ENGINEERING SCHOOL BULLETIN
NORTH CAROLINA STATE COLLEGE

Beneficiation of Olivine By Means of A Humphreys Spiral

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INDUSTRIAL INFORMATION SERIES

BULLETIN NO. 10

DEPARTMENT OF ENGINEERING RESEARCH
NORTH CAROLINA STATE COLLEGE
RALEIGH, NORTH CAROLINA
APRIL, 1955
(Price—$0.35)

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INTRODUCTION

For a number of years it has been rather well known that Western North Carolina and North Georgia contain large reserves of high-grade forsterite olivine. According to Charles E. Hunter, in his report "Forsterite Olivine Deposits of North Carolina and Georgia", published as Bulletin No. 41, Division of Mineral Resources, Department of Conservation and Development, Raleigh, N. C., this mineral occurs within a belt 175 miles long and 15 miles wide, extending from Watauga County, N. C. southwestward to White County, Georgia, with Asheville, N. C. approximately in its center. It was estimated by Hunter that there occur within the area 1,000,000,000 tons of dunite containing more than 40% MgO and 230,000,000 tons of "quarrable" high grade olivine averaging 48% MgO. The deposits mapped by Hunter contained from 60 to 95% coarse-grained, friable olivine. Only the larger, more accessible deposits were mapped.

Olivine is a magnesium iron orthosilicate — $2(Mg.Fe)O.SiO_2$. It offers possibilities for the production of various magnesium chemicals, magnesium metal, fertilizers, and special sands such as foundry sand and blasting sand. In spite of all these potentialities, however, it is currently produced only in small quantities from deposits in North Carolina, this production going chiefly for use as a refractory. Production is small - on the order of 5000 tons per year. The Minerals Yearbook 1951, also lists a small production from the state of Washington.

In August 1953, the N. C. State College Minerals Research Laboratory was contacted by Mr. C. A. Sanders, Vice President, American Colloid Company, Chicago, Illinois, through Dr. William C. Bell, of the Department of Engineering Research, N. C. State College. Mr. Sanders was interested in the potential use of olivine as a foundry sand and the possibility of its production on a commercial scale by his company.

There were two areas of immediate interest to American Colloid Company-deposits along the Murphy Branch of the Southern Railroad between Balsam Gap and Sylva, in Jackson County,

N. C., and deposits near the Clinchfield Railroad in Yancey County, N. C. Both areas contain sizable reserves of olivine.

Following conferences with Mr. Sanders, the Minerals Research Laboratory agreed to process several tons of crude olivine from a representative deposit in each of the areas under consideration.

Object of the processing was to produce from crude run-of-mine olivine several tons of relatively pure olivine sand prepared to American Colloid specifications. This sand was to be shipped to American Colloid customers so that Colloid might have the foundry market adequately sampled with olivine sand which had been prepared in a manner which could be reproduced on a commercial scale.

The sand was prepared and shipped to American Colloid in mid-1954. The following description of the method used in preparing the olivine sand is published now with the kind permission of American Colloid Company in the hope that it might prove of some use to the industrial minerals industry in developing the great reserves of olivine in the Southern Appalachians, whether this development be for special sand, fertilizer, chemical, or metal extraction. Rejection of impurities from the crude olivine would be of importance in any case.

Description of the Ore Samples

The ore samples processed in this investigation came from the Daybook deposit in Yancey County and the Balsam Gap deposit in Jackson County. A 19.6-ton sample of quarry-run olivine from the Daybook deposit was crushed and delivered to the laboratory by Ray Wiseman of Spruce Pine, N. C., who operates the Daybook quarry. Following the Daybook sample a 15.6-ton sample of quarry-run olivine from the Balsam Gap deposit was crushed and delivered by Richard Haynes, of Waynesville, N. C., who operates the Balsam Gap deposit. Mr Haynes designated his sample as "scrap olivine".

Screen analyses and chemical analyses of the crude samples are tabulated below.

