USING A HINDERED SETTLING HYDRAULIC SIZER TO PRODUCE A CLAY PRODUCT FROM A MICA PLANT WASTE STREAM

Louis M. Schlesinger[1], James T. Tanner[1], Jr.
Michael J. Garska[1], and James E. Barton[2]

(1) Minerals Research Laboratory
North Carolina State University
180 Coxe Avenue • Asheville, N.C. 28801

(2) KMG Minerals, Inc.
P.O. Box 709
Kings Mountain, N.C. 28086

USING A HINDERED SETTLING HYDRAULIC SIZER TO PRODUCE A CLAY PRODUCT FROM A MICA PLANT WASTE STREAM

Louis M. Schlesinger[1], James T. Tanner[1], Jr.
Michael J. Garska[1], and James E. Barton[2]

(1) Minerals Research Laboratory
North Carolina State University
180 Coxe Avenue • Asheville, N.C. 28801

(2) KMG Minerals, Inc.
P.O. Box 709
Kings Mountain, N.C. 28086

Abstract. KMG Minerals, Inc., a mica-feldspar-quartz producer in Kings Mountain, N.C., uses about 50% of its plant's -200 mesh slimes to manufacture brick. However, the company is unable to market the remaining 50% of this fine mineral mixture. The NCSU Minerals Research Laboratory operated a pilot plant to process these slimes to produce an additional product. The process, consisting of blunging and hydraulic sizing, was designed to separate a kaolin-enriched -270 mesh product from the bulk of the coarser +270 mesh "grit" minerals. Size analysis showed that this product was 80% finer than 20 microns and 50% finer than 6 microns (in equivalent spherical diameter). An evaluation indicated that it is a hydrous aluminum silicate that might be suitable in the filler and extender markets for traffic paint, some types of plastics, joint cements, and dusting compounds. Because of its high viscosity, it will be difficult to use more than a small percentage in cast ceramic bodies. However, it might be possible to use up to 10% in extruded ceramic bodies (i.e., electrical porcelain). The 15.2 cm (6 in.) diameter Linatex Hydrosizer was tested using a range of teeter water flowrates, so that the net rise velocity was varied from 0.10 cm/s to 0.40 cm/s. The solid feed rate to the sizer was maintained at approximately 1.1 $t/hr/m^2$ (0.12 $ton/hr/ft^2$). Tests were run using both "shallow" (i.e., 6 in.) and "deep" (i.e., 15 in. teetered beds. The best overall result was obtained when the sizer was operated with the "deep" teeter bed and a net rise velocity of 0.10 cm/s. About 97% of the +270 mesh material was rejected and approximately 79% of the -270 mesh material was recovered in a 14% solids slurry.

INTRODUCTION

Waste from mineral processing plants is a liability to producers, who must incur the cost of impounding the material in an environmentally acceptable manner. Fine waste (i.e., particles finer than 75 microns) poses a particular challenge.

Most of the many nonmetallic mineral producers in the state of North Carolina began operation with a single marketable commodity, such as feldspar or muscovite mica. Through the assistance of the North Carolina State University (NCSU) Minerals Research Laboratory (MRL), an extension of NCSU's College of Engineering, most state producers have seized the initiative and capitalized on opportunities to get the most from their ore bodies. They have modified their operations to produce marketable co-product minerals and a wide range of specialty products derived from additional processing of the various mineral concentrates (Redeker, 1987).

KMG Minerals, Inc., a company that mines and processes a weathered pegmatite ore near the town of Kings Mountain, N.C. is a case in point. The operation was originally confined to the use of Humphreys spirals to recover +48 mesh muscovite for wet-ground feedstock -- utilizing only 7% of the ore. Today, the operation utilizes slightly over 90% of the ore, having added a mica flotation product for dry-ground feedstock, feldspar and quartz sands for the ceramic and glass container industries, and a unique white brick manufactured from the plant's -200 mesh slimes. These slimes, a mixture of kaolinite, fine muscovite, and fine silica, have a unit value of $25/st. However, the company is currently unable to market 50% of this waste material and must impound it.

