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Reduce the Iron Content in Egyptian Feldspar Ore of Wadi Zirib for Industrial Applications

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Abstract The presence of coloring materials such as iron oxides in feldspar decreases its quality. To use feldspar minerals in industry, some upgrading processes should be executed to remove impurities. The most important uses of feldspar are in ceramic and glasses. The present paper aimed to reduce the iron content in Wadi Zirib feldspar ore, as well as, to obtain an optimal grade of feldspar concentrate for some industrial applications. The first processing stage was the disposal of slime's fraction (-38 µm) which contains clay minerals. Comminution and de-sliming processes removed about 30% of iron content into -38 µm fraction. The attrition process removed only about 6% of iron content. A dosage of 97 gm/ton of Quaternary ammonium salt solution was an optimum value for mica's minerals flotation where the percentage of Fe_2O_3 was about 13.65% with mass recovery of 0.44% and component recovery of 9.84%. The rejected percentage of valuable minerals into the floated mica's minerals didn't exceed 0.5%. A flotation test was carried out at optimum conditions for flotation of feldspar minerals. The mass recovery of feldspar concentrate was 52.11% of feed (-250+38) µm. At such optimum conditions, a suitable feldspar concentrate was obtained with 0.4% Fe_2O_3. The component recovery of iron content removed into feldspar tailing was about 56%. The specifications of feldspar concentrate obtained in this research fulfilled the requirements of some industries, i.e. glass, ceramic vitreous tiles, and semi vitreous tiles. The final results revealed that the total disposal percent of iron content was about 75% of that present into the feed head sample.

Keywords Flotation, Feldspar, Mica's minerals, Ceramics, Glass

1. Introduction

Feldspar is one of the most common minerals in the world where it forms about 60% of the rocks of the earth's crust [1-6]. Orthoclase (K-feldspar), albite (Na-feldspar) and anorthite (Ca-feldspar) are the most widespread feldspar minerals. The most associated minerals into feldspar ore are clays, mica's minerals (i.e. biotite and muscovite), tourmaline, rutile, and sphene [6-10]. The presence of coloring materials such as iron oxides and rutile decreases the quality due to forming a black spot in the product body during firing process [10]. To use feldspar minerals for different industrial applications, some upgrading processes should be executed to remove impurities [11].

Feldspar mineral intervenes in the ceramic and glass industries. Seventy percent of feldspar minerals productions in the world are used in manufacture of glass products, i.e. insulation fiberglass [12]. The rest is used in ceramic products and other applications such as fillers and extenders in plastics, paints, rubber, welding electrode, polymer, paper, and paint industries [4-5, 11].

The most efficient method for upgrading and removing the coloring materials from feldspars is magnetic separation. A High intensity magnetic separator is employed for the low iron content ores. Flotation is the most method that can handle many feldspar ores with different iron contents [8, 11].

Generally, the first processing stage of feldspar ore is to get rid of slimes which is usually clay minerals [9]. Slime fraction is about -38 µm which produces larger surface areas and consequently causes excess in collector consumption [13]. Feldspar can be separated from the associated minerals by using multi-stage flotation processes.

Quaternary ammonium salt and dodecylamine can be used as mica's mineral cationic collectors [14]. All mica's minerals can be readily floated in an acidic medium around a pH of 2 with a cationic collector at a dosage of about 0.1-0.5 kg/ton. Under these conditions, neither quartz nor feldspar will float unless activated [3, 15]. Feldspars are floated from quartz using primary long-chain alkyl amine cationic collectors at acidic medium [4].

Abdel-Khaled et. al. [16] used quaternary ammonium salt as a cationic collector for feldspar flotation. Sekulic et. al. [17] compared between different types of cationic collectors like Flotigam DAT, Armoflot 64, and Aero 3030C for

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flotation of feldspar and mica. They revealed that Aero 3030C was more selective and preferred in feldspar and mica's mineral flotation. The present paper aimed to reduce the iron contents of Wadi Zirib feldspar ore and also to obtain an optimal commercial grade of feldspar which is convenient for some industrial applications.

2. Experimental Work

2.1. Geology

The barrier of Wadi Zirib feldspar ore is considered the intersection of Wadi Al-Asyud with Wadi Bayda Al-Atshan which is located at the Eastern Desert, Egypt. The entrance of Wadi Zirib is 15 Km away from qusier on qusier Marsa Alam paved road. Wadi Zirib area lies between latitudes 25° 59' and 25° 01' N and longitudes 34° 11' and 34° 14' E as shown in Fig. 1 [18]. This region extends from north to south for about 10 Km. The topography of this area is mostly granitic rocks containing feldspar minerals. The average percentages of K_2O and Na_2O are about 4.5 and 4.0%, respectively. The basement rocks are of Precambrian age. They are classified into four outcrops. The youngest one is granite, the younger is gabbro, the older is granitoids and the oldest one is meta-volcanic. The emplacement of the granitic pluton is followed by injection of dykes and veins of different shapes and composition [18].

2.2. Procedure

The sample used in the present work was crushed to -10 mm in a laboratory jaw crusher then to -5 mm in a small jaw crusher. The -5 mm sample was crushed to -2 mm using a roll crusher in a closed circuit with 2 mm sieve. The roll crusher product was ground to -250 µm using a porcelain mill in a closed circuit with 250 µm sieve. The slimes (-38) µm was separated by wet screening.

An attrition process was carried out on the fraction (-250+38) µm in an attrition apparatus. The attrition process was executed at optimum conditions with solids percent of 65% and 1430 rpm impeller speed for 15 min. The attrition product was wet sieved on a screen of 38 µm.

