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Different Methods of Beneficiation of Feldspar, Mini Review

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Abstract
Feldspar is a valuable raw material in the manufacture of glass, ceramic, fillers, enamel Frits, and welding electrodes. Feldspar is the single most abundant mineral in the earth's crust and is generally associated with other silicate, titanium, and iron minerals. As a result, beneficiation of feldspar is necessary to obtain high-grade materials for industrial uses. However, the beneficiation of feldspar ores from other silicate gangues is very difficult owing to their similarities in physical–chemical properties. Hydrofluoric acid (HF), which is the main regulator used in the flotation of feldspar, may cause serious environmental and health-related problems. Therefore, to satisfy the quality of advanced materials, the concentration of feldspar using clean and efficient methods remains a formidable challenge. This paper reviews importance of feldspar all over the world, the beneficiation technology and mechanism of feldspar proposed in the literature to identify the important parametersand best methods to upgrade feldspar.

Keywords
Feldspar,Flotation, High-grade products,Çine-Ceyhan, Abu Dabbab, Gafsa, Wadi Zirib, Thailand, Milas-Mugla.

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I. INTRODUCTION

Feldspars are a group of rock-forming tectosilicate minerals, which are the most widespread consequential mineral group in the world, composing about 60% of the earth's crust. Feldspar occurs in granites, transit, syenite and pegmatites, together with quartz and mica minerals. It is an igneous rock which contains mainly aluminum silicates in a combination with Na, K and Ca as an alkali ion. Commercial feldspars are as follows; albite ($NaAlSi_3O_8$), anorthite ($CaAl_2Si_2O_8$) and orthoclase ($KAlSi_3O_8$). Albite is a famous mineral inthe series of plagioclase feldspar. Albite is characterized by its luster appearance as its color could be white, gray, yellowish and greenish. Albite is customarily presented together with quartz, mica, iron oxides and otherfeldspar minerals [El-Sayed R. E. Hassan et. Al,2017]. Current world production is in 7000Mt, as shown in Table (1).

Table1: World Mine Production of Feldspar (thousand metric tons) in 2019

	Mine production,2019
United States	NA
Argentina	14
Brazil	18
Burma	44
Canada	110
China	4,000
Germany	45
Iran	55
Mexico	1,200
Mongolia	670
Morocco	100
South Africa	240
Spain	140
Thailand	50
United Kingdom	21
Vietnam	240
Other countries	41
World total (rounded)	7,000

U.S. Geological Survey, Mineral Commodity Summaries, January 2020

Feldspar is used in glass manufacturing, ceramic production, and in value-added industrial applicationslike fillers and extenders in paint, rubber and plastics [El-Sayed R. E. Hassan et. Al,2017]. Albite is industrially important inthe manufacture of ceramics. It is ground to very fine size and then mixed with kaolin and quartz. Upon heating, it is fused and acted as cement binding the materials together. The fused albite is also the primary constituent inthe glaze on porcelain. Both albite and feldspar are used as suppliers to alumina in the glass manufacture. Thereare different albite specifications for marketing as illustrated in Table (2).

Table 2: Chemical Analysis of Albite Products in Market

Item	Chemical analysis % for industrial applications			
	Glass	Ceramics	Porcelain	Enamel
Na_2O	9.3	9.5	9.5	9.5
Al_2O_3	18	18	18	17
SiO2	64	65	61	65
K_2O	0.5	0.35	0.35	0.5
Fe_2O_3	0.5	0.4	0.38	0.35

Albite is often associated with iron oxide,which decreases its economic value and hinders its application.Albite is generally separated from iron and quartz by physical separation and flotation techniques. Iron-bearingminerals could be separated using acid leaching and/ or floatation using sulfonate or fatty acid type collectors. The presence of slimes in feldspar flotation resulted in low separation efficiency [Hosseini et al., 2016]. Feldspars used as fluxing agents by ceramicand glass industries are mainly obtained from high quality feldspar deposits.