At the request of KMG's marketing arm, the MRL has embarked upon a pilot-scale study to develop processes to make additional products from the slimes: 1) a -270 mesh product to be marketed as a component of a ceramic body and 2) a high grade kaolinite product. Work with the former of these products is reported here.

EXPERIMENTAL

Sample

A 2 t bulk sample of "-200 mesh slimes" was received from KMG Minerals. The feed was oven-dried in batches at 110° C. to permit accurate feeding in the pilot plant. Table 1 shows the size and chemical analyses of the material.

Pilot Plant Tests

The feed, consisting mostly of clay balls 13 mm (0.5 in.) or smaller, was fed dry at a rate of about 20 kg/hr (44 lb/hr) to a 46 cm (18 in.) diameter conditioner by means of a Vibra-Screw volumetric feeder. Sufficient water and 10% sodium silicate solution was added to create a 40% solids slurry with a pH of 7.5-8.0. The conditioner "blunged" the clay balls, causing the particles to deagglomerate and disperse throughout the slurry. The slurry was pumped without dilution to the top of a 15.2 cm (6 in.) diameter pilot scale Linatex Hydrosizer (Fig. 1) to classify the finer kaolinite particles from the coarser grit particles. The hydrosizer was selected as a classifier because of prior success in desliming North Carolina phosphate ore (Schlesinger and Hutwelker, 1993).

Taking into the account the 5.0 cm (2 in.) feed well, the sizer's available overflow area was 167 cm^2 (0.18 ft^2). The operating conditions of the sizer (i.e., teeter water flowrate and bed density) were varied according to a test plan to study their effect on making a 270 mesh size split. The sizer's teeter bed density was regulated by means of a proportional-integral (PI) electronic control loop. The loop worked by throttling the discharge of underflow (+270 mesh oversize) from the bottom of the unit. The overflow product (-270 mesh undersize) was gravity fed to an 18-in. Sweco vibrating screen equipped with a 270 mesh screen. The screen served two roles: 1) to remove trash associated with the slime waste and 2) to compensate for the imperfect performance of the hydrosizer during some of the tests.

Two series of four tests each were run. The first series used a "shallow" teeter bed height -- about 15 cm (6 in.). The teeter water flowrates were varied to produce net rise velocities ranging from 0.26 cm/s to 0.40 cm/s. The terminal settling velocity of a spherical quartz particle is 0.24 cm/s. Despite the use of rise velocities greater than 0.24 cm/s, short-circuiting of ultrafine (-10 micron) clay to the underflow was evident. Thus, the second test series was run using a "deep" teeter bed height of 38 cm (15 in.). The teeter water flowrates were varied to produce net rise velocities ranging from 0.10 cm/s to 0.21 cm/s. With the use of lower velocities, the recovery of -270 mesh material to the overflow was reduced. However, the deeper teeter bed decreased the turbidity of the underflow water -- indicating that the short-circuiting of -10 micron clay was reduced. The test conditions, summarized in Table 2, are shown in the order of descending net rise velocity.

Timed samples of the overflow and underflow streams were taken under steady-state conditions. The overflow sample was taken before the material reached the screen so that the sizer's performance could be accurately quantified. The samples were weighed wet and dry so that percent solids and a mass balance could be determined. Representative sub-samples were dispersed and sieve analyzed by wet screening. Table 3 shows the classification data that were calculated from these analyses.

Product Evaluation

The -270 mesh products from the second test series were combined. The slurry was flocculated and the solids permitted to settle. The supernatant was decanted, and the solids were oven-dried at 110° C. Table 4 shows the properties that were determined.

RESULTS AND DISCUSSION

Pilot Plant Tests

Table 5 shows a summary of the test results. Plots of the partition curves for each test are displayed in Figure 2. Figure 3 shows two plots of "Percent -270 Mesh Recovered to the O'Flow versus Percent of +270 Mesh Material Rejected to the U'Flow": one plot for the "shallow" teeter bed tests and a second plot for the "deep" teeter bed tests.