The fraction (-250+38) µm, obtained from comminution process, was used for mica's minerals flotation experiments. A flow sheet of comminution and attrition processes of feldspar sample was illustrated in Fig. 2.

Laboratory flotation tests were carried out in a 3 L Wemco Fagergren cell. All flotation tests were carried out at acidic medium with pH of ≈ 3. The impeller speed was fixed at 1200 rpm and an aeration rate of 6 L/min was used. All tests were performed at room temperature. The total conditioning time was 7 min and the solids percent are about ≈ 25%.

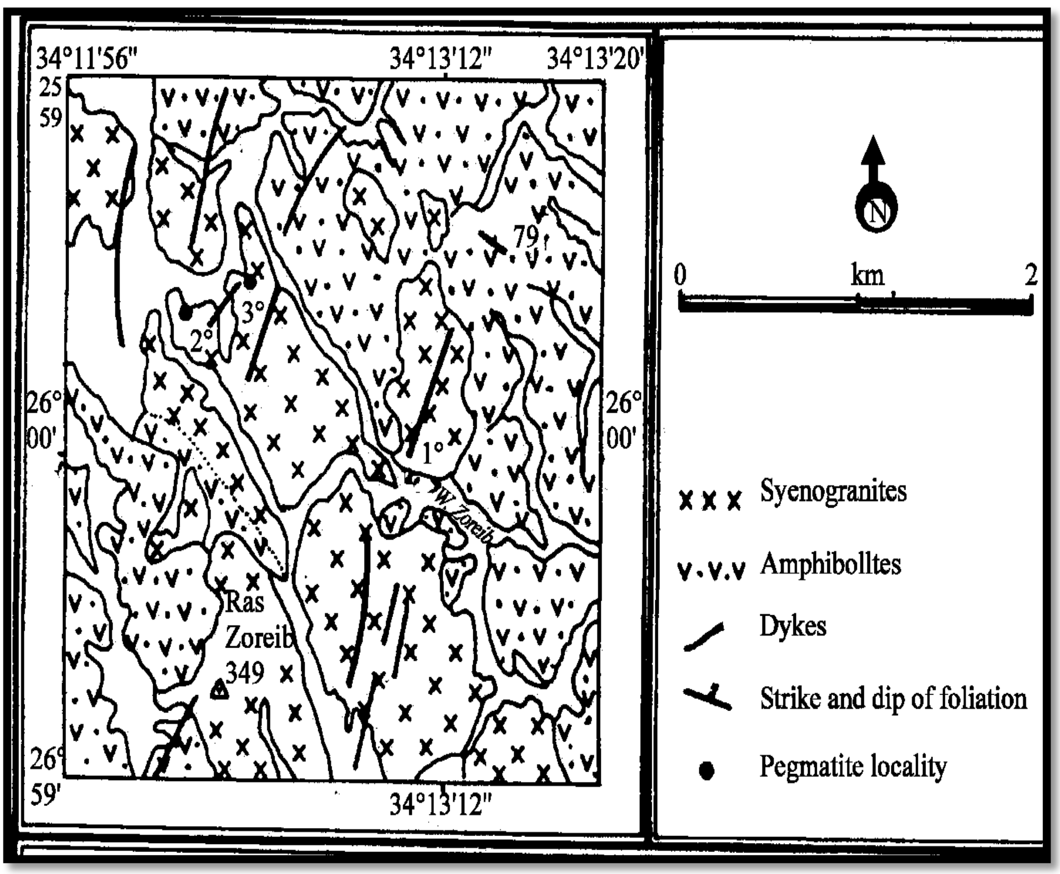

Figure 1. A geological map of Wadi Zirib area, Eastern Desert, Egypt [18]