Chemical Analyses

	SiO_2	Fe_2O_3	MgO	R_2O_3, RO_2 & R_2O_5	Cr_2O_3	CaO	Ign.	Total
Daybook Crude	44.5	6.2	45.5	1.2	0.11	0.7	1.4	99.6
Balsam Gap Crude	42.7	6.4	46.5	2.0	—	0.2	2.1	99.9

Screen Analyses

Daybook Crude Size	% Wt.	Cum. % Wt.	*Balsam Gap Crude* Size	% Wt.	Cum. % Wt.
+ ½"	8.5	8.5	+ ½"	7.8	7.8
− ½" + ⅜"	25.7	58.8	− ½" + ⅜"	15.4	23.2
− ⅜" + 4 Mesh	24.6	58.8	− ⅜" + 4 Mesh	18.6	41.8
− 4 + 8 Mesh	8.3	67.1	− 4 + 8 Mesh	10.6	52.4
− 8 + 20 Mesh	5.1	72.2	− 8 + 20 Mesh	13.0	65.4
− 20 + 35 Mesh	4.4	76.6	− 20 + 35 Mesh	10.4	75.8
− 35 + 60 Mesh	7.6	84.2	− 35 + 60 Mesh	8.1	83.9
− 60 + 80 Mesh	4.0	88.2	− 60 + 80 Mesh	3.7	87.6
− 80 +100 Mesh	3.2	91.4	− 80 +100 Mesh	2.7	90.3
−100 +150 Mesh	2.7	94.1	−100 +150 Mesh	2.9	93.2
−150 +200 Mesh	2.2	96.3	−150 +200 Mesh	1.6	94.8
−200 Mesh	3.7	100.0	−200 Mesh	5.0	99.8

Mineralogy of the samples was estimated as follows:

	Balsam Gap	*Daybook*
Olivine	65.00	70.00
Serpentine	5.00	3.00
Chromite	0.50	0.25
Talc	20.00	10.00
Chlorite	4.00	5.00
Actinolite	—	10.00
Vermiculite	2.00	—
Asbestos	1.00	1.00
Hypersthene	Tr.	—
Bronzite	Tr.	1.00
Ferruginous Clay	3.00	—

The particles in the Daybook sample were liberated one from another at approximately 28 mesh. The particles in the Balsam Gap sample were liberated one from another at approximately 8 mesh.

Sand Production Technique

The problem in producing foundry sand from crude, run-of-mine olivine, was to take it as it came from the quarry, that is 65% to 70% olivine, and bring it up to 90 to 95% olivine having the desired particle size distribution. There are numerous accessory minerals in the olivine deposits that make up from 5% to 35% of the rock (see estimated mineralogy of crude samples). They are all objectionable impurities in a foundry sand (with the possible exception of chromite) and should be removed as completely as is practicable from the finished sand.

It goes without saying that removal of these accessory minerals must be done as cheaply as possible, since foundry sand is a relatively low-priced commodity.

