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DEPARTMENT OF MINES AND TECHNICAL SURVEYS

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MINES BRANCH INVESTIGATION REPORT IR 60-9

CONCENTRATION OF MAGNESITE FROM FORT STEELE, B. C.

by

W. J. D. STONE AND R. A. WYMAN

MINERAL PROCESSING DIVISION

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SUMMARY OF RESULTS

A process has been developed for the production of calcined magnesite with an MgO content of over 90% and a density of 3.0 gm/cc from magnesite samples ranging in grade from 47 to 87% $MgCO_3$. The process applies flotation to "high grade" feed, "low grade" feed, or mixtures of the two, under conditions of controlled density, temperature, pH, and fineness of grind, followed by pressure pelletizing, and calcination at 1650°C or higher.

The flotation problem is assessed from the point of view of recirculation of middlings, and side circuit treatment of middlings. The number of cleaning stages required is shown to increase as the grade of feed becomes lower.

Gravity methods were found not to apply to this material.

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CONTENTS

	Page
Summary of Results	i
Introduction	1
Description of Samples	2
Analyses	3
Outline of Investigation	3
Preparation of Feed	4
Laboratory Tests	4
Data Applied to Pilot Plant Operations	10
Pilot Plant Operations	10
Description	10
Operation	12
Results	13
Pelletizing	29
Calcination	30
Discussion	31
Conclusions	35

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TABLES

No.		Page
1.	Mineralogical Composition of Samples	2
2.	Results of Typical Successful Tests on the Various Types of Material	6
3(a)	Primary Circuit System for Pilot Plant Treatment of "High Grade"	14
3(b)	Side Circuit System for Pilot Plant Treatment of "High Grade"	15
3(c)	Recirculation System for Pilot Plant Treatment of "High Grade"	16
4.	Comparison Between Side Circuit and Recirculation Systems for "High Grade"	17
5(a)	Primary Circuit System for Pilot Plant Treatment of "Low Grade"	19
5(b)	Side Circuit System for Pilot Plant Treatment of "Low Grade"	20
5(c)	Second stage of Recirculation System for Pilot Plant Treatment of "Low Grade"	21
6.	Comparison Between Side Circuit and Recirculation Systems for "Low Grade"	22
7(a)	Primary Circuit for Pilot Plant Treatment of 60 "Low"/40 "High" Mixture (Side Circuit System)	23
7(b)	Side Circuit System for Pilot Plant Treatment of 60 "Low"/40 "High" Mixture	24
8(a)	Primary Circuit for Pilot Plant Treatment of 60 "Low"/40 "High" Mixture (Recirculation System)	25
8(b)	Second Stage of Recirculation System for Pilot Plant Treatment of 60 "Low"/40 "High" Mixture	26
9	Comparison Between Side Circuit and Recirculation Systems for Mixture of 60 "Low"/40 "High"	27

(continued

TABLES (concluded)

No.		Page
10.	Concentrate Grade and Recovery	28
11.	Chemical Analysis of Magnesite Concentrates	29
12.	Firing Characteristics of Some Magnesite Flotation Concentrates	31

FIGURES

1-20	General Effect of pH, Fineness of Grind, Temperature, and Collector Concentration	7-8
21	Pilot Plant Flow Sheet	11

INTRODUCTION

Correspondence between Harbour Natural Resources Limited, of Calgary, Alberta, and the Mines Branch, Ottawa, relative to deposits of magnesite controlled by that company, began in the spring of 1958. Subsequently samples were submitted for mineralogical examination, and of these the material from Fort Steele showed most promise as a possible deposit for development. An investigation was initiated into the prospects for concentrating the magnesite, and products containing up to 97% $MgCO_3$ were obtained. A progress report, No. IM 58-107, was issued covering the results of the initial test work.

Because the initial trials were so promising Harbour Natural Resources, in collaboration with their consulting engineers, Millar, Hannigan and Associates, proceeded to develop preliminary plant costs, and approached Wright Brothers of Vancouver, with regard to plant design. The latter firm approached the Mines Branch for pilot plant data which would assist them in the necessary calculations. As a result a more comprehensive study was agreed to, including pilot plant testing, and some six tons of samples for this purpose were sent to the Mines Branch late in December, 1958.