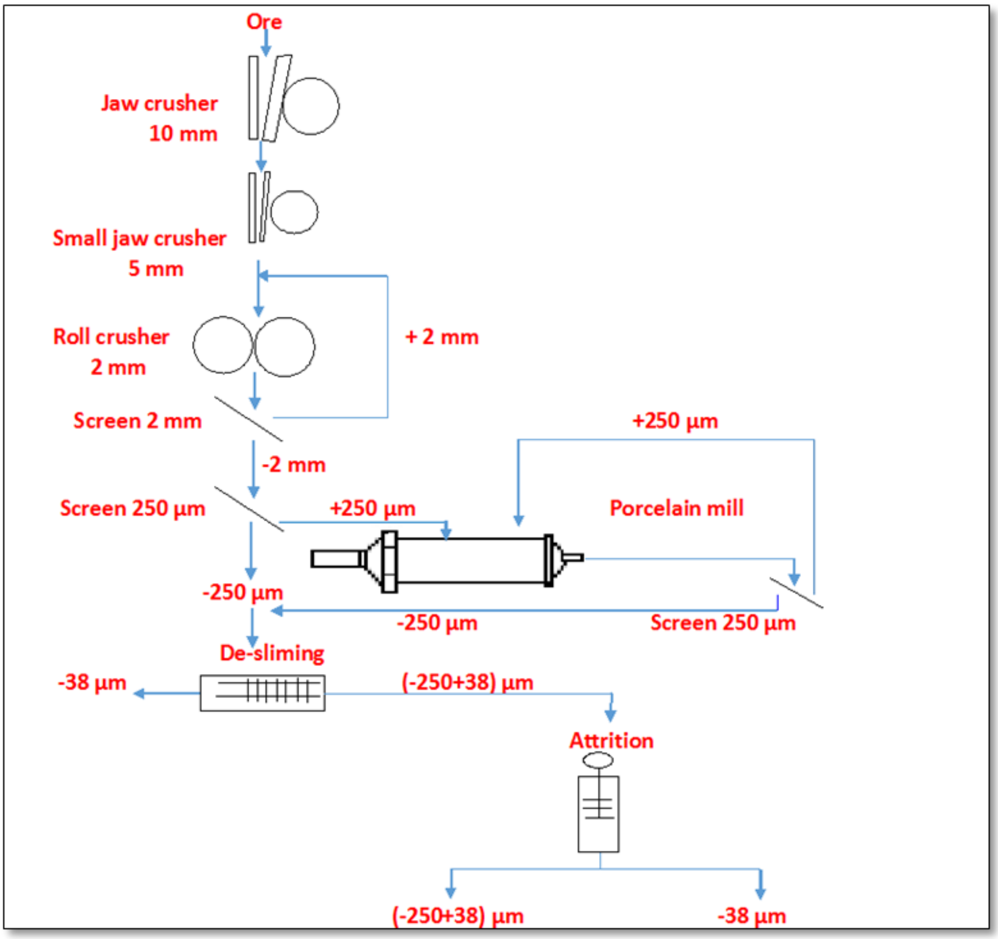

Figure 2. Flow sheet of comminution and attrition processes of head sample

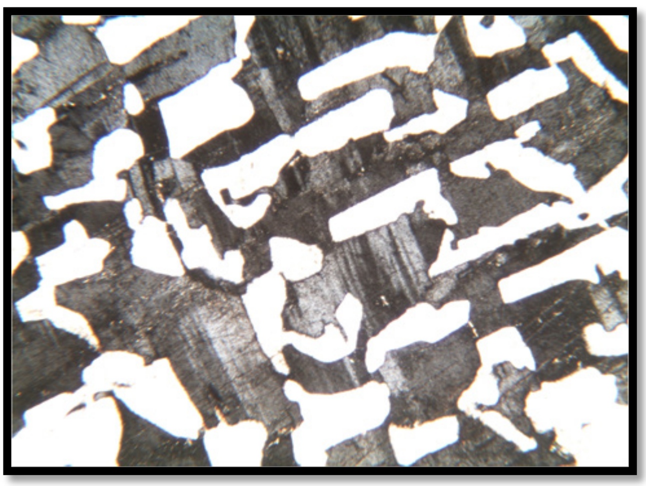

Figure 3. Photomicrograph showing graphic texture (25 X, C.N)

In order to remove the mica's minerals and consequently reduce the iron content, a cationic collector was used [3, 6, 15]. All the mica's minerals flotation tests were executed using quaternary ammonium salt solution. The collector dosage was changed from 97 to 291 gm/ton. The used frothing agent was pine oil. Sulfuric acid was used as a pH modifier. After flotation of mica's minerals, the tailings were dewatered and washed many cycles to disengage residual reagents on particles [9]. The tailings were taken as a feed sample for the flotation of feldspar.

Quaternary ammonium salt solution was used again as a cationic collector to separate feldspar from quartz in an acidic medium. Quaternary amines are strong collectors and are completely ionized at all pH values, while ionization of primary, secondary and tertiary amines depends on pH values [9, 16]. The flotation test of feldspar was carried out at pH ≈2.5 [3, 16]. Hydrofluoric acid was used as a depressant agent for quartz with 2000 gm/ton [3, 5, 19]. A dosage about 582 gm/ton of quaternary ammonium salt solution was used. Pine oil was used as a frother. The impeller speed was fixed at 1200 rpm and the total conditioning time was 8 min.

3. Results and Discussions

3.1. Mineralogical Description

The microscopic study of the samples illustrated that the rock containing feldspar minerals is holocrystalline, hypidiomorphic with equigranular textures. They are composed mainly of potash feldspar, quartz and plagioclase in variable proportions and minor amounts of muscovite, biotite, and rare opaque minerals. Plagioclase crystals are coarse to medium grained. Sometimes the outlines of plagioclase phenocrystals are corroded by quartz having graphic texture as shown in Fig. 3. Fresh plagioclase crystals showed albite and pericline twining. They were partially to completely altered to sericite and clay minerals as illustrated in Fig. 4.

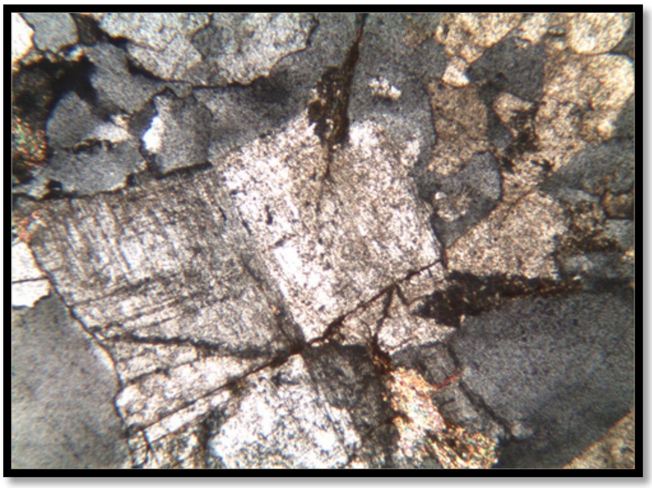

Figure 4. Photomicrograph showing plagioclase cracked which partially altered to sericite and clay minerals (25 X, C.N)

Potash feldspar is the major constituents of the rock and is represented by microcline and orthoclase which occurred as coarse to medium-grained anhedral crystals and partially altered to clay. Potash feldspar intergrowths with graphic quartz and forms distinctive graphic texture in all parts of the rock. Quartz is considered an essential mineral constituent. It occurs as anhedral, medium to coarse crystals including intergrowth with potash feldspar and having graphic texture.