Mica minerals are prevalent layer silicates that exhibit in sediments, soils, and a verity of ore depositsand metamorphic rocks. Main mica minerals are Muscovite, Lepidolite, Phlogopite, Biotite, and Lepidomelane[Hosseini et al., 2016]. Mica subsists in pegmatite ore bodies that mostly contain lithium or rare earths. Biotiteas a major mica mineral is affluent in iron and magnesium. Biotite also exists in most of polymetallic deposits ofigneous origin [El-Sayed R. E. Hassan et. Al,2017]. Mica is engendered in the forms of sheets and flakes which are utilized in themanufacturing of various end products. Mica flakes are obtained from mica mines or engendered as a secondaryproduct of feldspar and quartz production. Mica is used in electronic, building, pigment, and plastic industries. Mica is utilized in paints as a pigmentextender helping to brighten the toneof colored pigments. It is a superior insulator. Therefore, mica is utilized as a thermal insulator in the electrical industry and as an electrical insulator in electronic equipments. Mica is used in toothpaste and cosmetics due to itsshinyand glittery appearance. It is also used in fillers, extenders as it provides a smoother uniformity, preventscracking and improves the workability. It could be used as an insulator in concrete blocks and home attics. Itincreases the durability of grease and giving it a better surface. Beneficiation of mica includes both physical separationand flotation. Micais concentrated by physical separation such as involving Humphrey spirals [Gulsoy et al., 2006; Kademli et al., 2012], shaking tables [Françaet. al., 2008; Gershenkop et al., 2004] and screens [Burt, 2013;Mular et al., 2002; Zhongyin, 2008]. It could beseparated also by air or hydraulic separation [Gershenkop et al., 2004]. Flotation of mica was carried out in acidic and basic systems using an anionic and cationic collector.

Beneficiation of Çine-Ceyhan Sodium Feldspar Ore

Samples from the Çine-Ceyhan pit, owned and operated by Kalemaden A.S., were taken and sent to the Mineral Processing Laboratory, Mining Engineering Department of Hacettepe University, Ankara, Turkey.In this,the results were presented of laboratory flotation tests and industrial application to separate coloring minerals [Muscovite, biotite, rutile, Sphene], some iron oxides and clays from Çine-Ceyhan sodium feldspar ore owned by Kalemaden A.S. In the first stage,theconventional mica flotation was carried out at pH 2·5–3by using tallow amine acetate as collector together witha frother mixture of 50% MIBC and 50% pine oil.Following mica flotation, in the second stage, the effectof sodium oleate, pH and the fineness of grind were tested. Experimental studies indicated that the oreshould be ground to –300 µm and clayey slimes (–25µm) washed out prior to flotation so as to separate coloring gangue minerals effectively. Under optimumconditions, a high-quality concentrate containing 0.1%TiO_2+$Fe_2O$and giving very glossy white firing testbutton at 1260°C was obtained by two stage flotation atpH 2·5–3 with 225 g/t Armac TD for micas and at pH5·5–6·5 with 2000 g/t Na-oleate for titanium and ironoxidesand suggested flow sheetin figure (1).