Since that time, other groups have become interested in the Fort Steele property, and the pilot plant results are being studied with a view to participation with Harbour Natural Resources in development of the deposit. It is expected that the original purpose of the investigation will be served and the data used as a basis for commercial plant design.

The present report includes pertinent information related to laboratory flotation testing, pilot plant operations, pelletizing and calcination, on the six ton lot.

DESCRIPTION OF SAMPLES

The shipment was composed of two samples of approximately 3 tons each, representing the two main zones of the deposit. Both were made up of lumps measuring as much as 1 foot in diameter. The "high grade" sample was chiefly magnesite, the "low grade" only about 1/2 magnesite the rest being a fine grained chlorite schist. In the deposit the "high grade" zone was said to compose 40%, the "low grade" 60% of the bulk.

A mineralogical assessment of the samples was made using chemical analyses, X-ray diffraction, and microscopic observations to arrive at the following mineral content.

TABLE 1

Mineralogical Composition of Samples*

Mineral	"High Grade"	"Low Grade"
Magnesite	87%	47%
Chlorite	5	32
Talc	6	1
Quartz	1	18
Iron Oxide	1	2
	100	100

*A complete mineralogical report, No. MPT 59-68, covering the examination of these samples will be issued separately.

ANALYSES

To allow quick evaluation of laboratory and pilot plant test products it was necessary to have some form of rapid but reasonably accurate analysis. It was determined that CO_2 provided a sufficiently close representation of the $MgCO_3$ content but LOI did not usually equal CO_2, particularly in the lower magnesite products. On the other hand it was observed that when LOI was plotted against CO_2 a straight line relationship was obtained. Accordingly some 15 points were obtained for each of the three flotation feeds, "high grade" "low grade" and "40-60 mixture" by determining both LOI and CO_2 on products ranging from low magnesite tails to high magnesite concentrates, and a plot was made for each type of feed. Thus quickly determined LOI values could be converted to CO_2 immediately, and with sufficient reliability for test purposes. Values in this report are given as CO_2, pure magnesite being 52.4% CO_2. The CO_2 values may be converted to magnesite by multiplying by 1.91.

OUTLINE OF INVESTIGATION

Beneficiation methods other than flotation were ruled out so far as the "high grade" sample was concerned. Gravity methods prior to flotation were included for the "low grade". Wet and dry jigging, wet and dry tabling, Humphreys Spiral concentration, and heavy media concentration all failed to effect sufficient upgrading of the "low grade" sample without excessive losses. Because of this all flotation methods were accepted for both "high" and "low" grade samples, and also for mixtures of the two.

Flotation tests fell into two distinct phases (1) the laboratory bench work, and (2) the pilot plant runs devised therefrom.

Auxiliary testing included pelletizing and calcination of flotation concentrates, and tests to develop a satisfactory grinding system for pilot plant feed.

PREPARATION OF FEED

The "high grade" and "low grade" bulk lots were reduced separately by jaw crusher and sampled for laboratory test feeds. These were further reduced by cone crushing and pebble milling for various grinding times. All laboratory flotation feeds were -35 mesh and for comparison purposes the percent passing 325 mesh was used.

Based on the laboratory results the bulk lots were further reduced, to produce pilot plant feed, by hammer milling and dry grinding in a Patterson mill.

LABORATORY TESTS

Laboratory testing was conducted on four types of feed material (1) "low grade", (2) high grade", (3) 60% "low grade"-40% "high grade" mixture, and (4) 70% "low grade"-30% "high grade" (or 100 parts to 40 parts) mixture. Tests were performed in 500 gram and 2000 gram Denver laboratory flotation cells. Sufficient work was done on each type of feed to outline a set of conditions for pilot plant operation. While acceptable recovery and grades were obtained these were not necessarily optimum. Moreover the system developed was not necessarily the best for this material. A time element was involved in the investigation and at the request of the principals an acceptable working process was sought as quickly as possible rather than the best possible process.