Muscovite presents as fine to very fine flakes scattered in potash feldspar and plagioclase and was partially altered to chlorite and iron oxides. Mafic minerals are represented by minor amount of muscovite and biotite. They occur as fine flaky crystals at the boundaries of essential constitutes. Biotite was partially to highly altered to iron oxides and chlorite as shown in Fig. 5. Opaque minerals are present in rare amounts as fine to very fine grained single crystals and aggregates scattered in the rock. They commonly associated with altered biotite as shown in Fig. 6.

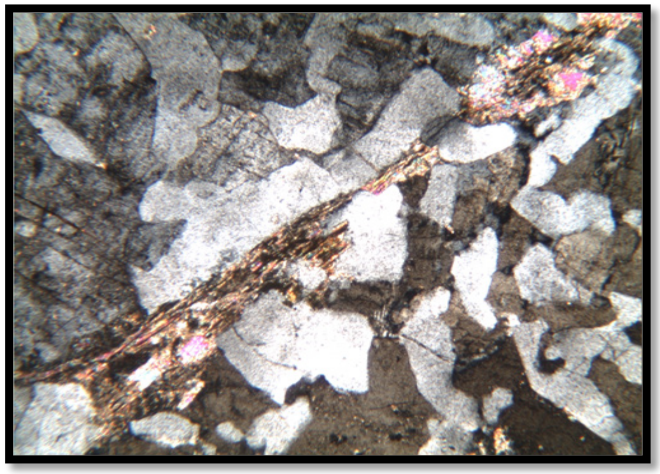

Figure 5. Photomicrograph showing biotite partially altered to iron oxides, muscovite and chlorite (25 X, C.N)

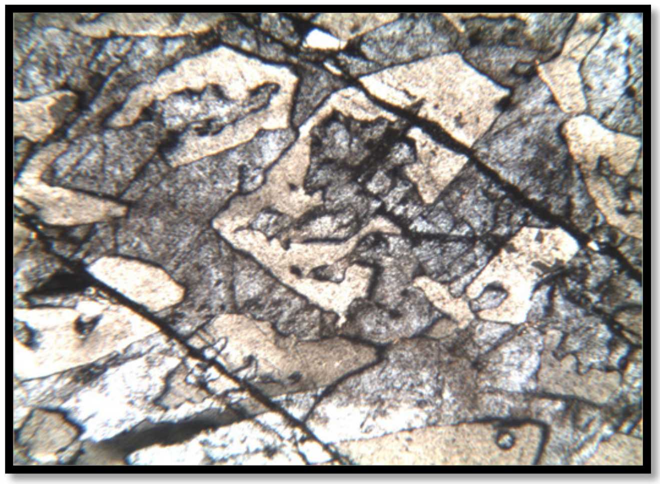

Figure 6. Photomicrograph showing micro fracture partially filled with opaque minerals which cutting across essential mineral constituents and takes nearly the same directions (25 X, C.N)

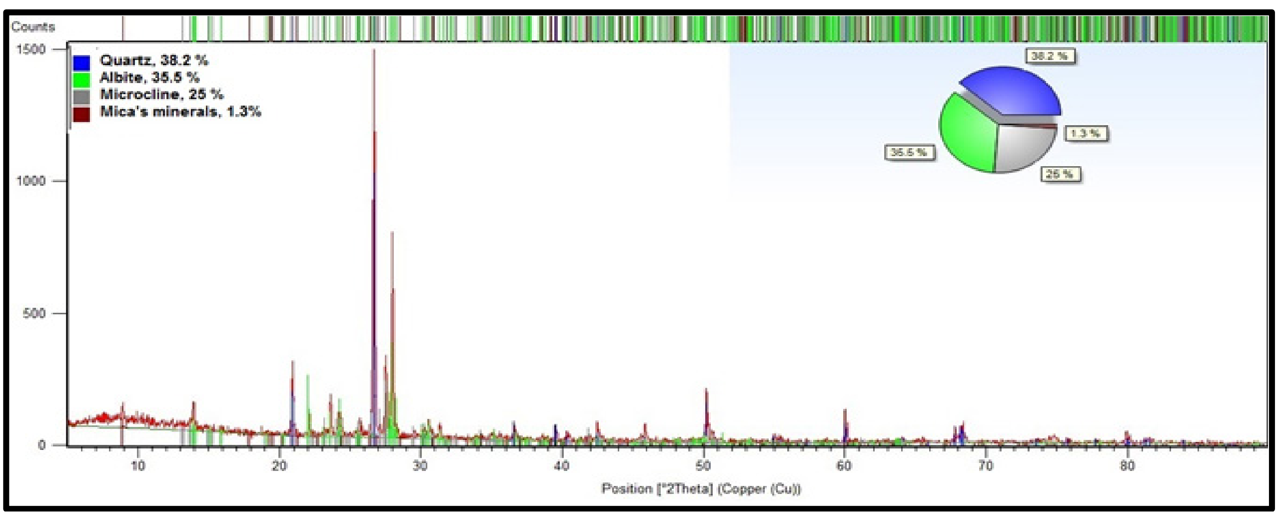

Figure 7. XRD results

3.2. Sample Analysis

The chemical composition of feed sample was obtained by XRF analysis as follows: 75.1% SiO_2, 14.0% Al_2O_3, 0.07% TiO_2, 0.71% Fe_2O_3, 4.0% Na_2O, 4.5% K_2O, 0.16% MgO, 0.61% CaO and 0.46 L.O.I. The results of XRD analysis revealed that the main minerals in feldspar ore are quartz, albite, and microcline and the secondary minerals are mica's minerals (i.e. muscovite, biotite, chlorite, rare opaque minerals, and iron oxides) as illustrated in Fig. 7.