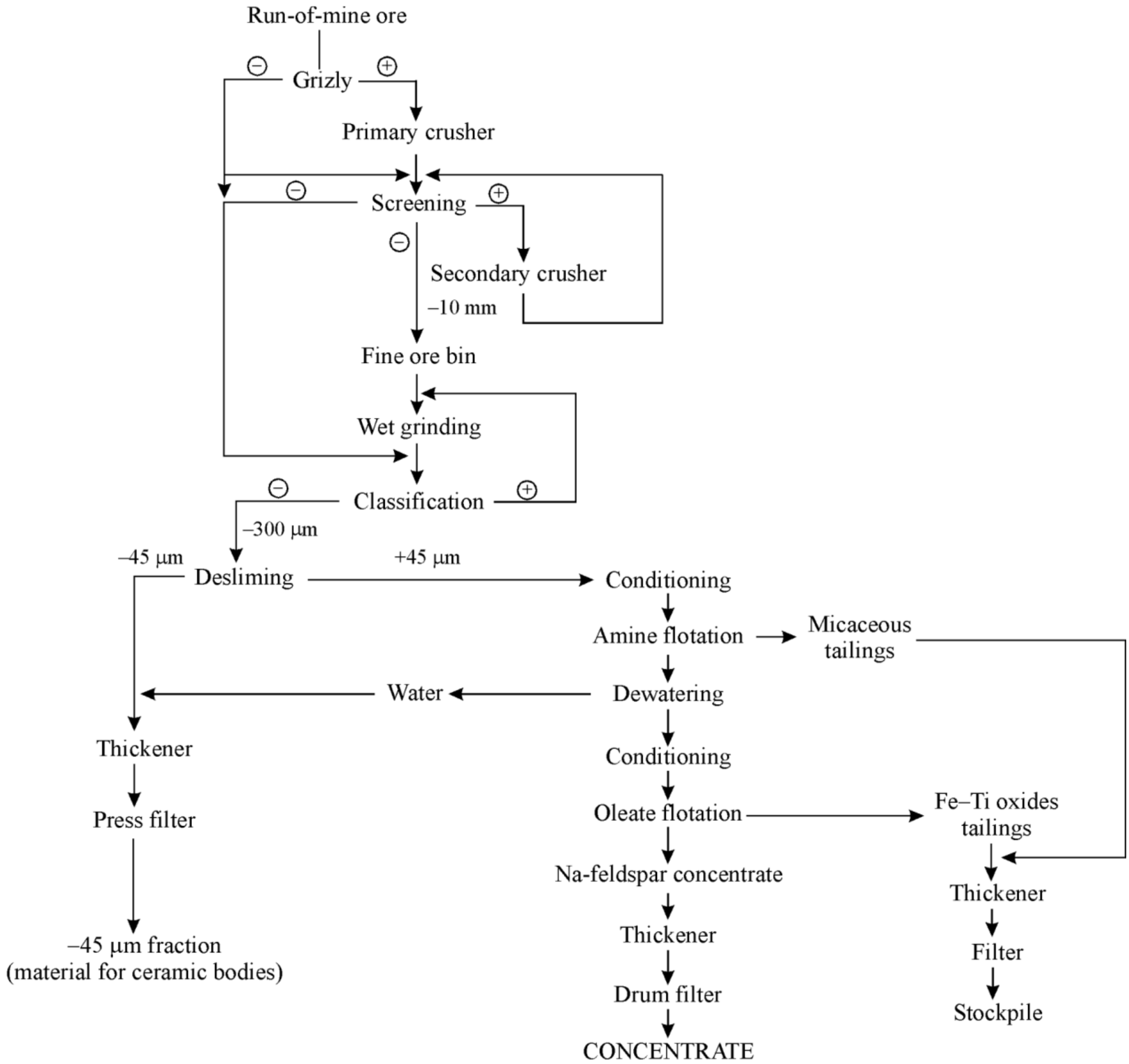

Fig. (1): Proposed and Applied Flowsheet for the Concentration of Albite Ore at the Çine-Ceyhan Concession of KalemadenA.S

It has been shown that it is possible to produce a highquality (TiO_2 + Fe_2O< 0·12%) sodium feldspar concentrate from the Çine-Ceyhan pit by two stage flotation. Despite some inevitable minor mechanical problems and variations in the ore grade were encountered during the first 3 months, the quality of the concentrate from the very beginning was similar tothat of the laboratory scale study [O.Y. Gulsoy et al.,2004].

Beneficiation of Egyptian Abu Dabbab AlbiteOres

The study,toseparate albite and mica from Abu Dabbab area at the South Eastern Desert of Egypt. The beneficiation was successfully performed using Shaking table concentrator and dry magnetic separation. A Box-Behnkendesign was applied successfully in order to evaluate the best conditions for the beneficiation process. Albite, as nonmagnetic mineral, was successfully separated from biotite (mica) which has magnetic properties. The nonmagnetic fraction, albite rich fraction, could be subjected to further processessuch as flotation in order to eliminate the small content of quartz to obtain a pure albite content. Both albite andmica products were found to contain very low content of iron impurities which satisfy the requirements of various industrial applications. This was suggested flow sheet in figure (2)[El-Sayed R. E. Hassan et al, 2017].