Although numerous tests were performed on each feed no useful purpose would be served by recording them all. A typical successful test from each group has therefore been outlined in Table 2.

Out of the combined test work the general effect of such variables as pH, fineness of grind, temperature, collector concentration, and so forth gradually emerged. In Figures 1 to 20 these variables are studied graphically. Two or more comparable tests were used in compiling each graph. Solid lines show concentrate grade and broken lines recovery.

In dealing with temperature, where rougher and cleaning stages remained the same the term "constant temperature" was applied. Where there was a decrease in temperature from that of the rougher through each succeeding cleaner stage then the term "graded temperature" was applied.

TABLE 2

Results of Typical Successful Tests on the Various Types of Material

Type of Material	Concentrate CO_2 (%)	Recovery of CO_2 (%)	No. of Cleanings	Conditions
Low Grade	49.5	54.5	9	Harfat 1.84 lb/ton Av pH 10.3 Av Graded Temp. 28°C Size 58%, -325 mesh
60 Low/ 40 High	50.3	72.2	6	Harfat 2.76 lb/ton Av pH 10.4 Av Graded Temp. 21°C Size 51%, -325 mesh
100 Low/ 40 High	50.5	81.0	4	Harfat 2.76 lb/ton Av pH 10.2 Av Graded Temp. 24°C Size 66%, -325 mesh
High Grade	49.6	84.4	2	Harfat 1.84 lb/ton Av pH 10.1 Av Temp. 17°C Size 48%, -325 mesh

