SELECTIVE FLOTATION SEPARATION OF FELDSPAR
IN NON-FLUORIDE MEDIUM

Subhas G. Malghan
Mineral Engineer

NORTH CAROLINA STATE UNIVERSITY
MINERALS RESEARCH LABORATORY
ASHEVILLE, NORTH CAROLINA

This paper is to be presented at the SME Fall Meeting,
Denver, Colorado - September 1-3, 1976.

INTRODUCTION

Feldspathic deposits occur widely throughout the United States, but North Carolina, California, Connecticut and South Carolina accounted for over 80% of the total domestic feldspar output for the year 1973.[1] Pegmatites and granites constitute the major feldspar reserves of the United States,[2] and in addition, feldspar is produced as a by-product by firms whose major products are spodumene and mica.[3] Feldspar is concentrated by hand-cobbing and flotation; the latter forms the major method of separating and concentrating feldspar. Feldspar flotation is practiced in the United States, Mexico, Finland, Norway, West Germany, Japan and the USSR. According to the U. S. Bureau of Mines estimates, the production of feldspar in the United States and rest of the world were 704,000 tons and 2,514,000 tons respectively. Feldspar is principally used as a flux in making glass, pottery, porcelain, enamel, tile and other ceramic products.

In recent years, the domestic feldspar industry is faced with a number of problems. As a result of increased cost of energy and the introduction in 1972 of new legislative programs relating to air, water, and noise pollution, land-use restrictions, and mined-land rehabilitation, the production costs have increased. Apart from the increased cost of operation, an operational problem exists with the feldspar producers in North Carolina, especially those in the Spruce Pine area. This problem is concerned with the use of hydrofluoric acid in the feldspar flotation. Feldspar producers in Spruce Pine, North Carolina have been discharging process waste water into the North Toe River. The mill waste water contains active fluoride ions. Fluoride in excessive concentrations is undesirable in waters used for drinking. It is stated that water

containing 0.9-1.0 ppm fluoride will seldom cause mottled enamel on children's teeth; and for adults, concentrations less than 3-4 are not likely to cause endemic cumulative fluorosis and skeletal effect. Although the literature on this subject is rather confusing and inconclusive, the inference that concentrations over 4 ppm may affect bone structure is clear.

According to the recent Federal Register,[4] maximum fluoride level of 1.4 ppm at 79°-98°F is considered to be adequate and safe for the protection of health of the consumers. The EPA and state environmental agencies have accelerated their drive to reduce water pollution on a faster schedule. By 1977, the EPA specifications for maximum contaminant level of fluoride ions in the discharge waters of feldspar milling operations is expected to be reduced to 2.0 ppm. The other problems of using hydrofluoric acid are the following: toxicity, hazards of handling and storage, and high cost as compared to other inorganic acids (almost 16 times the cost of sulfuric acid).

In order to reduce fluoride levels in mill discharge waters, mining companies have taken the following steps:

1) Recirculating a part of their mill water. Even though recirculation of mill water seems to be a novel method of reducing fluoride contamination of the discharge water, there are certain operational and handling problems.

2) Conducting research on the treatment of fluorides in mill waste water. The technology of treatment of fluoride ions has received considerable interest in the recent years. A recent research report [5] estimates that the cost of fluoride ion removal to meet the present specifications in the feldspar industry is approximately $0.25/ton of ore processed, and about $0.50/ton of feldspar

produced.

At the request of the feldspar producing industries in North Carolina, the North Carolina State University Minerals Research Laboratory has taken up a research program directed towards overcoming the fluoride ion pollution problem. After a close study of the operational, technical and economic aspects of feldspar flotation, it was decided to attempt to replace the conventional hydrofluoric acid process.

CONVENTIONAL FELDSPAR FLOTATION USING HF

Since the inception of the feldspar flotation process using hydrofluoric acid by O'Meara[2, 6] the process has achieved a great commercial success. In the conventional flotation separation of feldspar-quartz, hydrofluoric acid is used to suppress quartz and activate feldspar, and a long chain amine salt (acetate or chloride) is used as a collector. The bulk of amine collectors used in current feldspar operations are applied as the water-soluble acetates of the free-base amines. These products are pastes or waxy solids which are available in a range of acetic acid neutralization levels -- generally 50 to 100% neutralized. In spite of the problems mentioned in connection with the use of hydrofluoric acid, this process is extremely stable with respect to changes in the process variables.

With the exception of a few operations, alaskite and pegmatite are the major sources of feldspar.[7] In the flotation treatment of a pegmatite that contains iron-bearing minerals (heavy minerals), mica, feldspar and silica, a logical order of removal presents itself considering the following:[8]

1) Mica is readily floated by an amine collector in a pulp pH

<3.5. Some iron-bearing minerals will usually respond to amine collector in acid circuit with the mica concentrate.