Table 1. Analysis of KMG "-200 Mesh Slimes"

Particle Size Analysis

(Tyler Mesh)	% Passing
100	92.3
150	84.6
200	74.9
270	65.8
325	59.4
400	56.9

Chemical Analysis

Constituent	KMG Slimes	Theoretical Kaolinite
% Al_2O_3	29.4	39.5
% SiO_2	53.9	46.5
% Fe_2O_3	2.06	---
% Na_2O	0.448	---
% K_2O	3.27	---
% CaO	<0.02	---
% MgO	0.233	---
% TiO_2	0.137	---
% LOI	10.2	14.0

Figure 1. Pilot-Scale Linatex Hydrosizer

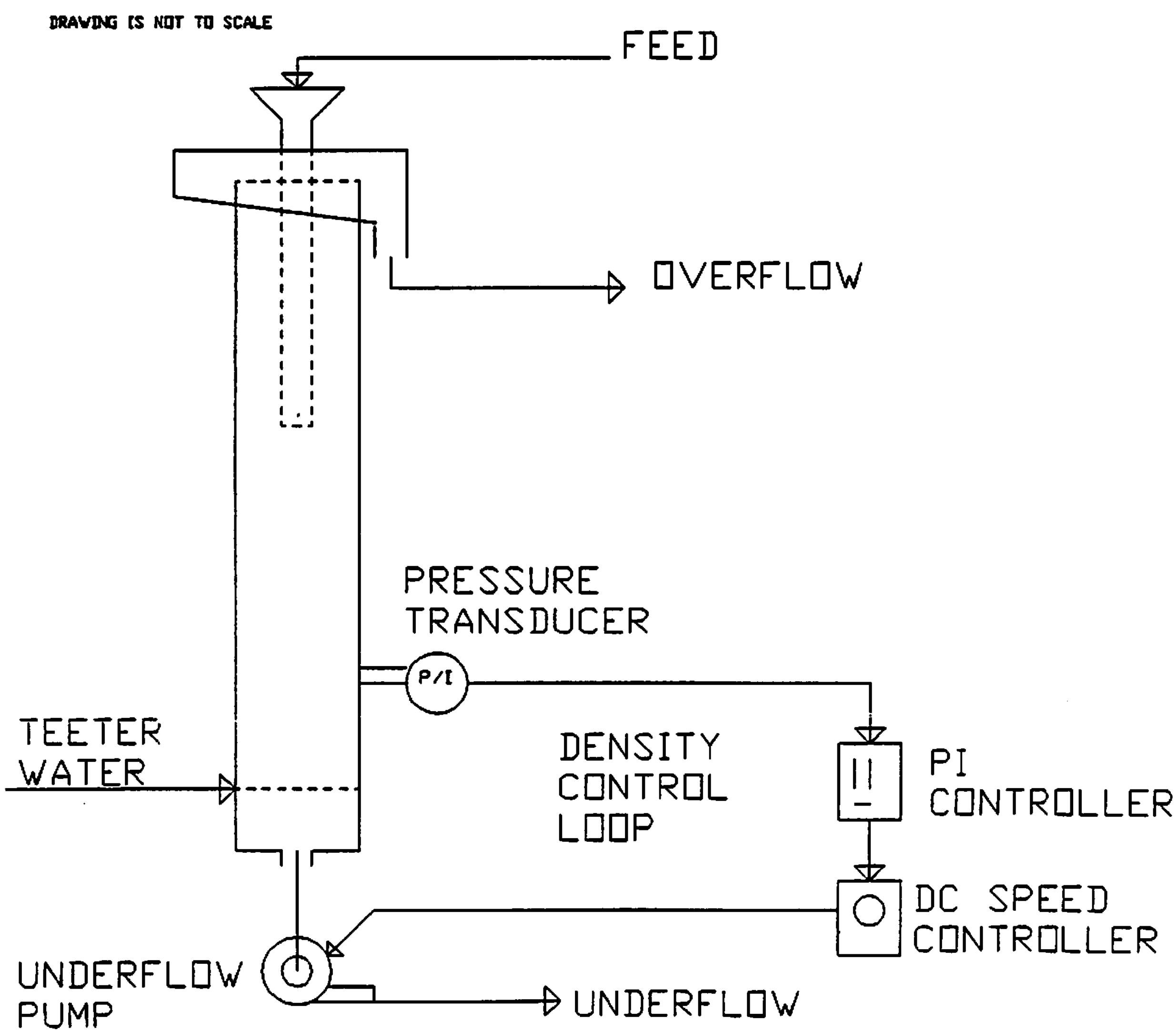


Table 2. Summary of Pilot Plant Test Conditions

Condition	Test No.	SERIES 1 "Shallow" Teeter Bed PP-8	PP-7	PP-6	PP-5	SERIES 2 "Deep" Teeter Bed PP-10	PP-9	PP-11	PP-12
Solids Feed Rate:	(kg/hr)	21.4	21.5	19.3	18.7	18.7	18.0	18.6	19.0
	(lb/hr)	47.1	47.5	42.5	41.1	41.1	39.5	41.0	41.8
Solids per Unit Area:	(t/hr/sq.m)	1.23	1.24	1.10	1.07	1.07	1.03	1.07	1.09
	(ton/hr/sq.ft)	0.13	0.13	0.12	0.11	0.11	0.11	0.11	0.12
Teeter Water:	(L/min)	3.7	3.0	2.7	2.4	1.9	1.5	1.1	0.76
	(gpm)	0.97	0.79	0.71	0.63	0.50	0.40	0.30	0.20
Teeter per Unit Area:	(L/min/sq.m)	219	179	158	142	114	89	69	45
	(gpm/sq.ft)	5.4	4.4	3.9	3.5	2.8	2.2	1.7	1.1
Net Water Upflow:	(L/min/sq.m)	240	195	175	154	126	102	77	61
	(gpm/sq.ft)	5.9	4.8	4.3	3.8	3.1	2.5	1.9	1.5
Percent Solids:	Feed	40	40	41	40	40	43	45	42
	Overall	8	9	9	10	12	14	17	21
Net Rise Velocity (cm/s)		0.40	0.33	0.29	0.26	0.21	0.17	0.13	0.10
Bed Density (g/cc)		1.07	1.08	1.06	1.10	1.11	1.13	1.15	1.18

Table 3. Data Calculated from Analysis of Pilot Plant Samples

Oversize Efficiency, E_o = Percentage of +270 in feed recovered to oversize.

Undersize Efficiency, E_u = Percentage of -270 in feed recovered to undersize.

Coefficient of Separation, CS = Total efficiency, expressed as a number between 0 (no classification) and 1 (ideal classification).

$CS = [(E_o + E_u) - 100]/100$