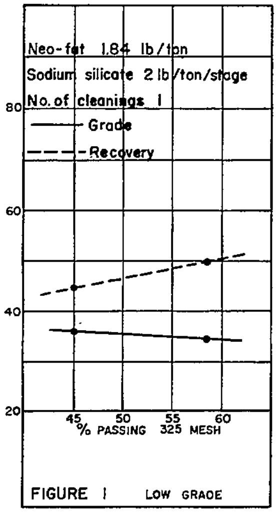

FIGURE 1 LOW GRADE

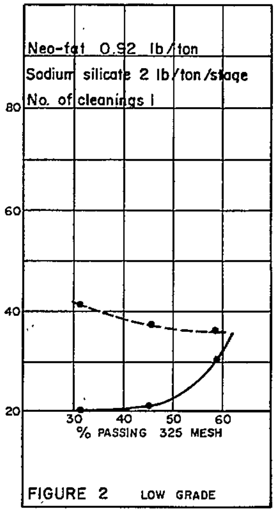

FIGURE 2 LOW GRADE

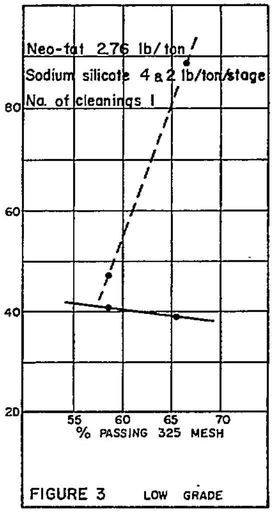

FIGURE 3 LOW GRADE

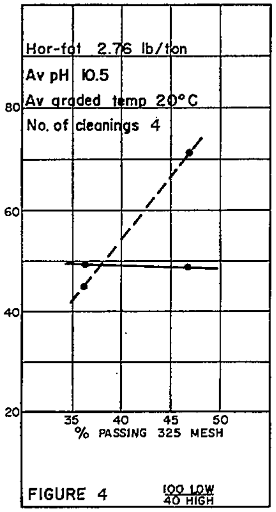

FIGURE 4 100 LOW / 40 HIGH

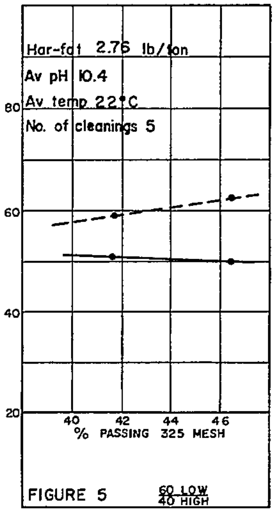

FIGURE 5 60 LOW / 40 HIGH

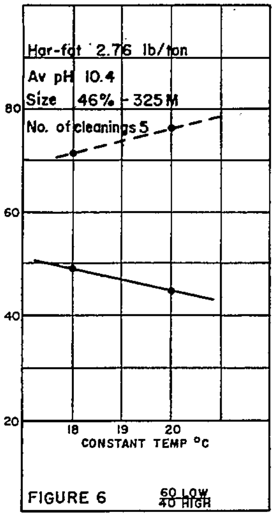

FIGURE 6 60 LOW / 40 HIGH

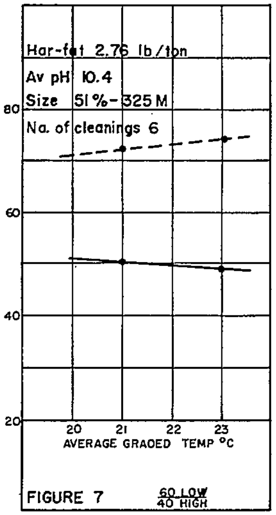

FIGURE 7 60 LOW / 40 HIGH

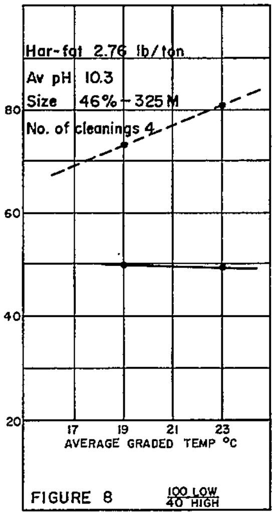

FIGURE 8 100 LOW / 40 HIGH

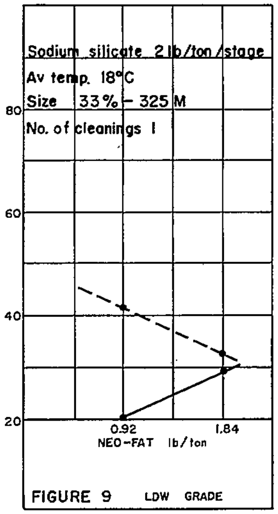

FIGURE 9 LOW GRADE

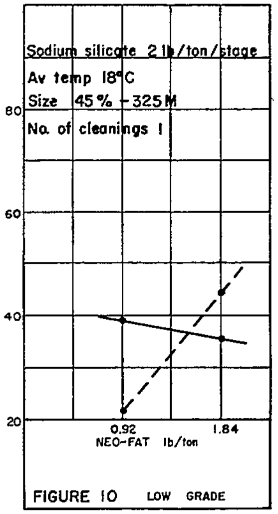

FIGURE 10 LOW GRADE

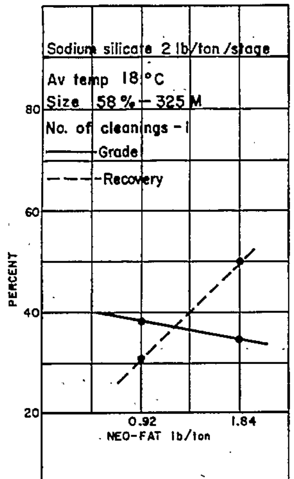

FIGURE 11 LOW GRADE

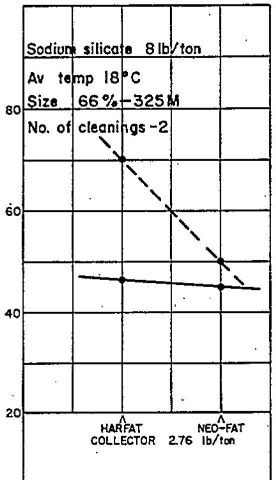