2) Since iron minerals tend to occur invariably in the feldspar concentrate, it is desirable to remove most of these prior to feldspar flotation. A fatty acid or a petroleum sulfonate collector used in this flotation step in acid circuit will float iron-bearing minerals.

3) Using hydrofluoric acid to maintain pH of 2.5, an amine collector employed in a final step will float feldspar away from silica, usually leaving the latter in the tailing as a high-grade silica concentrate.

The problems connected with the flotation separation of feldspar-quartz arise due to the similarities in their chemical structure. Therefore, any reagent system that is likely to succeed in feldspar-quartz separation should have adsorption affinity towards one of the minerals and depression effect towards the other mineral.

THE NON-HF FELDSPAR FLOTATION METHOD

In recent years, several researchers have investigated[9-11] methods for replacing HF in feldspar-quartz flotation. The process described by Katayanagi[9-10] requires the use of a diamine acetate plus a sulfonate as flotation reagents in acid circuit. The acidic pH is maintained by using either sulfuric[9] or hydrochloric acid[10]. This process is extremely sensitive to flotation reagent concentrations. Klyachin[11] has proposed substitutes for hydrofluoric acid such as salts of hydrofluoric acid or polyhydro fluorides. The investigations at the NCSU Minerals Research Laboratory have led to a very successful method for feldspar-quartz separation by flotation. This paper summarizes the results of one phase of these studies.

The process developed was effective on alaskite ores from two loca-
tions and has been applicable to several other feldspar-bearing
ores to be reported elsewhere.[12]

Description of Ores

The ores used in the investigations were obtained from Lawson-
United Feldspar and Mineral Company, and IMC Chemical Group, Inc.,
both located in Spruce Pine, North Carolina. The two ores were
mixed prior to obtaining samples for testing. This alaskite or
granitic-type ore contains muscovite, biotite, garnet, clay, feld-
spars (orthoclase, albite, and anorthite), quartz, etc. The approx-
imate mineral composition of this ore, as calculated from chemical
analysis, is given in Table I.
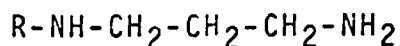
The ore sample received for testing was feed to the rod mills
in the two plants.

Process Description

Numerous tests were made at the NCSU Minerals Research Labora-
tory to determine if some flotation reagent system could be used to
selectively float feldspar from feldspar-quartz mixture. The in-
vestigation led to development of a process using a simple reagent
system that gave a good recovery of feldspar and grade of concentrate
-- as good as that obtained in the conventional process; in most
cases the recovery and grade were comparable.

Briefly described, the process included grinding the ore to
at least minus 30 mesh, desliming, floating the mica and iron min-
erals, and then conditioning the pulp at 50-60% solids with Duomeen
TDO, sulfuric acid and Hunticol-26 for feldspar flotation. The
separation was not particularly sensitive to conditioning time, and
percent solids in conditioning. Excellent flotation results were
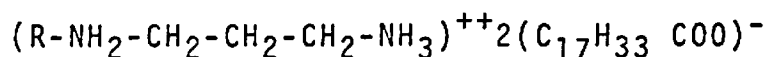obtained in the pH range 1.8-2.6.

Duomeen TDO is a commercial name for di-oleate salt of alkyl propylene diamine whose alkyl group is derived from tallow fatty acids. This product is presently produced and marketed by Armak Chemicals Division. Commercial manufacture[13] of this compound consists of reacting one molecule of alkyl (tallow) propylene diamine,

$$R-NH-CH_2-CH_2-CH_2-NH_2$$

with two molecules of oleic acid

$$CH_3(CH_2)_7CH=CH-(CH_2)_7COOH$$
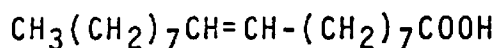
to yield di-oleate salt. The structual formula,

$$(R-NH_2-CH_2-CH_2-CH_2-NH_3)^{++}2(C_{17}H_{33} COO)^-$$

of Duomeen TDO indicates that the compound has both primary and secondary amine groups. Composition of the fatty acid radical (R) in the diamine is similar to the composition of the corresponding primary amine. In this case, R has approximate molecular weight of 287, and the approximate molecular weight of Duomeen TDO is 924. The existence of strong organic bifunctional base gives rise to greater cationic activity than the corresponding amines containing only primary amines.

Duomeen TDO is not water soluble. To prepare aqueous solutions (normally 2.5-5%), part of the required water is first heated slightly to 50-70°C and caustic soda (NaOH) added (1.0-2.0% of reagent weight) to raise the pH to approximately 10. To this water, required weight of pasty Duomeen TDO is added with constant agitation. As the oleate salt dissolves, more water is added with continuous stirring until solution is complete.