3.3. Method Description

The present work explained the possibility of reducing the percentage of iron content into the feldspar ore to be suitable for industrial applications. Figures 8 and 9 showed the final results of preparation the head sample to flotation process. These figures included flowcharts of the comminution and de-sliming processes of the head sample. The results showed that these processes reduced the percentage of Fe_2O_3 from 0.71% into the head sample to 0.61% into (-250+38) µm fraction with a mass recovery of 81.53%. The component recovery of Fe_2O_3 was about 70%. The final results are illustrated in Table 1. The obtained results revealed that comminution and de-sliming processes removed about 30% of iron content into fraction -38 µm. The diminution of Fe_2O_3 by comminution processes suggests that iron is not completed to feldspars and should be related to Fe-associated minerals. The comminution process liberated the associated minerals that contain part of iron from the feldspar.

Table 1. The final results of comminution and de-sliming processes

Fraction	(-250+38) µm	-38 µm
Mass recovery, %	81.53	18.47
Fe_2O_3, %	0.61	1.151
Component recovery of Fe_2O_3, %	70.05	29.95

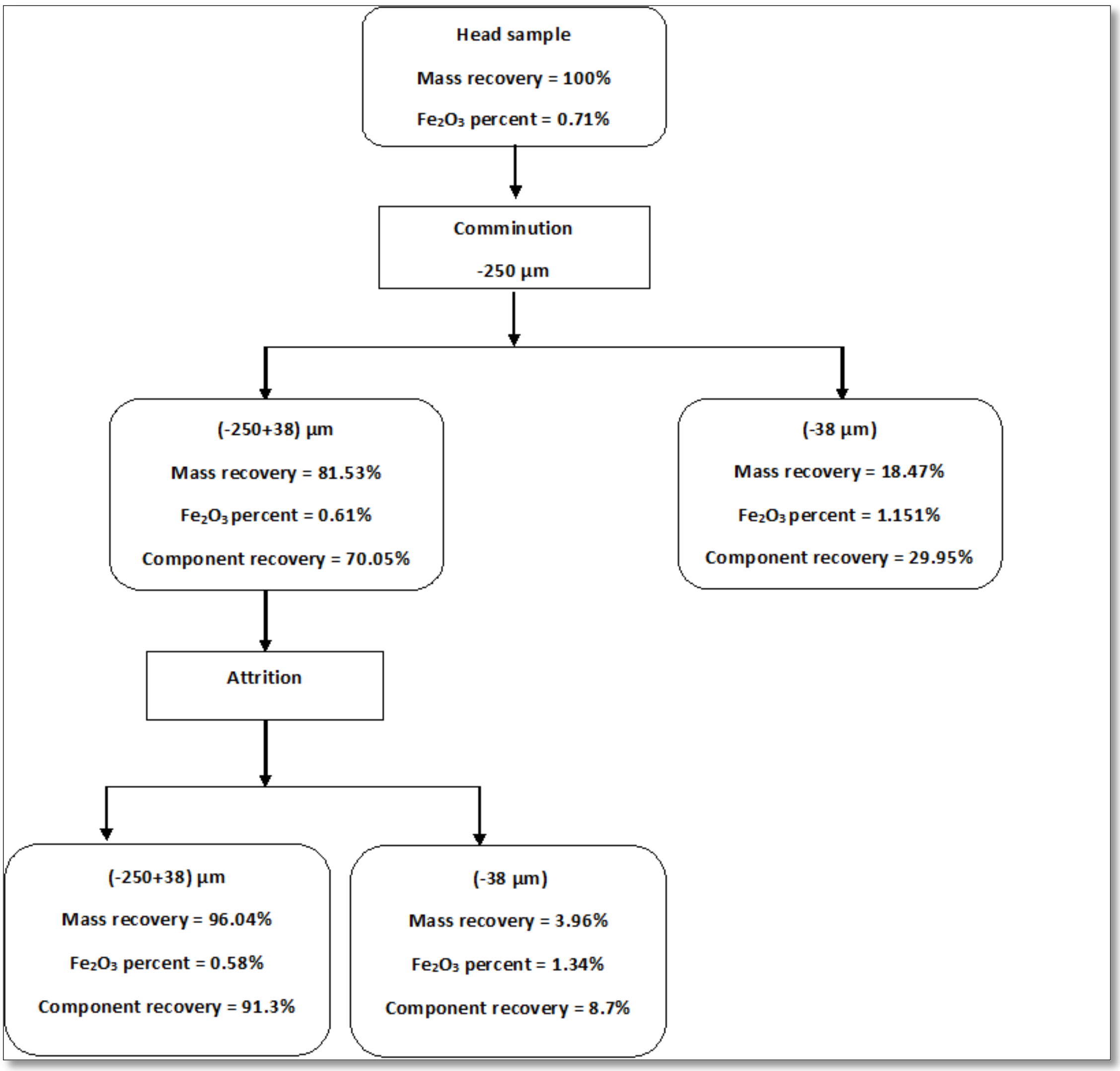

Figure 8. Flow sheet of the results of comminution and de-sliming processes of head sample