Partition Curve = Plot of particle size versus cumulative percent weight of the that particle size which reported to the oversize. Key points on the plot are:

D_{50} = the particle size which reported to the oversize and undersize in equal amounts.

D_{25} = the particle size which had 1/4 of its original material report to the oversize.

D_{75} = the particle size which had 3/4 of its original material report to the oversize.

Sharpness Index, SI = Slope of the partition curve -- a number between 0 (no classification) and 1 (ideal classification).

$SI = D_{25}/D_{75}$

Imperfection, I = Measure of the misplaced material -- a number between 0 (ideal classification) and 1 (no classification).

$I = (D_{75} - D_{25})/2D_{50}$

Table 4. Properties Determined During -270 Mesh Clay Product Evaluation

Evaluation	Property Determined	Method/Instrument
Chemical Analysis	Oxides of Si, Al, Fe, Ti, K, Na, Ca, Mg, and LOI	Atomic Adsorption
Physical Properties	Particle Size Analysis % Grit (+270 and +325) Specific Gravity pH Bulk Density Refractive Index Oil Adsorption Grit Mineralogy	Micromeritics Sedigraph 500E Disperse and Wet Screen Air Comparison Pycnometer 50 grams in 200 ml DI water Scott Volumeter Petrographic Analysis Gardner Rub-Out Method Petrographic Analysis
Rheological Properties	Low Shear Viscosity Casting Rate and Thickness Cationic Exchange Equiv.	Brookfield Viscometer Baroid Test Filter Baroid Methylene Blue Method
Dry Properties	Dry Brightness/Color Bleached Brightness/Color	Photovolt Reflectometer Photovolt Reflectometer
Extruded Properties	% Water of Plasticity % Linear Shrinkage Modulus of Rupture	Water to Plasticize After 48 Hr Slow Dry Transverse Load Reading
Fired Properties	Fired Brightness/Color % Linear Shrinkage % Water Adsorption (Soak) % Water Adsorption (Boil)	Photovolt Reflectometer After Firing to Cone 10 After 24 Hr Soak After 24 Hr Soak + 5 Hr Boil