The function of Duomeen TDO is to selectively adsorb on feldspar particles and suppress quartz particles. The mechanism of tallow alkyl propylene diamine dioleate salt in the flotation of feldspar has not been definitely determined. However, it is

certain that, at low concentrations of the flotation reagent and high concentrations of hydrogen ions (i.e., low pH), the reagent shows high affinity for feldspar surface and no affinity for silica surface. Such high affinity of this reagent to the feldspar surfaces may be due to formation of intermolecular complexes possessing high hydrophobic capability.[14, 15] The amount of this reagent in feldspar flotation varies according to the proportion of feldspar to quartz and fineness of particles in the pulp. The reagent consumption increases with higher proportion of feldspar to quartz and decreases with fineness of particle size in the pulp. Excessive concentration of the reagent tends to float silica along with feldspar. Starvation quantities of reagents tend to produce high grade feldspar and leave behind some feldspar with quartz. However, at a particular conditioning pH, the reagent concentration can be varied over a small range, well enough to withstand fluctuations of feed and reagent in an operating plant.

Hunticol-26 frother is a water-soluble product of the polypropylene glycol type. This frother was found to produce brittle froth, thus reducing the mechanical entrapment of undesirable mineral particles in the froth. In this regard, this type of frother is preferred to pine oil and cresylic acid because the presence of Hunticol-26 (H-26) in the pulp did not influence selectivity and performance of Duomeen TDO. H-26 is presently distributed by Hunt Chemicals, Marion, North Carolina.

EXPERIMENTAL RESULTS

Laboratory Batch Tests

Batch tests were undertaken to determine conditions for separating feldspar-quartz by flotation. The feed sample received from

the mines was rolls crushed to yield feed suitable for the laboratory rod mill. The size distribution and chemical assay of the resulting feed are given in Table II. Results of preliminary tests using various experimental conditions and reagents led to adoption of the following procedure:

The test sample was ground in one stage in a laboratory rod mill using Asheville city water. A small amount of sodium hydroxide was used in grinding to aid in dispersing and removing clay slimes. The pulp was screened on 30 mesh and deslimed on 400 mesh. The deslimed pulp was conditioned at 60% solids in a mechanical-agitation cell for 5 minutes with Armac-T, sulfuric acid, fuel oil and Hunticol-26. This was followed by flotation of the mica in a Denver 500-gram laboratory flotation cell. Machine discharge from this flotation stage was dewatered after standing for 3 minutes, and conditioned for 10 minutes at 70% solids with petroleum sulfonate (Morco M-70), sulfuric acid and Hunticol-26. The conditioned pulp was subjected to flotation of iron-bearing minerals. Again, the machine discharge from this flotation step was dewatered and conditioned with Duomeen TDO, sulfuric acid and Hunticol-26 for 5 minutes at 55% solids. This was followed by flotation of feldspar and cleaner flotation of feldspar flotation product without adding additional reagents.

In another series of experiments, mica and iron-minerals flotation was conducted using the same experimental procedure; however, feldspar-quartz flotation separation was conducted using hydrofluoric acid, Armac-T, fuel oil and Hunticol-26.

Summarized results of the tests showing the mineral distributions, recovery, grade and reagent consumption are given in Table III and Table IV.

Continuous Pilot Plant Tests

Small-scale continuous pilot plant tests were made on the ore to confirm test data obtained in the batch laboratory flotation investigations. The pilot plant flowsheet that was used in testing the alaskite ore is shown in Figure 1. The feed rate to the pilot plant was approximately 300 lbs/hr, and at least 15 continuous pilot plant runs were made.

The minus 4 mesh ore was fed to a 17" X 34" ball mill through a constant weight feeder. The ball mill discharge was pumped to a hydrosizer, the oversize (plus 30 mesh) from which was dewatered in a Sweco vibro-energy separator and recirculated to the mill. The undersize (minus 30 mesh) from the hydrosizer was deslimed in a cyclone, the underflow of which was dewatered in a screw classifier and fed to mica conditioner cells. The pulp was conditioned at 60% solids for 5-7 minutes with the same reagents as in batch testing. Mica was floated from the conditioned pulp in two Agitair cells, the underflow from which was dewatered in a screw classifier and fed to the iron-minerals conditioner. The pulp was conditioned at 70% solids for 10 minutes with the required reagents and iron minerals flotation carried out in two Agitair cells. The iron minerals flotation underflow was dewatered in a screw classifier and fed to the feldspar conditioner. The pulp was conditioned at 55% solids for 5 minutes using the reagents required for either the HF or non-HF process. The conditioned pulp was subjected to flotation in 4 Agitair cells. The underflow from these cells was a good quality silica sand, and the froth product was cleaned once in 2 Denver flotation cells to drop off entrapped silica particles. All the reagents were monitored from a central location using a Brosites reagent pump feeder. The water flow rate was monitored from a

single location using appropriate flowrators. An automatic sample splitter split samples every 5 minutes from the 5 products -- mica, iron minerals, feldspar, quartz and cleaner tails. All the slimes were channeled to one location for ease of sampling.