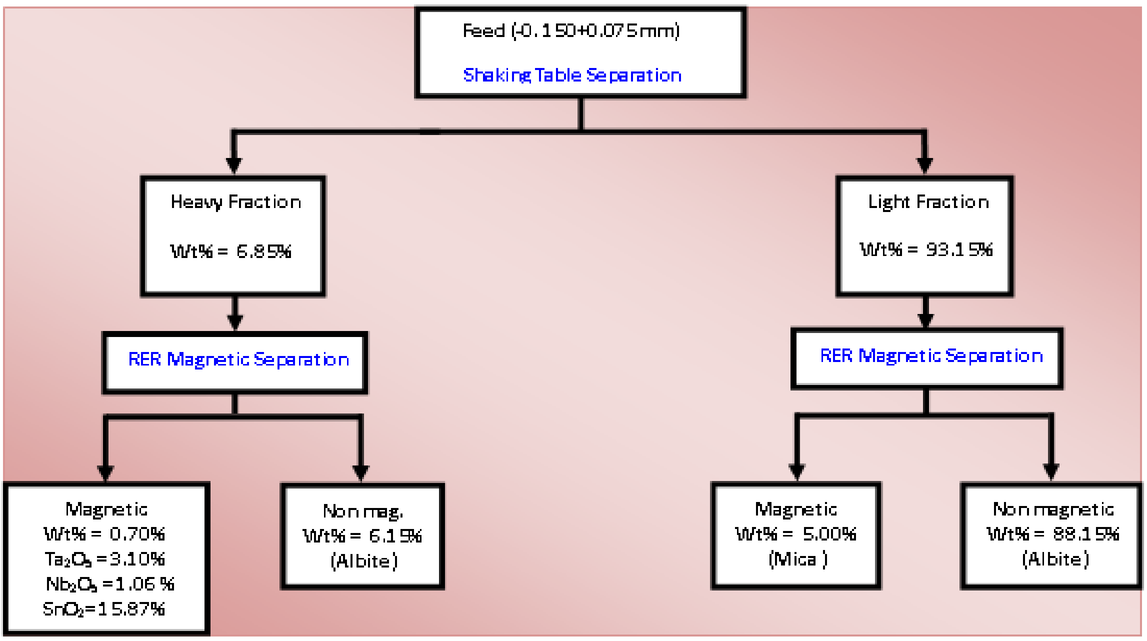

Fig. (2): Proposed and Applied Flowsheet for the Concentration of Egyptian Abu DabbabAlbiteOre

Beneficiation of Gafsa region south – western Tunisia

This studied alkali feldspars petrographically clarified intro microcline with a minor amount of albite.The total alkali content (sum of Na_2O + K_2O) in Sidi Aich feldspars is about 4%.

Experimental studies indicate that produced concentrates acceptable for the ceramic industry,can be obtained from this sand. Flotation tests with HF or H_2SO_4 as pH regulators and

Aero3030C,Cutusamine 9002, amine acetate collectors led to yields of 95.44% and86.99%, respectively, and provided feldspar concentrates assaying 17% Al_2O_3. These concentrates contained 0.14% total iron oxide. The results of the physical tests were illustrated by water absorption,shrinkage and bending strength beside their good resistance for electric charges suggest that the feldspar of the studied area can also satisfy therequirements of the ceramic industry the requirements of the ceramic industry[M.E.Gaied et. Al., 2015].

