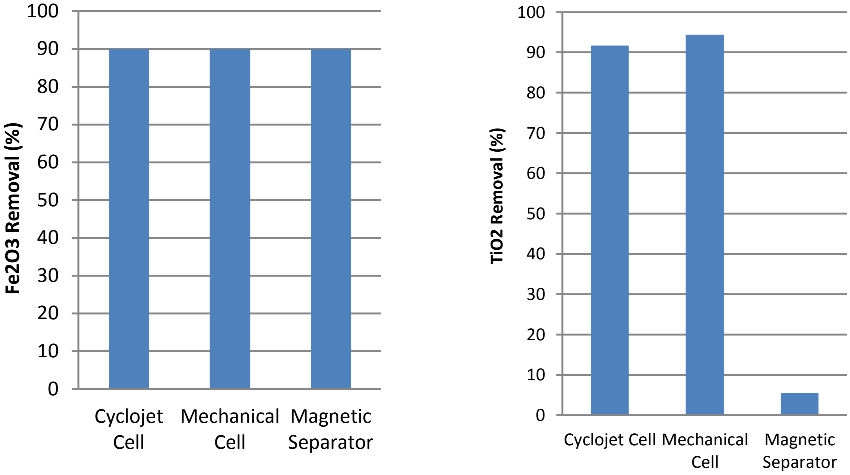

Fig. 5. Comparison of $Fe_2O_3$ and $TiO_2$ removal from feldspar by various devices

Table 3. Complete chemical analysis of feed and concentrates obtained from cyclojet, mechanical and magnetic separation

| Component | Feed % | Cyclojet Cell Concentrate, % | Mechanical Cell Concentrate, % | Magnetic Sep. Concentrate, % |
|---|---|---|---|---|
| $SiO_2$ | 67.380 | 67.810 | 67.920 | 67.540 |
| $Al_2O_3$ | 19.280 | 19.430 | 19.550 | 19.270 |
| $Fe_2O_3$ | 0.100 | 0.010 | 0.010 | 0.010 |
| $TiO_2$ | 0.360 | 0.030 | 0.020 | 0.340 |
| MgO | 0.250 | 0.010 | 0.010 | 0.100 |
| CaO | 1.080 | 0.950 | 0.940 | 1.150 |
| $Na_2O$ | 10.070 | 10.310 | 10.300 | 9.970 |
| $K_2O$ | 0.430 | 0.210 | 0.210 | 0.320 |
| $P_2O_5$ | 0.080 | 0.010 | 0.010 | 0.020 |
| MnO | 0.010 | 0.010 | 0.010 | 0.010 |
| $Cr_2O_3$ | 0.002 | 0.002 | 0.002 | 0.020 |
| Others | 0.058 | 0.060 | 0.060 | 0.078 |
| L.O.I. | 0.900 | 1.140 | 0.980 | 1.170 |

## 4. Conclusion

It is known that the coloring minerals found in feldspar ore can be removed by various methods. It has been observed that 90% of $Fe_2O_3$ can be removed by the performed flotation and magnetic separation processes, but $TiO_2$ content can only be removed by flotation. As a result of cyclojet flotation experiments $TiO_2$ content was reduced from 0.360% to 0.030%, and by magnetic separation $TiO_2$ content was reduced in a negligible amount down to 0.34%. Similarly, $TiO_2$ content was reduced down to 0.020% by the conventional flotation cell. On the other hand, all 3 devices showed similar performances in respect to $Fe_2O_3$ removal. The reason of this situation is that $Fe_2O_3$ mineral has magnetic sensitivity, but $TiO_2$ mineral have no magnetic sensitivity or low magnetic sensitivity. It is clearly seen from the results of this study that for the ores containing small amounts of $\text{T\.{I}O}_2$ only magnetic separation is sufficient, but for the ores containing high amount of $TiO_2$ cyclojet or mechanical cell can be used.

**Acknowledgement**

The authors would like to give a special thanks to Esan Inc. for the supply of the samples and XRD analyses.

### References

ANONYMOUS, 2010, *Feldspar Report*, TMMOB Chamber of Mining Engineers. No.169; ISBN:978-99444-89-905-5.

BAYRAKTAR, I., ERSAYIN, S., GÜLSOY, O.Y., 1998, *Magnetic separation and flotation of albite*, Innovations in Mineral Processing, Atak, Önal & Çelik (eds), Balkema, Rotterdam, ISBN:90-5809-013-2.

BAYRAKTAR, L., ERSAYIN, S., GÜLSOY, Ö.Y., 1997, *Upgrading titanium bearing Na-feldspar by flotation using sulphonates, succinamate and soaps of vegetable oils,* Miner. Eng. 12(1), 1363–1374.

COWBURN, J., HARBORT, G., MANLAPIG, E., POKRAJCIC, Z., 2006, *Improving the recovery of coarse coal particles in a Jameson cell*, Miner. Eng., 19 (6-8), 609–618.

ÇINAR, F., ŞAHBAZ, O., ÇINAR, M., ÖTEKAYA, B.,KELEBEK, Ş., 2007, *A parametric study on Jameson cell flotation of quartz*, XII Balkan Mineral Processing Congress, 10-14 June, Delphi, Greece, 251–256.

DOĞU, I., AROL, A.I., 2004, *Separation of dark-colored minerals from feldspar by selective flocculation using starch*, Powder Technol. 139, 258–263.

El-REHIEM, F.H., ABD EL-RAHMAN, M. K., 2008, *Removal of coloring materials from Egyptian albite ore*, Trans. Inst. Min. Metall., Sect. C. 117(3), 171–174.

GÜNEY, A., ÖNAL, G., ERGUT, Ö., 2002, *Benefication of fine coal by using the free jet flotation system*, Fuel Process. Technol. 15, 141–150.

HACIFAZLIOGLU, H., 2009, *Development of a new flotation machine (cyclojet cell) for flotation of fine coals*, Ph.D.Thesis, Karaelmas University, Zonguldak, Turkey.

HACIFAZLIOGLU, H., TOROĞLU, I., 2008, *Flotation of Bituminous Coal Slimes in the Cyclojet Cell and a Comparison of Cyclojet Cell and Jameson Cell in Terms of Their Flotation Performance*, Min. J. 47(1), 3–12.

KARAGÜZEL, C., ÇOBANOĞLU, G., 2010, *Stage-wise flotation for the removal of colored minerals from feldispathic slimes using laboratory scale Jameson cell*, Sep. Purif. Technol. 74, 100–107.

KANGAL, O., GUNEY, A., 2002, *Beneficiation of low-grade feldispars using free jet flotation*, Miner. Process. Extr. Metall. Rev. 23(3-4), 129–140.

STYRIAKOVAA, I., STYRIAK,I., MALACHOVSKY, P., LOVASA, M., 2006, *Biological, chemical and electromagnetic treatment of three types of feldspar raw materials*, Miner. Eng. 19(4), 348–354.