Table 5. Summary of Pilot Plant Test Results

		SERIES 1 "Shallow" Teeter Bed				SERIES 2 "Deep" Teeter Bed			
Condition	Test No.	PP-8	PP-7	PP-6	PP-5	PP-10	PP-9	PP-11	PP-12
Net Rise Velocity (cm/s)		0.40	0.33	0.29	0.26	0.21	0.17	0.13	0.10
Bed Density (g/cc)		1.07	1.08	1.06	1.10	1.11	1.13	1.15	1.18
Percent Solids:	Overall	8	9	9	10	12	14	17	21
	U'Flow	25	27	29	26	34	37	41	42
	O'Flow	7	8	7	8	8	9	11	14
Partition Data (microns)	D 25	53	50	47	46	43	36	28	25
	D 50	68	65	58	56	50	48	44	37
	D 75	106	101	73	75	66	58	50	46
Separation Efficiency (%)	Undersize	96.6	92.8	91.2	89.9	90.0	86.0	81.7	78.5
	Oversize	60.5	63.7	73.1	72.8	84.1	88.2	94.2	97.1
	CS (0 - 1)	0.54	0.57	0.64	0.63	0.74	0.74	0.76	0.76
Sharpness Index, SI (0 - 1)		0.50	0.50	0.64	0.61	0.64	0.62	0.56	0.54
Imperfection, I (0 - 1)		0.39	0.39	0.22	0.26	0.23	0.23	0.24	0.28