Beneficiation of Egyptian Feldspar Ore ofWadi Zirib

The presence of coloring materials such as iron oxides in feldspar decreases its quality. To use feldspar minerals in the industry, some upgrading processes should be executed to remove impurities. The most important uses of feldspar are in ceramic and glasses. 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. Commenting 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 mineral 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. On such optimum conditions, a suitable feldspar concentrate was obtained with 0.4% Fe_2O_3[Ahmed M. M., et al.,2016]. 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 presents into the feed head sample. The suggested flow sheet infigure (3).

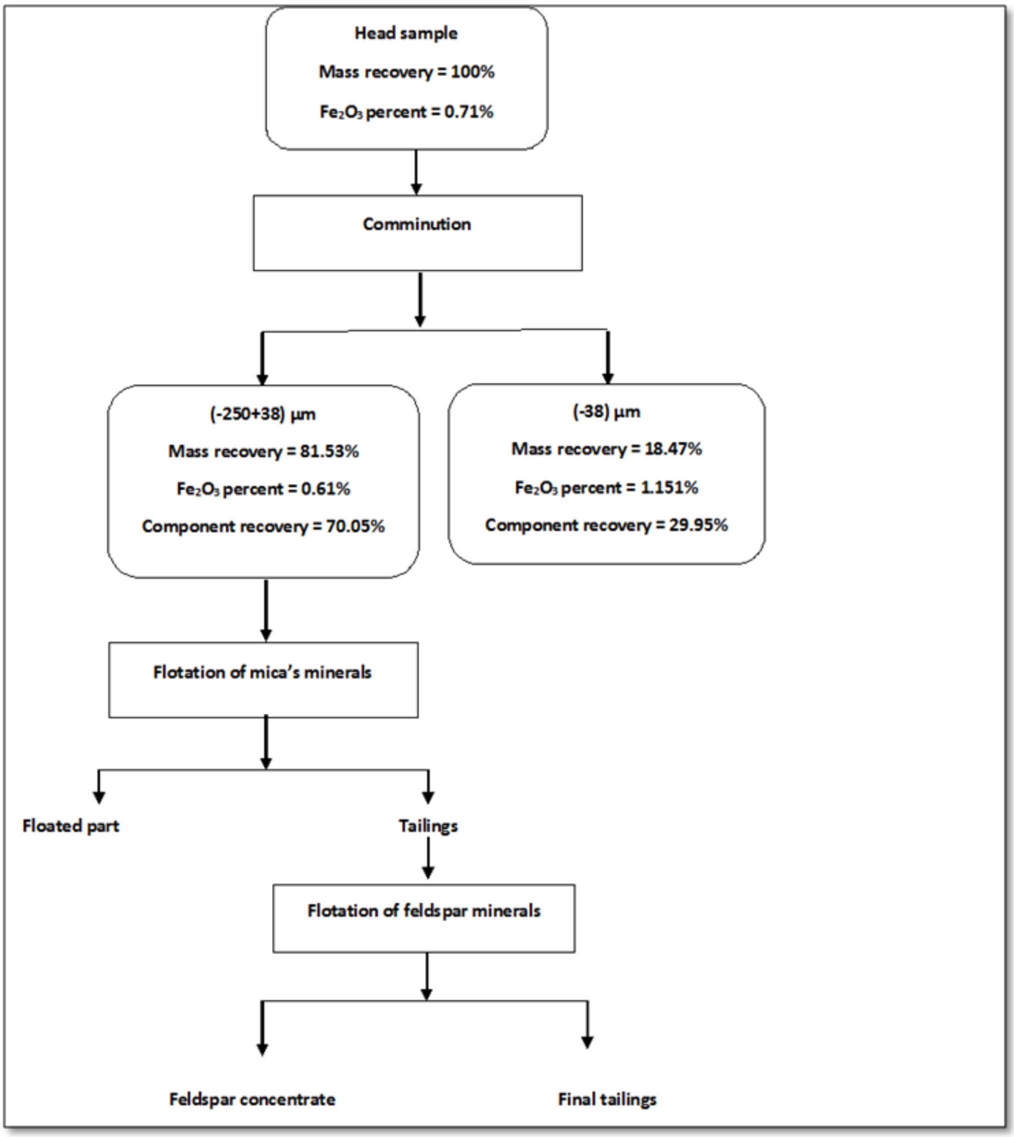

Fig. (3): Proposed and Applied Flowsheet for the Concentration of Egyptian Wadi ZiribAlbite Ore