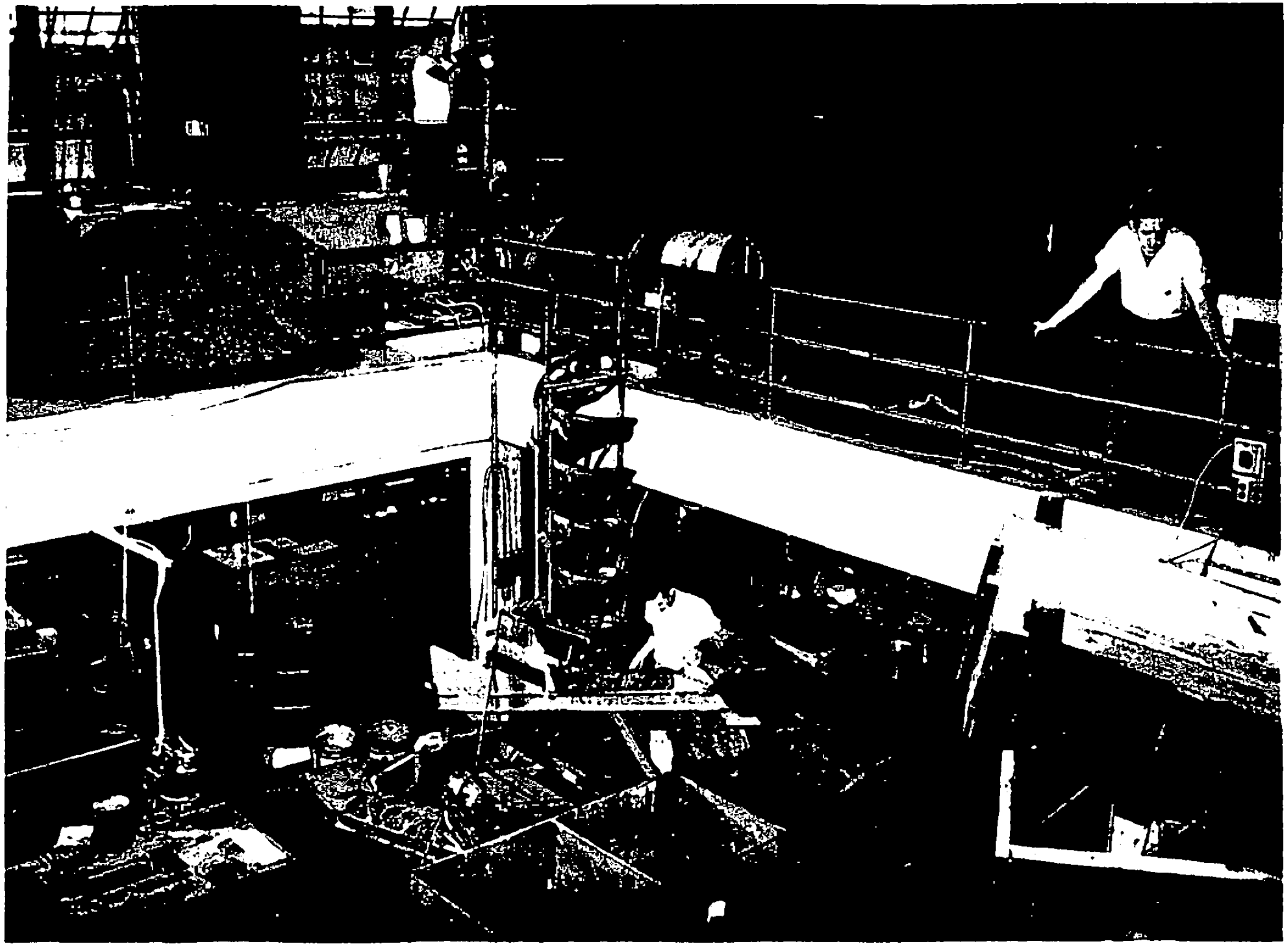


Fig. 1 Overall view of wet plant - from crude ore pile to drain bins

General particle size distribution, as desired by American Colloid Company, is outlined below.

Desired Size Range - Olivine Foundry Sand

Screen Size	*% Weight*
On 30	—
Thru 30 On 40	0.8— 2.4
Thru 40 On 50	9.0—20.0
Thru 50 On 70	28.6—34.7
Thru 70 On 100	36.7—26.1
Thru 100 On 140	17.9—12.3
Thru 140 On 200	5.5— 3.4
Thru 200	1.2— 0.7

The method used in rejecting the accessory minerals and producing olivine sand in the desired particle size range is briefly described below.

Crude, quarry-run, olivine, crushed to pass ¾" was fed to the 16" x 34" Denver rod mill at low pulp density, around 25-35% solids. Mill discharge went to a 14-mesh trommel screen which was attached to the end of the mill. The grind was adjusted so that nearly all the mill discharge passed 14 mesh, with the trommel merely acting to protect the system from tramp oversize. This was essentially an open circuit grind.

Mill discharge passing the 14 mesh trommel went to a commercial-size, 5-turn, 24" Humphreys spiral. This unit achieved most of the beneficiation accomplished by the system. The spiral throws most of the accessory minerals into the outside stream, while the olivine grains tend to hug the inside and are taken off through the ports. The separation is largely due to the wide difference in shape between the olivine and the accessory minerals rather than their difference in specific gravity. Olivine theoretically has a specific gravity of around 3.4 while most of the accessories have a specific gravity of 2.9-3.2. Such a small difference in specific gravity would not be sufficient to serve as a basis for separation. However, it happens that nearly all of the accessories are either micaceous and "flaky" or elongated and "needle-like" in shape. This differs widely from the more or less equidimensional olivine grain, and it is upon this difference in shape that the beneficiation herein described is based.

The application of the spiral for rejection of accessory minerals from olivine is essentially the same as its use for the separation of flake mica (or scrap mica) from its ores. The use of the spiral for concentration of flake mica was developed in detail at this laboratory, and a description of the method was published by Adair, McDaniel, and Hudspeth as a laboratory Report of Investigations, and later as an AIME Technical Paper. Since that time a number of commercial scrap mica installations have been made which are built around the Humphreys spiral. It is difference in particle shape that accounts for the mica-gangue separation as well as the olivine-accessory mineral separation.