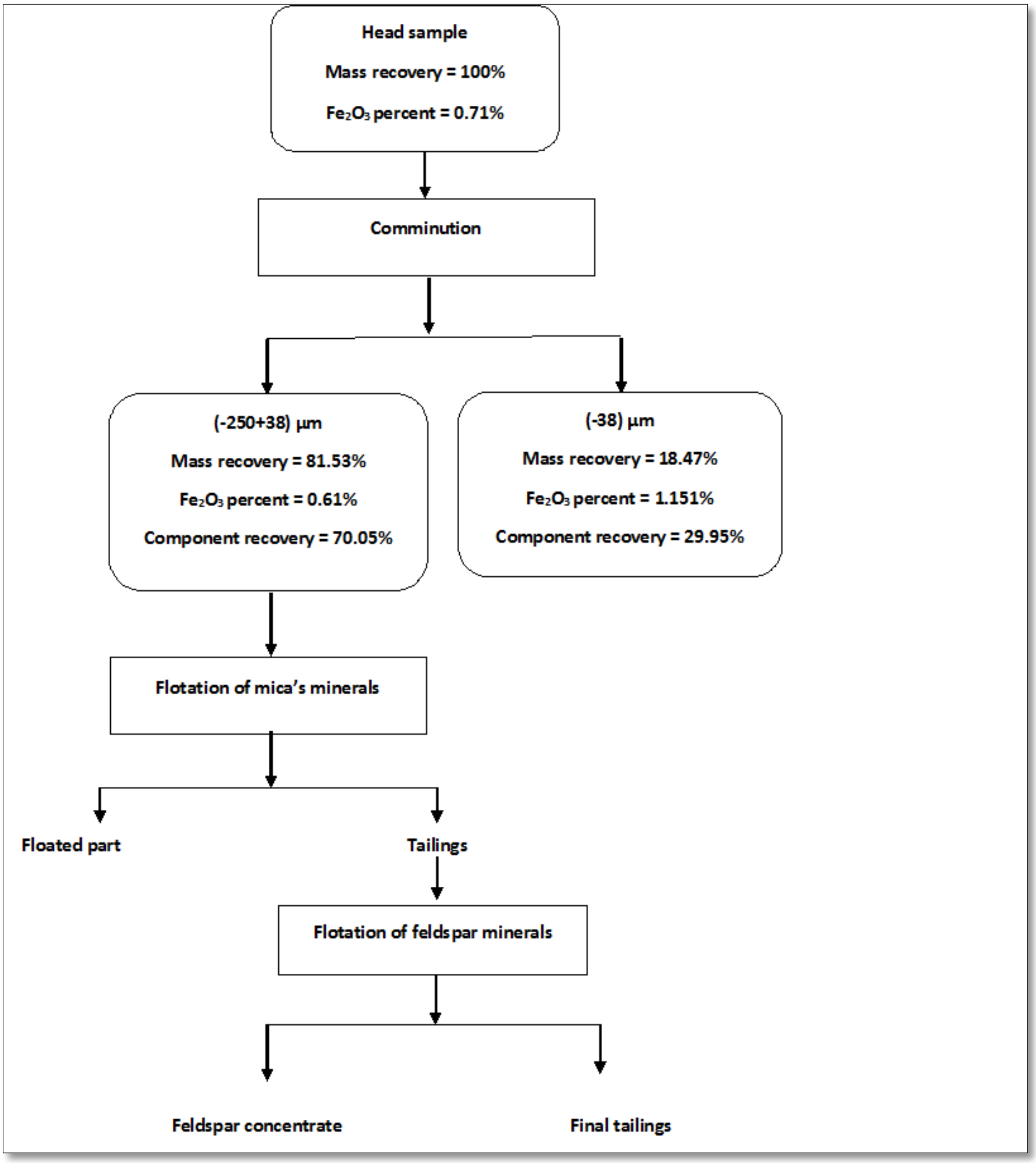

Figure 9. The final results of head sample to flotation process

Attrition process was carried out to the fraction (-250+38) µm. This process reduced Fe_2O_3 percent from 0.61% to 0.58%. This process removed only 6.09% of Fe_2O_3. This means that the attrition process didn't reduce the iron content with promising percent. The final results of attrition process were tabulated in Table 2.

Table 2. Mass recovery, Component recovery and Fe_2O_3% into (-250+38) µm fraction before and after attrition process

	Mass recovery, %	Fe_2O_3, %	Component recovery of Fe_2O_3, %
Before attrition	81.53	0.61	70.05
After attrition	78.30	0.58	63.96

Table 3 and Fig. 10 illustrated the effect of changing the dose of quaternary ammonium salt solution on the flotation of mica's minerals and consequently on the reduction of iron content into the samples. These results indicated that a slight increase of collector consumption from 97 to 291 gm/ton caused an apparent increase in mass recovery from 0.44% to 5.33%. The results in Table 3 and Fig. 11 showed that as the concentration of collector increased from 97 to 291 gm/ton, the percentage of Fe_2O_3 in floated mica's minerals decreased from 13.65% to 1.69%. The results of component recovery of Fe_2O_3 in floated part shown in Table 3 and Fig. 12 indicated that the component recovery slightly decreased to 7.39% with increasing the amount of collector dosage to 194 gm/ton and above this value it began to increase again. The component recovery reached to 14.77% with 291 gm/ton collector dosage.

The addition of collector to float the wanted minerals is usually in small amounts. The used dosages are those required to form a monomolecular layer on particle surfaces. The increased dosages, apart from cost, tend to float other minerals, and consequently reducing selectivity. An excessive concentration of a collector can have an adverse effect on the recovery of the floatable minerals, possibly due to the development of collector multi-layers on the particles [20].

The further increase in collector dosage decreased the selectivity of flotation process of mica's minerals, i.e. reduced the percentage of Fe_2O_3. This is due to the flotation of valuable minerals with mica's minerals. From the above discussion, it seemed that a value of 97 gm/ton of quaternary ammonium salt solution is considered an optimum dosage for mica's minerals flotation where the percentage of Fe_2O_3 is the maximam one (13.65%).

Table 3 and Fig. 12 revealed also the component recovery of valuable minerals in floatable part. From these results it can be shown that the values of component recovery increased from 0.38% to 5.24% with increasing the collector dosage from 97 to 291 gm/ton. The results showed that the rejected percentage of valuable minerals into floated mica's minerals didn't exceed 0.5% in the selected experiment.