Intensified flotation of fine feldsparSeparation slimes in feldspar at Thailand

Slimes in feldspar flotation (generally −38 µm size for feldspar mineral) have a negative effect on flotation by coating the feldspar surfaces owing to electrostatic interaction and decreased flotation recovery [Ye Zhang,et al.,2018]. Recovering feldspars from slimes can provide economic and environmental benefits. The fine particles have unique features such as low mass, impact forces, and high interfacial energy, resulting in very low flotation efficient. Some techniques such as coagulation, polymeric flocculation, shear flocculation, and oil agglomeration [Attia, 1982, Da Rosa and Rubio, 2005, Ozkan et al., 2009, Patil,et al., 2001, Song and Lopez-Valdivieso, 2002] are used to recover valuable minerals from slimes by selectively enlarging the particle size. Other technologies used for improving the flotation efficiency of fine particles are picobubbles, dissolved air flotation (DAF), electro-flotation, colloid gas apron, effervescent atomizer, and electrostatic spraying air [Ye Zhang,et al.,2018]. A combination of these technologies with the traditional technologies is utilized to enhance flotation efficiency. In electro-flotation technique, bubble production is improved by electrolyzing water to generate 22–50 µm bubbles [Ye Zhang, et al.,2018].To study on the recovery of feldspar from slime waste was conducted by Soonthornwiphat,et al., 2016. The slime waste from the feldspar flotation plant inAttanee International Co., Ltd. in Thailand, contains orthoclase, albite, quartz, and ferrous impurity minerals such as biotite, Muscovite, mica, and −230 mesh garnet. Magnetic separation and froth flotation, where HF and A-TD was used as pH modifier and collector, respectively, were performed to upgrade the slime waste with the feldspar concentrates containing 67.82% SiO_2, 6.88% K_2O and 6.07% Na_2O, 18.54% Al_2O_3, 0.03% TiO_2, and 0.14% Fe_2O_3, which satisfy the requirements of ceramic industry. Karaguzel (2010) also studied the separation of the feldspar mineral (albite) from slimes consisting of feldspars and iron-bearing minerals using DAF techniqueFigure (4) to generate bubbles <100 μm in size. The charged bubble method and the traditional conditioning technique were carried out. An albite concentration containing 11.07% $Na_2O + K_2O$ and 0.33% $Fe_2O_3 + TiO_2$ from a slime feed assaying 10.36% $Na_2O + K_2O$ and 1.06% $Fe_2O_3 + TiO_2$ was obtained using the charged bubble technique, which provides better results compared with the traditional conditioning method. The DAF system is a new approach toward separating valuable minerals from slimes waste, and it is conducive to the slime treatment both regarding environmental and economic benefits.