The cleaned olivine sand was taken from the spiral through the ports and dropped into a 12" screw classifier. The classifier removed additional fines by washing, and thickened the olivine sand before dropping it into drain bins. Spiral tailings and classifier overflow, containing the great bulk of the −200 mesh slimes and most of the accessory minerals, were sampled and then run to waste.

The drained olivine sand was then hoisted to a bin which fed the Sutton-type drier. After passing through the drier, the dry sand fell into a hopper from which it was fed by a vibrating feeder to a shaking screen employing a 30 mesh square opening cloth. Oversize from the screen was bagged and shipped as −14 +40 mesh olivine sand, and undersize was bagged and shipped as −40 mesh olivine sand. The −40 mesh sand fell into the size range for finished foundry sand specifications, while the −14 +40 mesh was ear-marked for dry grinding into olivine flour.

Rate of feed to this pilot plant was 1000 pounds per hour of crude olivine. A flowsheet, a list of equipment statistics, and three photographs of the pilot operation are attached to this report.

The entire plant worked as anticipated with one or two minor exceptions. The lowest moisture content obtained by draining the wet sand was 14% It was found that this could be lowered to 8% by vacuum filtration. Since this speeded up the drying step, the laboratory filter was placed in the system before the dryer. The capacity of the dryer was approximately 300 pounds per hour of dry sand. Since the wet concentration plant could produce twice this amount, it was necessary to run the dry plant twice as long as the wet plant to keep up with it.

Processing in general, however, followed expectations. Size requirements were generally met, and the finished sand was estimated to contain 90-92% olivine, whereas the crude ore had

Fig. 2 Hoisting sand from drain bins to Sutton dryer

Fig. 3 Screening the dried olivine sand

contained 65-70% olivine. Total recovery of olivine sand in round numbers was 70% by weight of the feed. This product contained 90% of the available olivine.

Results

The following tabulated data summarizes results obtained in processing the two large olivine samples.

Final Results - Daybook Sample

Total Feed to Wet Plant .... 19.2 tons
Approximate Moisture in Ore .... 0.4 tons
Approximate Total Ore Delivered to the Laboratory .... 19.6 tons

Dry Sand Prepared:	*−14 + 40 Mesh*	*−40 Mesh*	*Total*
	1.30 tons	13.00 tons	14.30 tons

Ratio of −40 mesh to −14 +40 mesh .... 10 to 1.
Recovery of dry sand .... 73%, by weight.
Fuel oil cost .... $1.75 per ton of dry sand.

	Wet Plant	*Dry Plant*
Hours Operated:	36.9 hours	103.5 hours
Sand Production Rate:	780 lbs/hr	280 lbs/hr

Distribution of Products

Product	*Tons*	*% Wt.*	*Ignition Loss**	*Specific Gravity*
−14 +40 Mesh Sand	1.30	6.8	1.33	—
−40 Mesh Sand	13.00	67.7	0.86	3.22
Spiral Tails	3.70	19.3	4.31	—
Classifier O'flow	1.20	6.3	3.05	—
Heads	19.20	100.1	1.59	

* Lowest ignition loss obtainable on Daybook olivine was 0.55%.

Screen Analyses of Products

−14 +40 Mesh Sand

Size	*% Wt.*	*Cum. % Wt.*
+ 14	Tr.	Tr.
− 14 +20	3.8	3.8
− 20 +30	14.0	17.8
− 30 +40	54.0	71.8
− 40	28.2	100.0
Total	100.00	

−40 Mesh Sand

Size	*% Wt.*	*Cum. % Wt.*
+ 30	Tr.	Tr.
− 30 + 40	2.7	2.7
− 40 + 60	35.3	38.0
− 60 + 80	23.6	61.6
− 80 +100	16.2	77.8
−100 +150	13.0	90.8
−150	9.1	99.9
Total	99.9	

Classifier O'flow

Size	*% Wt.*	*Cum. % Wt.*
+150	10.0	10.0
−150	90.0	100.0
Total	100.0	

Spiral Tails

Size	*% Wt.*	*Cum. % Wt.*
+100	29.0	29.0
−100 +150	6.5	35.5
−150	64.4	99.9
Total	99.9	