The tailings of mica's minerals that obtained from the suitable flotation experement, i.e. 97 gm/ton collector dossage were dewatred and washed many times before fed to the next flotation process. Quaternary ammonium salt solution was used again with dossage of 582 gm/ton for flotation of feldspar minerals. The flotation test was carried out at pH ≈ 2.5. Hydrofluoric acid was used as a depressant agent for quartz with a dossage of 2000 gm/ton [3,19]. At such optimum conditions, a suitable feldspar concentrate with 0.4% Fe_2O_3 was obtained. The compelete XRF analysis of feldspar concentrate was given in Table 4. The mass recovery of feldspar concentrate was 52.11% of the feed (-250+38) µm. The component recovery of iron content into the feldspar concentrate was 34.17%.

From Table 4, it can be seen that the feldspar concentrate satisfied the requirements for glass and ceramic industries.

The upper limits of feldspar composition to be used in glass and ceramic industries were given by the Bureau of Indian Standards (BIS). These spasifications were as follows: Max percent of Fe_2O_3 = 0.5%, the sumation of CaO and MgO = 1.0%, K_2O = 9%, Na_2O = 6%, and the sum of K_2O and Na_2O is approximately 13% [7].

Another classification of commercially acceptable feldspars are typically as follows: the sumation of Na_2O and K_2O is about (11–13)%, the sumation of CaO and MgO is less than 1.5%, the tatal amounts of Fe_2O_3 and TiO_2 are about (0.07–0.3)% and the free quartz is nearly (8–10)% [13].

Other chemical compositions of the main ingredients of commercial ceramic grade feldspar were as follows: SiO_2 is approximately 75%, Al_2O_3 is about 15%, Fe_2O_3 is nearly 0.3%, K_2O and Na_2O are about 3.3% and 4.5%, respectively [21].

From Table 4, it can be shown that the feldspar concentrate obtained from the present paper is suitable also for the vitreous tiles and semi-vitreous tiles industries according to Ghiani et. al. classification [22]. This classification is as follows: the sum of Na_2O and K_2O is between 8-9%, Fe_2O_3 percent is less than 0.5% for vitreous tiles and less than 1% for semi-vitreous tiles, and the percent of TiO_2 in vitreous tiles and semi vitreous tiles is less than 0.3% and 0.6%, respectively.

From above details and our results, it can be concluded that the feldspar concentrate specifications obtained in this reserch fulfilled the requirements of glass, ceramic,vitreous tiles, and semi vitreous tiles industries [2, 7, 13, 21-22].

Table 5 showed the final calculations of mass recovery, grade and component recovery of Fe_2O_3 in different products. The final calculations assured that the total percent of iron content which was removed into the final tailings represented about 75% of total iron present into feed head sample.

Table 3. Effect of collector dosage on the grade and recovery of floated mica's minerals

Collector dosage, gm/ton	Mass recovery, %	Fe_2O_3, %	Component recovery of Fe_2O_3 in floated part, %	Component recovery of valuable minerals in floated part, %
97.0	0.44	13.65	9.84	0.38
145.5	0.87	6.20	8.84	0.82
194.0	2.30	1.96	7.39	2.26
242.5	4.11	1.68	11.32	4.05
291.0	5.33	1.69	14.77	5.24

Table 4. XRF analysis of feldspar concentrate

Mineral	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	Cl	L.O.I.
%	69.04	0.4	17.34	0.4	0.01	0.17	0.69	5.26	6.26	0.01	0.03	0.05	0.67

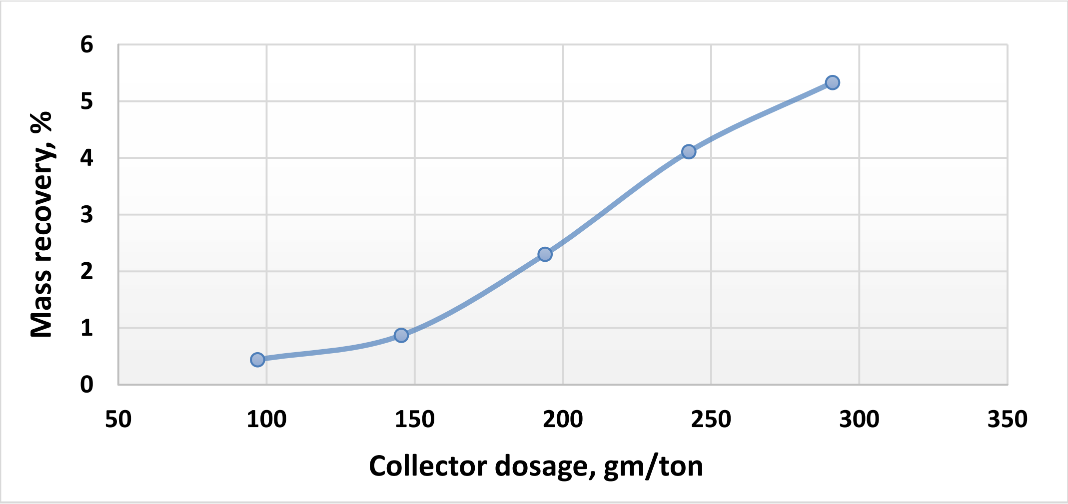

Figure 10. Effect of collector dosage on mass recovery of floated mica's minerals