FIGURE 12 100 LOW / 40 HIGH

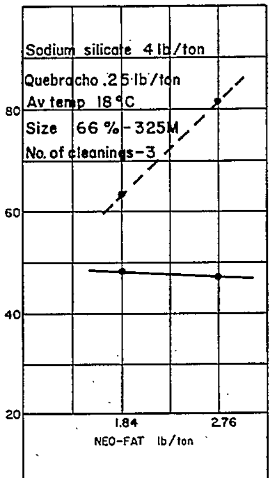

FIGURE 13 100 LOW / 40 HIGH

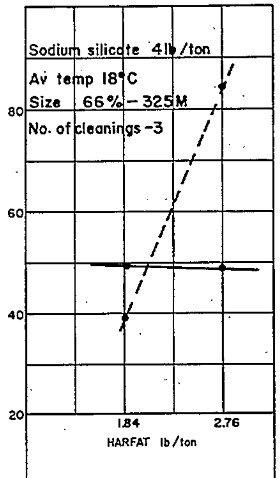

FIGURE 14 100 LOW / 40 HIGH

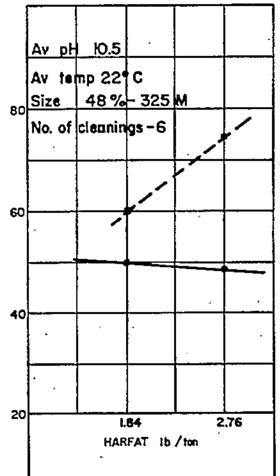

FIGURE 15 60 LOW / 40 HIGH

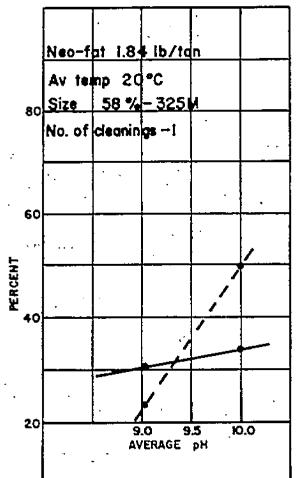

FIGURE 16 LOW GRADE

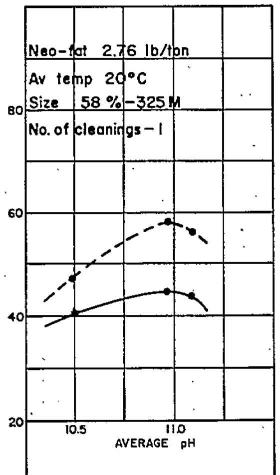

FIGURE 17 LOW GRADE

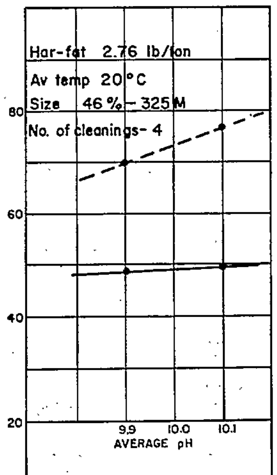

FIGURE 18 100 LOW / 40 HIGH

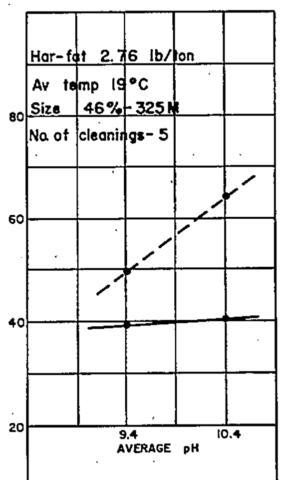

FIGURE 19 100 LOW / 40 HIGH

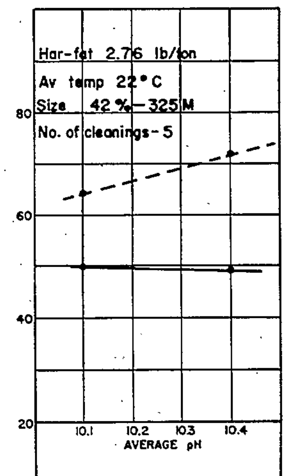

FIGURE 20 60 LOW / 40 HIGH

Except where collector concentration was below 1 lb/ton Fig 1-5 indicate that increasing fineness of grind produces a substantial recovery gain for a slight reduction in grade.