Chemical Analyses of Products

Product	SiO_2	Fe_2O_3	R_2O_3, RO_2 & R_2O_5	CaO	MgO	Cr_2O_3	Ign. Loss
Head Sample	44.5	6.2	1.2	0.7	45.5	0.11	1.44
−14 +40 Mesh Sand	42.4	8.0	1.7	0.2	46.4	0.14	0.92
−40 Mesh Sand	42.6	7.3	1.2	0.3	47.3	0.12	0.97
Spiral Tails	48.4	5.1	2.3	1.6	39.1	Tr.	3.93
Classifier O'flow	44.9	4.9	2.3	1.0	43.6	Tr.	2.75

Final Results - Balsam Gap Sample

Total Feed to Wet Plant............ 15.41 tons
Approximate Moisture in Ore............ 0.24 tons
Approximate Total Ore Delivered to the Laboratory............ 15.65 tons

Dry Sand Prepared:	*−14 +40 Mesh*	*−40 Mesh*	*Total*
	2.55 tons	8.30 tons	10.85 tons

Ration of −40 mesh to −14 +40 mesh .... 3.26 to 1.0.
Recovery of dry sand ...... 70.4%, by weight.
Fuel oil cost .... $1.52 per ton of dry sand.

	Wet Plant	*Dry Plant*
Hours Operated:	34.4 hours	72.0 hours
Sand Production Rate:	632 lbs/hr	302 lbs/hr

Distribution of Products

Product	*Tons*	*% Wt.*	*Ignition Loss**	*Specific Gravity*
−14 +40 Mesh Sand	2.55	16.6	1.44	—
−40 Mesh Sand	8.30	53 8	1.17	3.14
Spiral Tails	3.38	21.9	5.08	—
Classifier O'flow	1.18	7.7	3.80	—
Heads	15.41	100.0	2.20	

* Lowest ignition loss obtainable on Balsam Gap olivine was 0.75%.

Screen Analyses of Products

−14 +40 Mesh Sand

Size	*% Wt.*	*Cum. % Wt.*
+14	0.1	0.1
−14 +20	4.8	4.8
−20 +30	22.5	27.4
−30 +40	56.0	83.4
−40	16.6	100.0
Total	100.0	

−40 Mesh Sand

Size	*% Wt.*	*Cum. % Wt.*
+ 30	Tr.	—
− 30 + 40	4.3	4.3
− 40 + 60	40.0	44.3
− 60 + 80	19.4	63.7
− 80 +100	14.0	77.7
−100 +150	12.0	89.7
−150	10.3	100.0
Total	100.0	