Tables V, VI, and VII summarize the tests on continuous pilot plant with and without using HF in the feldspar-quartz separation. Size distribution of the feed to pilot plant and the products is the same for both the pilot plants. A typical size distribution for a pilot plant run is shown in Table VII. Pilot plant conditioning and flotation of mica, iron-minerals, and feldspar is shown in Fig.2.

Discussions

Comparison of the test results of feldspar-quartz separation on batch and pilot plant scale using hydrofluoric acid plus Armac-T and sulfuric acid plus Duomeen TDO, clearly demonstrates the feasibility of the non-hydrofluoric acid process. Numerous tests have been conducted to verify the results described in this report. A comparison of characteristics of the two processes is presented in Table VIII.

The non-hydrofluoric acid process was found to be sensitive to presence of plus 30 mesh particles in the flotation feed pulp. In order to get a good recovery of feldspar, the feed has to be ground to at least minus 30 mesh. If a feed coarser than 30 mesh is sub-jected to flotation, the coarser particles fail to float and remain with the tailings, thereby contaminating quartz with feldspar. However, the presence of coarse particles does not affect the grade of feldspar. Smaller particles in the feed, even as fine as minus 400 mesh, can be floated without any problem. Among the secondary benefits of grinding to minus 30 mesh are better mica flotation, and good removal of iron-minerals.

CONCLUSIONS

The process research on feldspar flotation without using hydrofluoric acid demonstrated the feasibility of separation of feldspar and quartz from alaskite ores of North Carolina. The research indicated that Duomeen TDO, sulfuric acid and H-26 may be used for flotation of minus 30 mesh ball mill ground product. The research also indicated that, in spite of its sensitivity to reagent levels in the conditioning pulp, the new method produces high grade feldspar as froth product and silica as machine discharge. The use of this method is expected not only to reduce fluoride ion pollution but also reagent cost. The research also demonstrated the effectiveness of a hydrosizer to classify coarse ore. The non-HF flotation process is being considered by at least one company in North Carolina to produce high grade feldspar and quartz products from tailings. A patent application is filed with the U. S. Patent Office to cover the process described in this paper.

ACKNOWLEDGEMENTS

TABLE I

MINERAL COMPOSITION

Mineral	% Wt
Potash feldspar	16.8
Soda feldspar	42.9
Lime feldspar	4.5
Total feldspar	64.2
Muscovite	4.4
Kaolinite	2.5
Quartz	28.5
Others (Garnet, Biotite, etc.)	0.4

TABLE II

SIZE DISTRIBUTION AND CHEMICAL ANALYSIS
OF BATCH TESTS FEED

Size, Mesh	% Wt	% Wt	% K_2O	% Na_2O	% CaO	% MgO	% Al_2O_3	% Fe_2O_3	% LOI*
+20	2.30								
-20+30	5.28	7.58	5.80	3.90	0.77	0.13	19.40	1.76	1.46
-30+40	6.54								
-40+50	16.46								
-50+70	19.88								
-70+100	15.32	88.34	3.70	4.70	1.00	0.03	17.20	1.48	0.30
-100+140	12.05								
-140+200	8.14								
-200+270	6.02								
-270+400	3.93								
-400	4.08	4.08	4.00	5.10	1.04	0.05	17.90	0.81	0.69
Total	100.00	100.00	3.87	4.65	0.98	0.038	17.48	1.47	0.40

*% LOI = % loss on ignition

TABLE III

BATCH FLOTATION OF FELDSPAR USING DUOMEEN TDO
IN FELDSPAR-QUARTZ SEPARATION

Products	% Wt	% K_2O	% Na_2O	% CaO	% Al_2O_3	% Fe_2O_3	% DTA
Feldspar, F.P.	52.53	4.9	7.0	1.28	19.9	0.054	98.97
Quartz, Tails	18.01	0.11	0.15	0.03	0.87	0.032	0.75
Cleaner Tails	3.07	0.25	0.33	0.06	1.2	0.040	0.28
Mica, F.P.	6.54						
Iron Min.,F.P.	7.58						
Slimes, -400 M.	8.50						
+30 Mesh	3.78						