Fig 6-8 show that in general higher temperatures produce a slight increase in recovery for a slight decrease in grade. Best overall results were obtained with a 40°C rougher temperature which gradually decreased to 20°C in the final cleaner.

In Fig 9-15 it is generally indicated that an increase of collector, up to 2.76 lb/ton results in a substantial recovery gain for a small grade reduction, except where a comparatively coarse grind was used (Fig 9). Fig 12 shows that Harfat 231 has superior collecting properties to Neo-fat 42-12.

The general effect of pH as shown in Fig 16-20 was better recovery and grade as pH increased. As seen in Fig 17, however, and in other tests not recorded, a depressing effect developed above pH 10.8. It was further observed that rather better results were produced when pH was gradually increased from rougher to final cleaner. A rougher pH of 9.8 increasing to 10.8 in final cleaner was indicated. Sodium silicate was used for pH control.

Depressants, such as quebracho did not produce significant improvement. A variety of reverse flotation trials - that is, flotation of gangue away from magnesite - produced some separation, but nothing to compare with the direct flotation of the magnesite from gangue.

DATA APPLIED TO PILOT PLANT OPERATIONS

Information of importance, particularly for pilot plant operation, developed from the laboratory trials, included the fact that roughing at 20% solids was satisfactory. A somewhat more dilute pulp down to 15% solids, could be used in cleaning. Distilled water did not show any particular advantage over Ottawa tap water. Desliming of feeds was not necessary. Harfat 231 proved more selective for the material under test than the fatty acid used at the start of the investigation, Neo-Fat 42-12. The most desirable temperature for flotation was about 40°C for roughing with a decreasing gradation through the cleaning stages to about 20°C. To produce concentrates of acceptable grade, up to 16 lb/ton of sodium silicate was used in the laboratory tests. A collector input of 2.76 lb/ton appeared to be the most appropriate.

PILOT PLANT OPERATIONS

Description

A pilot plant was assembled in accordance with the data derived from the laboratory investigation. A flow sheet is outlined in Fig 21. Feed was prepared by dry working to all -48 mesh and 56% -325 mesh. This reached the conditioner via a Hardinge constant weight feeder. Feed rate varied from 1 to 1 1/2 lb/min depending on the run. Sodium silicate, to control pH, was fed to the conditioner at approximately 4 lb/ton, and to each suceeding stage at 2 lb/ton, for