Classifier O'flow

Size	*% Wt.*	*Cum. % Wt.*
+150	8.7	8.7
−150	91.3	100.0
Total	100.0	

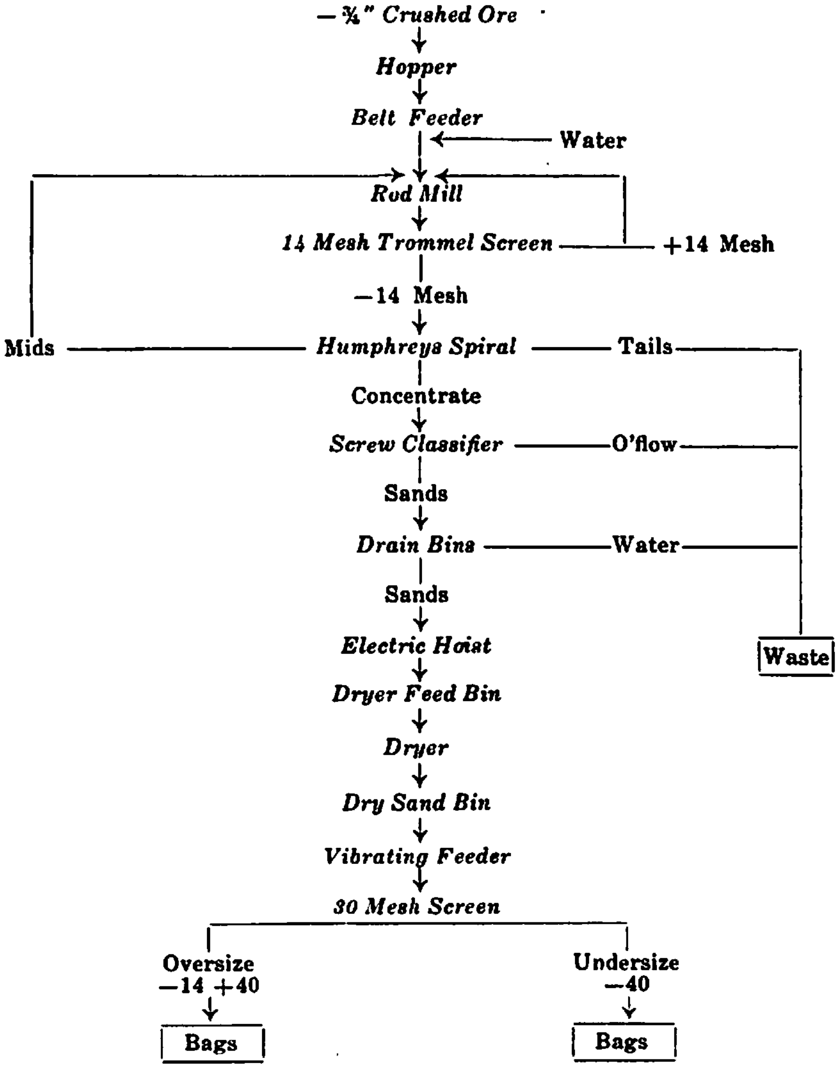
Spiral Tails

Size	*% Wt.*	*Cum. % Wt.*
+100	15.3	15.3
−100 +150	4.7	20.0
−150	80.0	100.0
Total	100.0	

Chemical Analyses of Products

Product	SiO_2	Fe_2O_3	R_2O_3, RO_2 & R_2O_5	Cr_2O_3	*CaO*	*MgO*	*Ign. Loss*
Head Sample	42.7	6.4	2.0	—	0.2	46.5	2.11
−14 +40 Mesh Sand	41.9	8.0	0.6	0.10	Tr.	47.8	1.52
−40 Mesh Sand	41.7	7.2	0.4	0.15	Tr.	49.0	1.37
Spiral Tails	44.8	8.8	4.0	—	0.2	36.4	5.57
Classified O'flow	42.0	6.8	1.9	—	0.5	44.9	3.65

Pilot Plant Flowsheet



Pilot Plant Statistics

1. *Ore Feeder*
   Hopper with belt feed - Denver. 6" belt 3.6 ft^3 hopper.
   ¼ Hp 1 phase 115 volt motor through Boston gear reducer.
   Rate of feed 1000 pounds per hour to rod mill.

2. *Rod Mill*
   Denver Ball and rod mill. 16" x 34" inside dimensions.
   3 Hp 3 phase 220 volt motor.
   Rod load 650 pounds of mixed ½", 1" and 1½" rods.
   Handling 1000 pounds per hour —¾" crude olivine and grinding to 14 mesh for spiral feed.

3. *Humphreys Spiral*
   Humphreys Investment Corporation. Standard Model *24-A*, 5-turn, 24-inch diameter.
   Handling 1000 pounds per hour 14 mesh mill discharge.

4. *Screw Classifier*
   Denver - Screw dia. 12", screw length 7.5', screw speed 15 RPM. Pool area 2.0 ft^2.
   ½ HP 3 phase 220 volt motor through Boston gear reducer.
   Handling 700-800 pounds per hour olivine sand from Humphreys spiral, O'flowing —150 mesh.

5. *Drain Bins*
   Home made ⅛" perforated plate bottom covered by 20 mesh screen.
   Three compartment - wood and angle iron construction mounted on wheels. Capacity 1500 pounds per compartment.
   Handling 700-800 pounds olivine sand from screw classifier at 30% moisture and draining to 14% moisture.

6. *Electric Hoist*
   Chisholm-Moore Hoist Company, Comet ¼-ton. 500 pound capacity bucket.
   Handling 300 pounds per hour of damp olivine sand from drain bins to dryer.

7. *Dryer*
   Indiana Foundry Company
   No. 2 Sutton Sand Drying Stove with external gratings.
   No. 212 Type "A" Hauck Oil Burner.
   Handling 300 pounds per hour drained olivine sand at 14% moisture and delivering dry to hopper below.

8. *Vibrating Feeder*
   Jeffrey
   Model 1-B, 1 ft^3 hopper, 3" x 17" Aluminum deck.
   Controlled by calibrated dial transformer.
   Handling 300 pounds per hour dry olivine sand from storage hopper to vibrating screen.