Figure 2. Partition Curves from Hydraulic Sizer Tests

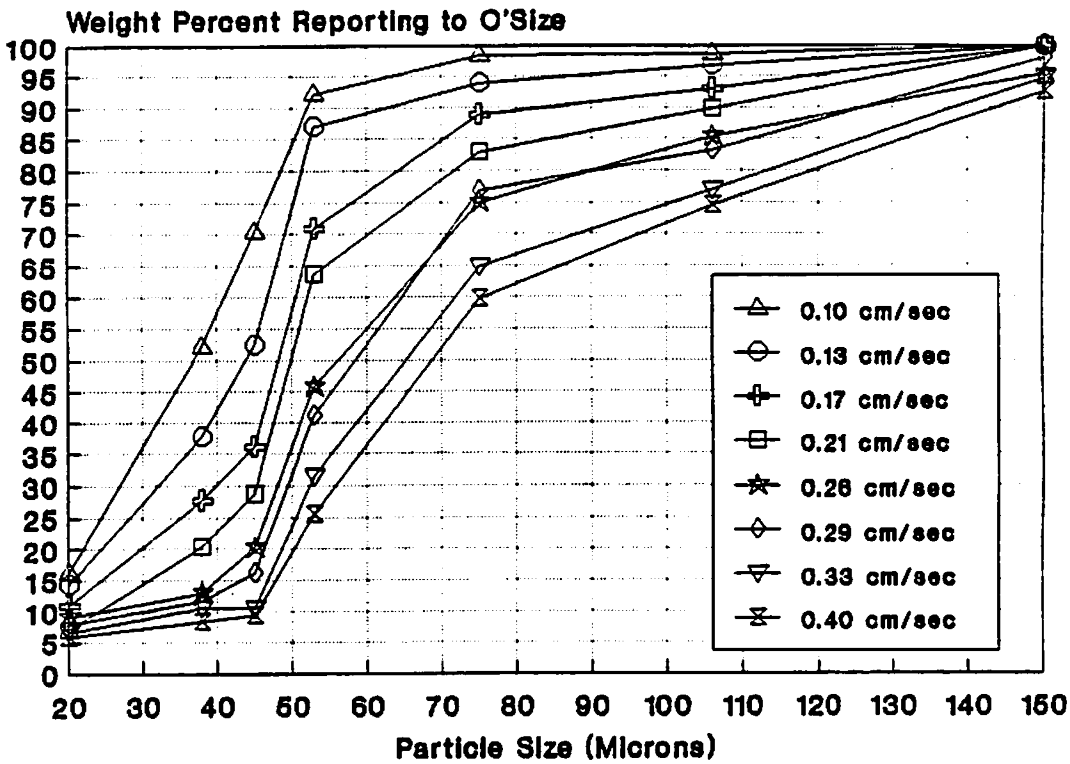
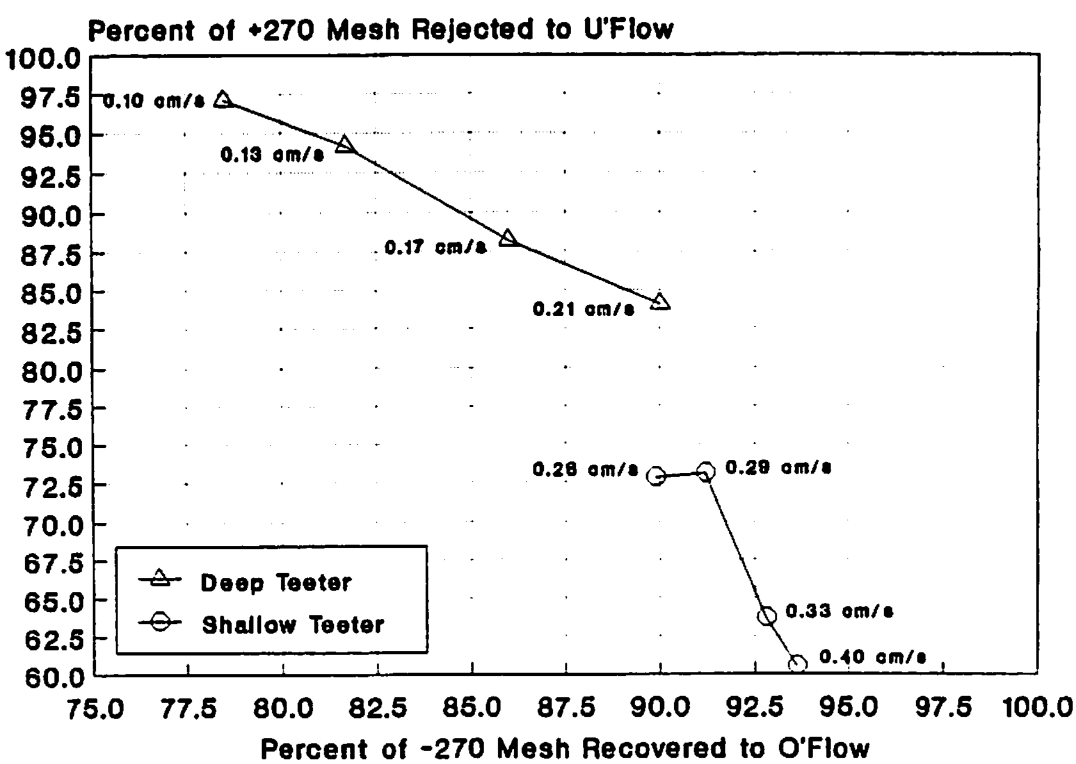


Figure 3. Percent of -270 Mesh Recovered to the O'Flow Versus Percent of +270 Mesh Rejected to the U'Flow



Removal efficiency of -270 mesh material to the O'Flow depended upon the net rise velocity: the higher the net rise velocity, the higher the undersize efficiency. Rejection of +270 mesh material to the U'Flow also depended upon net rise velocity: the lower the net rise velocity, the higher the oversize efficiency. As expected, the cut point of the classification (D_{50}) increased as the net rise velocity was increased (Fig.2).

The bed depth had a large effect on the coefficient of separation (CS): the deeper bed resulted in higher overall efficiencies. For the "shallow" bed tests, the range of CS was 0.54 - 0.63; the range increased to 0.74 - 0.76 for the "deep" teeter bed tests. The plots in Fig. 3 suggest that the "deep" bed depth might result in better classification for any upflow velocity. (The upper right corner of the graph represents perfect classification.)

The highest sharpness indices and lowest imperfections occurred when the net rise velocity ranged from 0.17 - 0.29 cm/s -- regardless of the teeter bed depth.