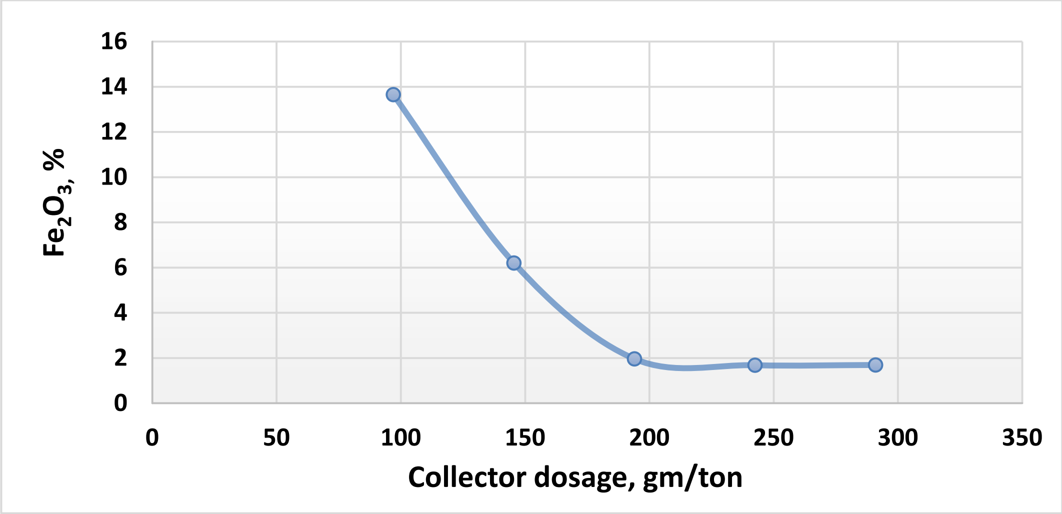

Figure 11. Effect of collector dosage on percent of Fe_2O_3 in floated mica's minerals

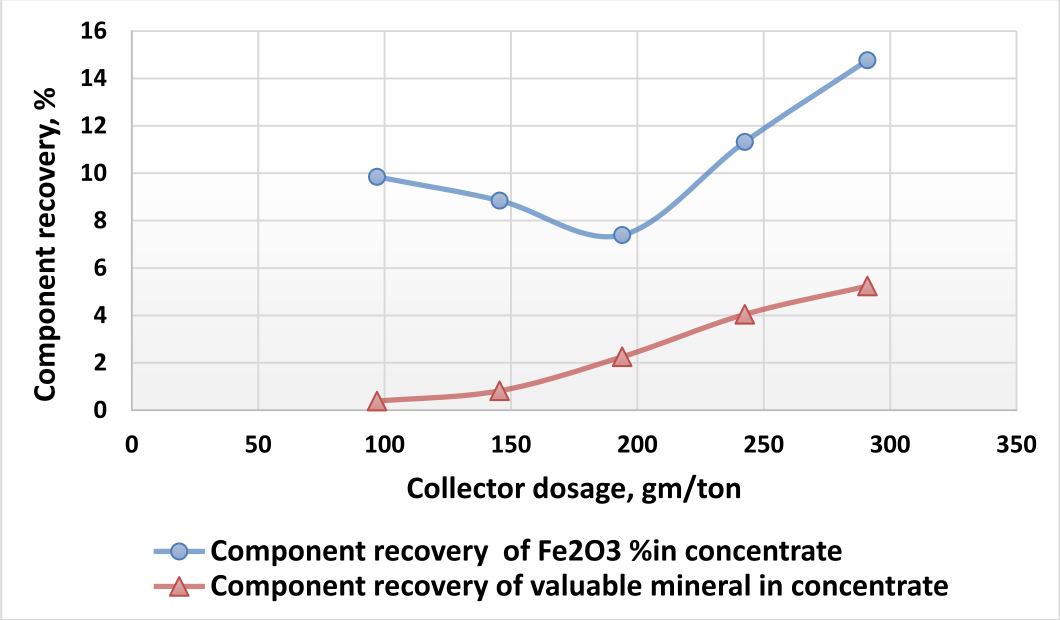

Figure 12. Effect of collector dosage on component recovery of mica's minerals and valuable minerals into floated part

Table 5. Final calculations of mass recovery, grade and component recovery of Fe_2O_3 in the final products

	Mass recovery, %	Fe_2O_3%	Component recovery, %
Head sample	100	0.71	100
-38 µm	18.47	1.16	29.95
(-250+38) µm	81.53	0.61	70.05
Mica's minerals	0.44(0.36*)	13.65	9.84(6.89*)
Feldspar concentrate	52.11(42.48*)	0.4	34.16 (23.94*)
Tailings	47.45(38.69*)	0.72	56.00(39.22*)

*These percentages were calculated according to original feed (Head sample)

4. Conclusions

1. The comminution and de-sliming processes reduced the percentage of Fe_2O_3 from 0.71% into the head sample to 0.61% into (-250+38) µm fraction with a mass recovery of 81.53%. The component recovery of Fe_2O_3 content was about 70%. These processes removed about 30% of iron content into fraction of -38 µm.
2. The attrition process decreased the percent of Fe_2O_3 from 0.61% to 0.58%. This process removed only 6.09% of the iron content into fraction of -38 µm.
3. a dosage of 97 gm/ton of quaternary ammonium salt solution is an optimum for mica's minerals flotation where the percentage of Fe_2O_3 was the maximam one (13.65%).
4. A feldspar concentrate with 0.4% Fe_2O_3 and mass recovery of 52.11% were obtained. The component recovery of iron content removed into the tailings of feldspar flotation was about 56%.
5. Feldspar concentrate specifications obtained in this reserch fulfilled the requirements for glass, ceramic, vitreous tiles, and semi vitreous tiles industries.
6. The total iron content removed into the final tailings represented about 75% of the total iron present into original feed sample.

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