	Conditions				Reagents (lbs per ton)						
Process	(Min) Time	% Solids	pH	rpm	NaOH	DuTDO	H_2SO_4	Ar-T	F.O.	M-70	H-26
Ball Mill Grind	8	50		41	0.7						
Screen +30 M. & desl. 400 M.											
Mica Cond.	5	60	2.4	1000			0.94	0.24	0.32		0.08
Mica Flot.											
Wash M.D. & Dewater											
Iron Min. Cond.	10	70	2.2	1000			1.05			0.61	0.18
Iron Min. Flot.				1200							
Wash M.D. & Dewater											
Feld. Cond.	5	55	2.5	1000	1.0	0.78					0.14
Feld. Flot.				1200							
Clean F.P. once											

Remarks

8" X 7" ball mill; 5 kg, 1-inch balls
Duomeen TDO : NaOH = 12.5 gr : 0.3 gm in 500 cc solution
% DTA = % distribution of total alkali in the flotation products
DuTDO = Duomeen TDO, H_2SO_4 = sulfuric acid
Ar-T = Armac T, NaOH = sodium hydroxide
M-70 = Morco M-70, F.O. = fuel oil
H-26 = Hunticol-26

TABLE IV

BATCH FLOTATION OF FELDSPAR USING HYDROFLUORIC ACID IN FELDSPAR-QUARTZ SEPARATION

Products	% Wt	% K_2O	% Na_2O	% CaO	% Al_2O_3	% Fe_2O_3	% DTA
Feldspar, F.P.	52.9	5.1	6.9	1.23	20.0	0.059	99.50
Quartz, Tails	19.8	0.04	0.07	0.02	0.55	0.030	0.37
Cleaner Tails	2.6	0.13	0.17	0.06	0.84	0.041	0.13
Mica, F.P.	9.7						
Iron Min.,F.P.	1.0						
Slimes, -400 M.	10.4						
+30 Mesh	3.6						
Total	100.0						

	Conditions				Reagents (lbs per ton)						
Process	(Min) Time	% Solids	pH	rpm	NaOH	HF	H_2SO_4	Ar-T	F.O.	M-70	H-26
Ball Mill Grind	8	50		41	0.7						
Screen +30 M. & desl. 400 M.											
Mica Condition	5	60	2.5	1000			0.81	0.24	0.25		0.10
Mica Flotation				1200							
Wash M.D. & Dewater											
Iron Min. Cond.	10	68	2.1	1000			1.05			0.43	0.10
Iron Min. Flotation				1200							
Wash M.D. & Dewater											
Feld. Condition	5	55	2.5	1000	1.00			0.80	0.10		0.10
Feld. Flotation				1200							
Clean F.P. once											