In practice, the condition used in Test PP-12 would probably represent the best condition, because: 1) the rejection of +270 mesh grit was nearly complete and 2) that condition required less water than the others. The percent solids of the O'Flow solids was 14%. Although the undersize efficiency at this condition was in the high 70s, that value and the O'Flow solids obtained both represent substantial improvements over the performance of the clay circuit at the old Harris Mining Company Plant near Spruce Pine, N.C., which processed a weathered pegmatite similar to KMG's deposit in Kings Mountain. That circuit used blungers and stirred hydroclassifiers.

Product Evaluation

Table 6 shows the results of the evaluation of the -270 mesh product from the Series 2 tests. The -270 mesh KMG product can best be described as a hydrous aluminum silicate that might be suitable in the filler and extender markets. Its chemical and physical properties are similar to the former Harris Mining Company's KMS filler, which was used in certain types of paints, plastic fillers, joint cement, and dusting compounds.

The KMG product would not be suitable as the main clay ingredient in ceramic casting bodies, because it is extremely thixotropic. As Table 6 shows, acceptable viscosities could only be obtained at a low slip specific gravity. Even at the lower specific gravity , the slip gelled upon sitting. However, small proportions (5%-10%) of this material might be used in a casting body without noticeable deterioration of the casting properties. In fact, the coarse particle size of this product might tend to open up the body and aid the casting rate. It was also observed that this product exhibited resistance to dry cracking. This feature will be attractive to the manufacture of extruded ceramic bodies.

Although the product has a high water of plasticity, a high fired absorption, and a low modulus of rupture, it would probably be beneficial when used in amounts of 5%-10% in extruded ceramic bodies for electrical porcelain and dinnerware applications. In fact, this product would help during extrusion because: 1) the presence of mica would act as a lubricant 2) of the aforementioned tendency to not crack upon drying.

Bleaching this product did improve the brightness considerably; however, the bleached material was still not bright enough to use in better paints, such as ceiling tile paint. A much better product might be produced by more selective mining to avoid schist -- which was apparent in the product.

SUMMARY

Pilot plant test results showed that a -270 mesh kaolinite-enriched product can be made by processing the slime waste stream from the mica-feldspar-quartz flotation plant operated by KMG Minerals, Inc. The process consisted of: 1) blunging a 40% solids slurry of the slimes, with the pH adjusted to 7.5-8.0 to deagglomerate the clay balls and disperse the particles, 2) classification of the dispersed slurry with a 15.2 cm (6 in.) diameter pilot scale Linatex Hydrosizer, and 3) screening of the O'Flow with a 270 mesh vibrating Sweco screen to remove trash and misplaced coarse particles.

Table 6. Results of -270 Mesh Clay Product Evaluation

Chemical Analysis

Constituent	Hydrosizer Feed	-270 Mesh Product	Theoretical Kaolinite
% Al_2O_3	29.40	33.50	39.5
% SiO_2	53.90	50.10	46.5
% Fe_2O_3	2.06	1.46	---
% Na_2O	0.45	0.33	---
% K_2O	3.27	1.69	---
% CaO	<0.02	0.29	---
% MgO	0.23	0.15	---
% TiO_2	0.14	0.08	---
% LOI	10.20	12.20	14.0
Total:	99.67	99.80	100.0

Physical Properties

Sedigraph Analysis

Size (microns)	% Passing
30	100
20	85
15	75
10	64
6	50
5	44
3	34
2	27
1	20

Specific Gravity 2.70
pH (50 g/200 cc) 4.6
Bulk Density .... 19.5 lb/ft^2
Refractive Index 1.58

Grit Analysis

% Grit (+270 mesh) 6.3%
(+325 mesh) 14.6%

Grit Mineralogy: % Quartz 11%
% Feldspars .. 25%
% Muscovite .. 49%
% Others 5%

Rheological Properties

Viscosity @ 1.53 sp.gr & pH 7.4	(20 rpm)	1142 centipoise
	(100 rpm)	off scale
Viscosity @ 1.44 sp.gr & pH 7.4	(20 rpm)	690 centipoise
	(100 rpm)	249 centipoise
Casting Rate @ 1.44 sp.gr. & pH 7.4	....	116.5 g / 43 cm_2
Thickness of Cast	....	1.52 cm
Cationic Exchange Equivalent	....	2.5 m.e./100 g