9. *Vibrating Screen*
   Denver-Dillon portable.
   1' x 3' screen cloth —30 mesh square openings.
   ½ HP 3 phase 220 volt motor.
   Handling 300 pounds per hour of dry olivine sand producing undersize of 95% —40 mesh and oversize containing 20% —40 mesh.

Ignition Loss as an Evaluation Tool

The use of ignition loss as a rapid means for evaluating the degree of beneficiation of the crude olivine samples seems deserving of special mention. The determination of ignition loss on crude olivine, finished olivine sand, spiral tails, and classifier overflow can indicate the degree of beneficiation by Humphreys spiral and screw classifier. The basis for using ignition loss is this - pure, unaltered olivine has no water of crystallation, therefore little or no weight loss on ignition. On the other hand talc, chlorite, vermiculite, ocherous clay, serpentine, bronzite, asbestos, in fact, nearly all the accessory minerals in the crude olivine have water of crystallization and consequently show from 5 to 15% weight loss on ignition. Therefore, determination of ignition loss on the various pilot plant products would serve as a crude index to the amount of accessory minerals contained therein.

The picture is complicated by the fact that there is usually a small amount of serpentinization on the olivine particles themselves. The degree of this serpentinization would vary from one deposit to another, and also from zone to zone within a given deposit. However the degree of serpentinization should be approximately constant if large tonnage production were made from a given deposit.

It was established empirically that pure olivine sand from which all detectable mineral impurities have been removed had an ignition loss of 0.55% in the case of the Daybook sample, and 0.75% in the case of the Balsam Gap deposit. This, then, is the "serpentine factor" and becomes the lowest point to which ignition loss on the respective samples may be brought.

In order to get an undistorted picture of the separation obtained it is necessary to correct actual ignition loss readings by subtracting 0.55X or 0.75X from them, when X equals the olivine content of the sample. We then get a numerical picture of the degree of purity reached by the beneficiation system. The lower the ignition loss on a sand, the cleaner it is, etc.

A system of control through use of ignition loss could be set up on any olivine deposit. However, the "serpentine" factor (0.55 in the case of Daybook) would have to be determined empirically on each deposit and would quite likely be different in each deposit. The procedure has several sources of error, and is not intended to be exact, but it is a quick, simple method to establish approximate analytical control on removal of talcy impurities from olivine. It has the further advantage that any technician could perform the analysis, and no analytical chemist would be necessary.

The following tabulated data illustrates the use of ignition loss as an analytical control.

	Daybook Sample			*Balsam Gap Sample*		
		Ignition Loss			*Ignition Loss*	
Product	*% Wt.*	*Actual*	*Corrected*	*% Wt.*	*Actual*	*Corrected*
−14 +40 Mesh Sand	6.8	1.33	0.86	16.3	1.44	0.80
−40 Mesh Sand	67.7	0.86	0.37	53.0	1.17	0.50
Spiral Tails	19.3	4.31	4.18	22.7	5.08	5.00
Classifier O'flow Classifier O'flow	6.3	3.05	2.83	8.0	3.80	3.54
Heads	100.1	1.59	1.21	100.0	2.20	1.71

By Product Possibilities

It is probable that two by-products could be recovered in this processing. Chromite could be separated from the sand before bagging, and the waste products might be recovered and sold as a mineral filler since they contain around 40% talcose minerals.

A short investigation into the possible recovery of by-products is planned, but other than casual mention, the subject is not considered within the scope of this report.

Conclusions

A total of 25 tons of olivine sand processed to specification of American Colloid Company for foundry sand use has been prepared from crude, run-of-mine, olivine. Two well-known deposits in Western North Carolina were sampled for the project.

Processing in general was easily controlled and is considered adaptable to commercial application. The general flowsheet used in the pilot plant is recommended for commercial scale production with two exceptions: (1) use of a filter instead of drain bins before drying sand, and (2) use of a rotary dryer instead of the Sutton stove for drying the sand.

Cost of production using this method is estimated to be on the order of $4.00-$5.00 per ton of finished sand, assuming a recovery of 70% finished sand from quarry-run material, and an operating capacity of at least 10 tons per hour.

Although the testwork described in this article was carried out with the object of preparing foundry sand, publication of the method is being made with the feeling that the production of granular olivine from quarry-run crude might be of interest to others in the field of industrial minerals.

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