Remarks

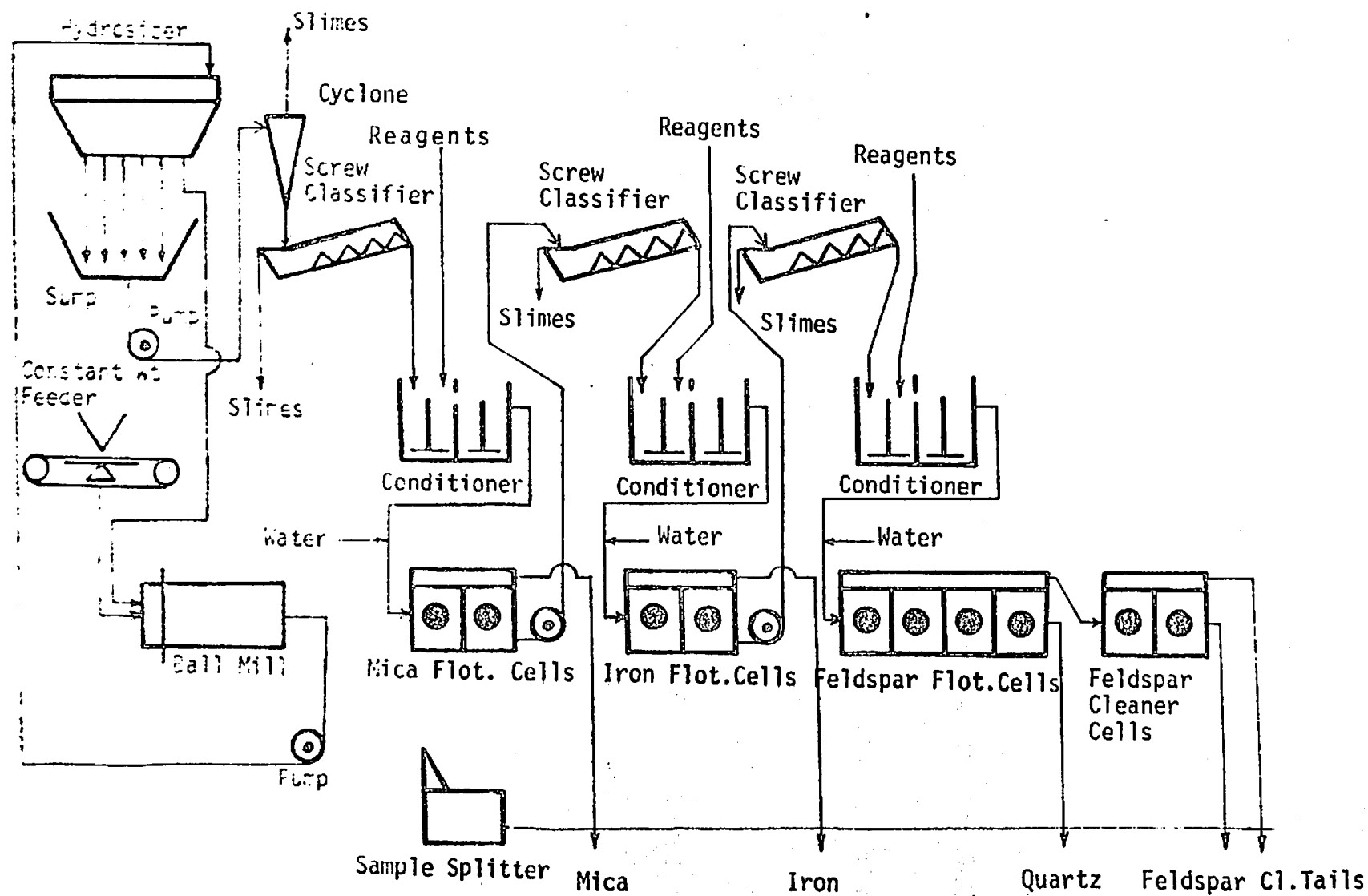8" X 7" ball mill; 5 kg, 1-inch balls

HF = Hydrofluoric acid

Figure 1. Pilot plant flowsheet of closed-circuit ball mill grinding with hydrosizer and feldspar flotation.

TABLE V

CONTINUOUS PILOT PLANT FLOTATION USING DUOMEEN TDO
IN FELDSPAR-QUARTZ SEPARATION

Product	lb/hr	% Wt	% K_2O	% Na_2O	% CaO	% Al_2O_3	% Fe_2O_3	% DTA
Feldspar, F.P.	145.7	46.6	4.90	6.90	1.23	19.0	0.063	95.10
Quartz, Tails	60.4	19.3	0.37	0.54	0.10	1.4	0.023	3.06
Cleaner Tails	14.7	4.7	1.00	1.30	0.21	4.6	0.036	1.84
Iron Min.,F.P.	13.5	4.3						
Mica Min.,F.P.	41.0	13.1						
Total Slimes	37.5	12.0						
Total Products	312.7	99.9						
Head Feed	308.8		3.92	5.62	1.18	16.21	1.49	
Mill Discharge	405.9							
% Circ. Load	31.4							

	Conditions		Reagents (lbs per ton)						
Process	pH	% Solids	NaOH	Ar-T	H_2SO_4	F.O.	H-26	M-70	DuTDO
Ball Mill	9.4	46	0.54						
Mica Cond.	2.2	60		0.24	2.40	0.49	0.19		
Iron Min. Conditioner	2.1	68			1.28		0.17	1.12	
Feldspar Conditioner	2.5	55			0.68		0.20		1.02

Remarks

% DTA = % distribution of total alkali in the feldspar flotation products.

TABLE VI

CONTINUOUS PILOT PLANT FLOTATION USING HF IN
FELDSPAR-QUARTZ SEPARATION

Product	lb/hr	% Wt	% K_2O	% Na_2O	% CaO	% Al_2O_3	% Fe_2O_3	% DTA
Feldspar, F.P.	145.3	47.1	5.1	6.7	1.28	19.0	0.071	98.96
Quartz, Tails	57.4	18.6	0.04	0.05	0.03	0.54	0.023	0.36
Cleaner Tails	12.2	3.9	0.41	0.56	0.12	1.84	0.036	0.68
Iron Min.,F.P.	15.2	4.9						
Mica Min.,F.P.	37.3	12.1						
Total Slimes	40.8	13.3						
Total Products	308.2	99.9						
Head Feed	300.8		3.4	5.0	1.15	16.0	1.53	
Mill Discharge	405.3							
% Circ. Load	34.7							

	Conditions		Reagents (lbs per ton)						
Process	pH	% Solids	NaOH	Ar-T	H_2SO_4	F.O.	H-26	M-70	HF
Ball Mill	9.7	48	0.56						
Mica Cond.	2.2	62		0.24	2.66	0.48	0.17		
Iron Min. Conditioner	2.2	68			1.39		0.16	1.10	
Feldspar Conditioner	2.5	56			0.67		0.30	0.15	1.76

Remarks

% DTA = % distribution of total alkali in the feldspar flotation products.