Dry, Extruded, and Fired Properties

% Water of Plasticity	....	43.3 %
% Linear Shrinkage	(dry)	3.3 %
	(fired)	6.7 %
Modulus of Rupture	....	55 psi
% Water Adsorption	(soak)	16.8 %
	(soak + boil)	18.4 %

	After Drying	After Bleaching	After Firing
Blue Filter (460 nm)	49.5	62.2	65.9
Green Filter (515 nm)	60.5	73.0	70.5
Amber Filter (600 nm)	65.5	76.5	82.5
Degree of Yellowness	+0.26	+0.20	+0.24

Yellowness = (Amber Reading - Blue Reading)/Green Reading.
If Yellowness >0, product has yellow shade. If <0, product has bluish-white shade.

The hydrosizer was operated using a range of teeter water flowrates, so that the net rise velocity was varied from 0.10 cm/s to 0.40 cm/s. (The terminal settling velocity of a 270 mesh spherical quartz particle is 0.24 cm/s.) The solid feed rate to the sizer was maintained at approximately 1.1 t/hr/m^2 (0.12 ton/hr/ft^2). Tests were run using both "shallow" (i.e., 6 in.) and "deep" (i.e., 15 in. teetered beds. The -270 mesh material from the "deep" teeter bed tests was composited and evaluated to identify potential markets. Size analysis showed that this product was 80% finer than 20 microns and 50% finer than 6 microns (in equivalent spherical diameter).

Test results showed that the hydrosizer's undersize efficiency (i.e., percentage of -270 mesh material recovered) increased as the net upflow velocity was increased. The oversize efficiency (i.e., percentage of +270 mesh material rejected) increased as the net upflow velocity was decreased. The best overall result was obtained when the sizer was operated with the "deep" teeter bed and a net rise velocity of 0.10 cm/s. About 97% of the +270 mesh material was rejected and approximately 79% of the -270 mesh material was recovered in a 14% solids slurry. The coefficient of separation was 0.75. It is plausible that the undersize efficiency might be increased by additional deepening of the teeter bed.

The evaluation of the -270 mesh product showed that it is a hydrous aluminum silicate that would be suitable in filler and extender markets for paint, plastics, joint cements, and dusting compounds. Because it is extremely thixotropic, however, it could be used in cast ceramic bodies only if it comprised no more than 5%-10% of the clay used. The material's high water of plasticity, low modulus of rupture, and high fired adsorption would also limit its use in extruded porcelains to no more than 5%-10% of the body. However, all of these potential markets together might enable KMG Minerals, Inc. to better utilize its milling waste and reduce impoundment costs.

Hydraulic classifiers such as the Linatex Hydrosizer are nearly exclusively marketed for sizing applications ranging from 28 mesh to 100 mesh. These results show that the device can be fine-tuned to facilitate high efficiency fine classification. Optimizing the operation may overcome some of the limitations in throughput. The potential unit value of a product may also help economically justify a hydraulic sizer. In the case of the KMG material, a purer kaolinite product (100% passing 20 microns) could be made by adjusting the net rise velocity to 0.05 cm/s.

ACKNOWLEDGEMENTS

This work was supported by funds from North Carolina State University College of Engineering. The mica plant slime sample was provided by KMG Minerals, Inc., of Kings Mountain, N.C. Linatex Corporation, of Gallatin, TN, donated the pilot scale Hydrosizer used in the study.

REFERENCES

Redeker, I.H. 1987. Applied Nonmetallic Mineral Processing Research at the North Carolina State University Minerals Research Laboratory in Asheville, N.C., U.S.A. MRL Report No. 87-14-P.

Schlesinger, L.M. and Hutwelker, J.F. 1993. Preliminary Desliming Tests with North Carolina Phosphate Using a Pilot-Scale Linatex Hydrosizer. Chapter 13 in Phosphate Beneficiation: Theory and Practice, Proceedings of the Engineering Foundation Conference (SME), Palm Coast, FL, December 5-10, 1993.