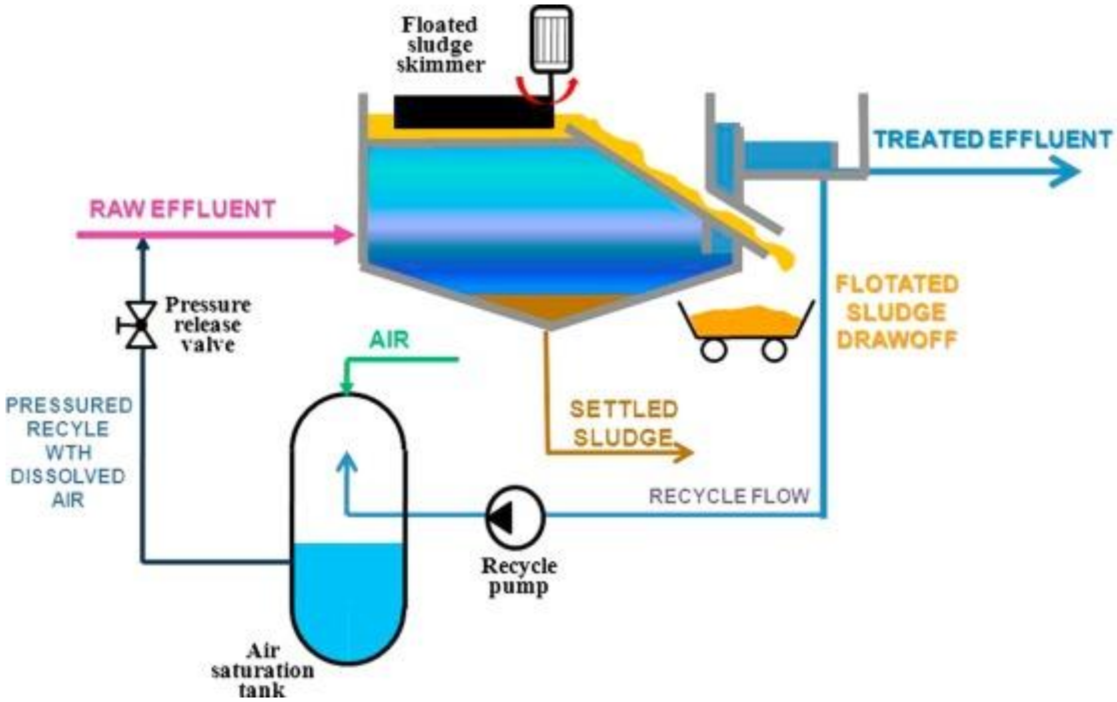

Fig. (4): DAF Technique to Separate Slimes from Feldspar

Effects of Ultrasound on Desliming Prior to Feldspar Flotation

The effect of ultrasonic waves during the desliming stage and on the flotation process in later stages were examined in order to reveal the success in removing impurities from feldspar and quartz concentrates from Milas- Mugla in Turkey. All experimental results were evaluated in the light of the first stage of feldspar flotation, the results of the success of the slime removal process and the further stages of the overall process. The negative effects of the presence of slimes in the flotation medium in the process are important not only in terms of concentrate grade but also in terms of reactive consumption and selectivity. Slime content of feldspar ore originating from the ore formation is a major cause of impurities due to its mica and heavy mineral content. Therefore, slime removal or desliming in feldspar flotation is a necessary process step. In many researches and plant applications, in order to improve concentrated product quality in feldspar flotation, the necessity of sliming has been also proved. Considering the fact that losses in feldspar ore content are removed at a significant amount, the optimization of these negative conditions caused by desliming in feldspar flotation should be evaluated in terms of both particle removal by impurity content and prevention of ore loss and providing positive gains in terms of process economy. In the flotation experiments carried out with the help of ultrasound for the U_1 ore desliming process in -32µm particle, 4.42% slime removal by weight was achieved. However, conventional desliming for the same sample caused 9.99% slime removal by weight. These data showed that ore loses could be prevented with the help of ultrasound. Similar successful results were also achieved for the sample U_2 which has different ore structure. In U_2 ore desliming process on -32µm particle, 8.59% slime removal by weight was achieved, while conventional desliming for the same sample caused 9.44% slime removal by weight. The results show that formation of slimes is reduced in the ultrasonic environment. The slime particles in the medium are agglomerated under the influence of ultrasonic forces and act as coarse grains in flotation to eliminate the negativities of slimes. This not only eliminates the effects of slimes, but also has a positive effect on the overall yield and grade of flotation. When the alkali and quartz content of slime and the mica and heavy mineral contents that constitute the impurity are examined, the numerical proof of slime removal on the ultrasonic environment defines the selectivity as the success of the process. In particular, the impurity of the concentrate obtained in the ultrasonic environment is an important indicator. It is also seen that the microcavitation characterized by ultrasonic treatment changes the distribution principles and mechanisms of fine particles in the pulp by subjecting the particle - particle bonds to degradation. Thus, the distribution of slime size particles in the ultrasonic environment is reduced, as is suggested by previous researchers [UfukMalayoglu andSafakGokhanOzkan,2019]. Furthermore, the agglomerates in the pulp provide a more homogeneous solution formation under the ultrasonic wave effect. Thus, coarse grains and fine grains are more easily separated, especially by decantation. The decrease in weight loss in mass of slime can be explained by these mechanisms of this ultrasound[UfukMalayoglu andSafakGokhan Ozkan,2019]and suggested flow sheet in Figure (5).