HF = hydrofluoric acid

TABLE VII

% WEIGHT SIZE DISTRIBUTION OF PILOT PLANT FEED AND PRODUCTS

Size, Mesh	H.F.	M.D.	F.F.	Mica	Iron Min.	Spar	Quartz
+10	60.5	0.1	0.0	0.0	0.0	0.0	0.0
-10+20	13.7	1.3	0.1	0.4	0.1	0.1	0.1
-20+30	4.8	3.6	0.5	1.0	0.3	0.4	0.3
-30+40	4.3	7.3	2.2	2.5	0.9	2.3	2.2
-40+50	4.0	10.2	7.8	4.8	3.3	8.9	9.5
-50+70	3.3	15.9	16.3	6.4	7.8	18.5	22.4
-70+100	2.2	16.3	16.4	6.5	12.9	18.7	20.1
-100+140	2.2	9.6	18.5	9.4	10.1	21.6	21.2
-140+200	1.6	10.0	12.4	11.5	15.8	15.2	12.4
-200+400	1.9	12.4	15.5	29.0	31.2	11.9	10.4
-400	1.6	13.3	10.3	28.5	17.6	2.4	1.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.1

Remarks

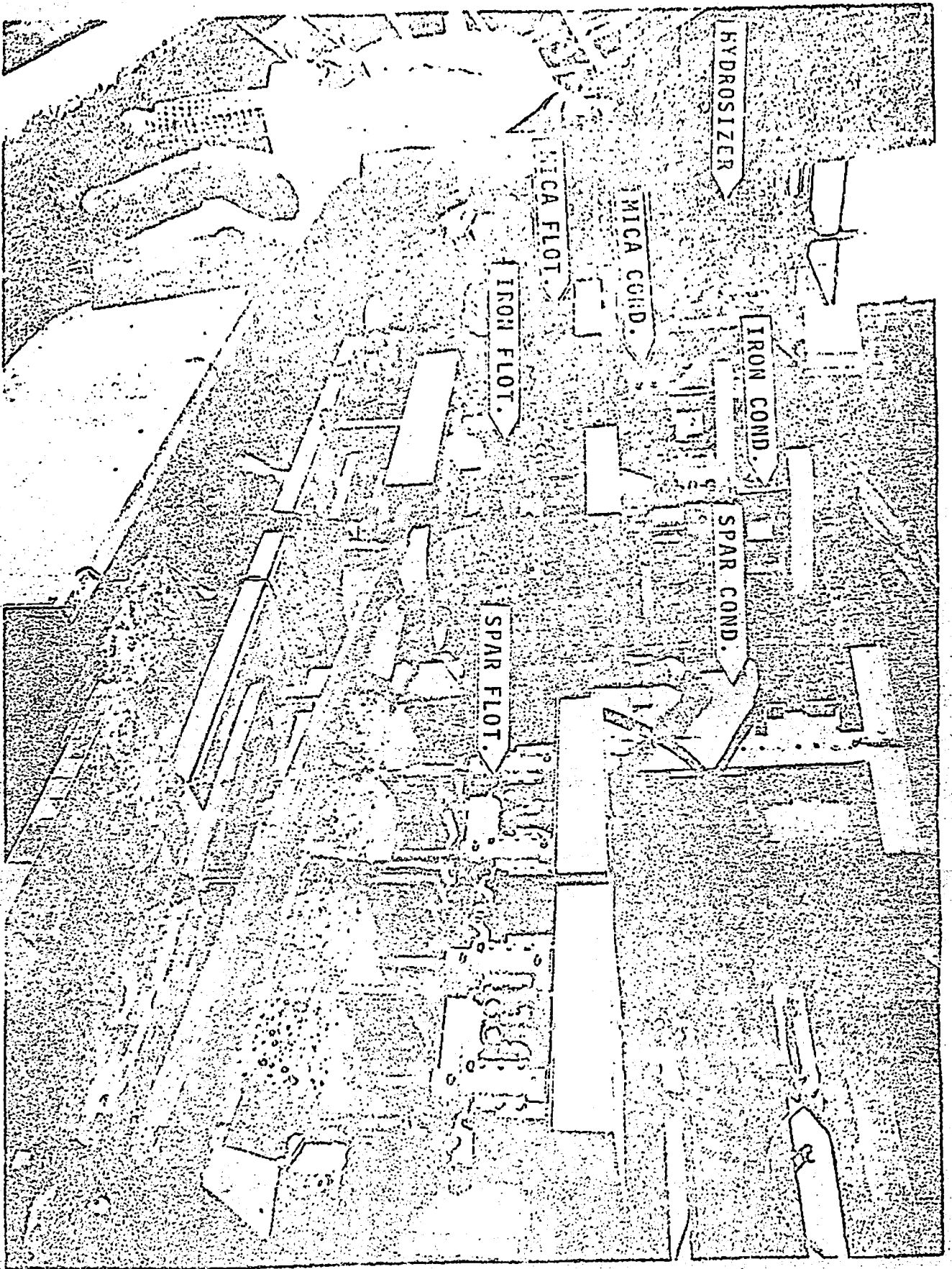|		
H.F.	=	Head feed
M.D.	=	Mill discharge
F.F.	=	Flotation feed
Mica	=	Mica flotation product
Iron Min.	=	Iron mineral flotation product
Spar	=	Feldspar flotation product
Quartz	=	Quartz tails

Figure 2. Conditioning and flotation cells setup of mica, iron minerals and feldspar in the pilot plant.

TABLE VIII

COMPARISON OF PROCESS CHARACTERISTICS

Process Characteristics	Non-HF Process	HF Process
1. Reagent Handling Problem	None	Serious
2. Pollutants in Mill Discharge Waters	None	Serious, fluoride ions
3. Process Stability	Excellent	Excellent
4. Estimated Cost of Reagents	50-80% of HF process	$0.75-$0.80/ton of flotation feed
5. Sensitivity to Process Variables		
Flotation reagent concentration	Insensitive over a limited range	Insensitive over a wide range
% Solids in conditioning & flotation	Insensitive	Insensitive
Conditioning time	Insensitive	Insensitive
Flotation rate	Equal to HF process	High
Particle size of flotation feed	Approximately -30 M.	-20 Mesh
Order of addition of reagents	No effect	No effect
Conditioning temperature or reagent temperature	No effect	No effect

REFERENCES

1. Wells, Robert J., "Feldspar, Nepheline Syenite and Aplite," Minerals Yearbook, vol. I, Metals, Minerals and Fuels, United States Dept. of the Interior, 1973, pp 503-510.

2. O'Meara, R. G., Norman, J. E., Walter, E. H., "Froth Flotation and Agglomerate Tabling of Feldspar," Bull. Am. Ceram. Soc., vol. 18, no. 8, August 1939, pp 286-292.

3. Cooper, James D., and Wells, R. J., "Feldspar" Chapter in Mineral Facts and Problems: Bu. Mines Bull. 650, 1970, pp 977-988.

4. Anon. Federal Register, vol. 40, no. 248, November 24, 1975.

5. Parker, L. C. and Fong, C. C., "Fluoride removal: technology and cost estimates," Industrial Wastes, Nov./Dec. 1975, pp 23-27.

6. O'Meara, R. G., "Separation of feldspar from quartz," United States Patent No. 2,297,689, October 1942.

7. Rogers, C. P., and Neal, J. P., "Feldspar and Aplite," Industrial Minerals and Rocks, Ed. Lefond, S. J., 4th Edition, AIME, Inc., 1975, pp 637-652.

8. Baarson, R. E., Ray C. L., and Treweek, H. B., "Plant Practice in Nonmetallic Mineral Flotation," in Froth Flotation, 50th Anniversary volume, Editor D. W. Fuerstenau, The Am. Institute of Min., Met., and Petr. Engineers Inc., New York, 1962, pp 427-454.

9. Katayanagi, A., "Flotation Separation of Feldspar," United States Patent No. 3,844,939, October 29, 1974.

10. Katayanagi, A., "Flotation Separation of Feldspar," United States patent pending, March 1976.

11. Klyachin, V. V., "New effective reagents for the flotation of feldspar." Translated from Stekla i Keramika, No. 9, September 1972, pp 30-31.

12. Malghan, S. G., "Further testing of non-hydrofluoric acid process of feldspar flotation," in preparation.

13. Anon., Product data bulletin No. 72-7. Armak Chemicals Div., Chicago, Illinois.

14. German, T. P., "Combined use of cationic and anionic collectors during flotation," Vop. Teor. Prakt. Obogashch. Rud (1971), pp 79-85 (Russ.) Edited by Turchaninov, I. A., "Nauka" Leningrad, USSR.

15. Schulman, J. H., "Oppositely charged mixed collectors in flotation - surface chemistry," Proceed. 2nd Scandinav. Symposium on Surface Activity, Copenhagen, Munksgaard, 1965, pp 9-20.