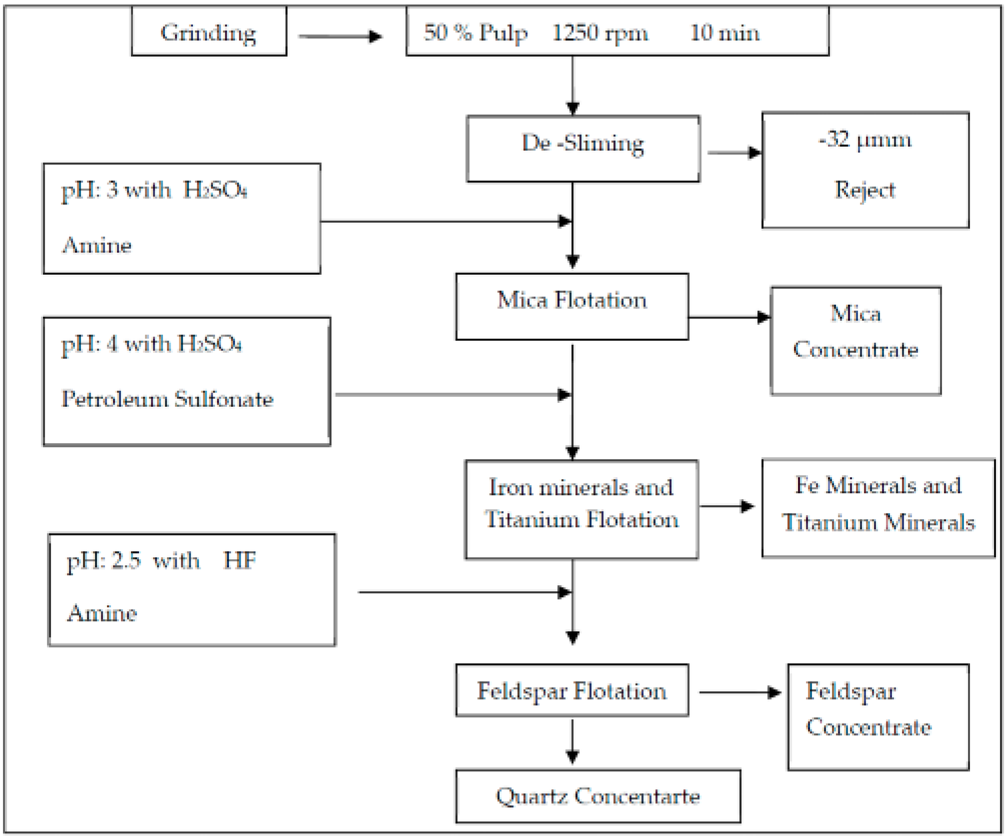

Fig. (5): TheFlowsheet for the Using Ultrasound on Desliming Prior to Feldspar Flotation.

II. CONCLUSION

Various ore dressing methods must be found to obtain the qualified feldspar products, especially the high-grade ones which are scarce, because pure feldspar minerals are extremely rare worldwide.Many technologies for recovering feldspar were studied in the past few decades. Flotation is the most common method for removing gangue minerals and recovering feldspar. Various reagents as a cationic/anionic collector, HF, and monovalent salts were used in the flotation. Additionally, other technologies as gravity separation, magnetic separation, selective grinding, and DAF were also developed.

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Conflict of interest statement

There is no conflict of interest.The data from the literature are duly recognized.