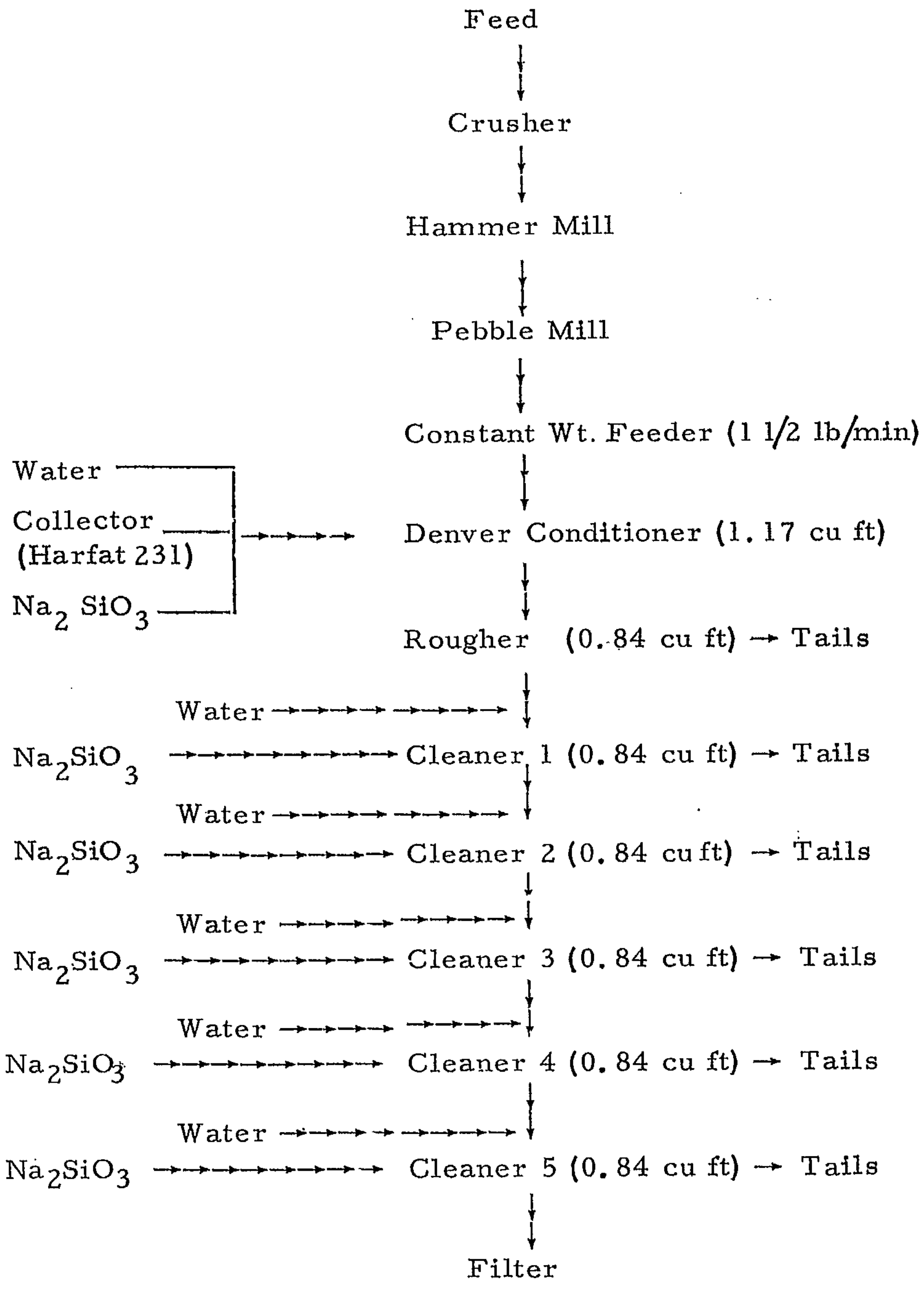

Figure 21. - Pilot Plant Flow Sheet

all runs. The collector reagent was fed to the conditioner only. Percent solids and temperature for each stage were controlled by using make-up water of constant temperature and pressure fed to the conditioner and each cleaning stage at the required rate. Tailings from each stage were collected separately. A 3 ft x 3 ft pan filter was used to dewater concentrates.

Operation

Since only 18 cells, set up as described in the preceeding section were available for this investigation, and more than five cleaning stages were required to obtain grade products, except for runs on "high grade", a break in the cleaning chain existed which was undesirable but unavoidable. In such cases the concentrate from cleaner 5 was accumulated. When the equipment had been cleaned out, following the first section of the run, this was fed back into the head of the circuit so that the necessary number of cleaning stages could be obtained.

In each run the equipment was operated until steady conditions were obtained, one to two hours, before any samples were taken. The temperature and pH for each stage of the operation were recorded at half-hourly intervals, and samples of each tailing and the concentrate were obtained by cutting the whole flow of each stream for 30 seconds. Such samples were composited over the period of steady running conditions, three to four hours, to provide average information on the run. Each sample was filtered, and the volume of water it contained was measured; the solids were dried and weighed. As the volume of of make-up water between flotation stages was measured, it was thus possible to calculate the average percent solids for the various stages.

Three types of feed were tested by pilot plant operation, the "high grade", the "low grade", and a mixture of 40% "high" and 60% "low". For each feed, data were accumulated on (1) the primary runs (no recirculation of middlings), (2) recirculation of middlings, and (3) treatment of middlings in a side circuit. A number of runs were made with each feed for each type of circuit using certain variable changes from run to run. The best results only are presented in order to keep the size of this report to reasonable limits. Primary run information is presented together with side circuit results on middlings from the primary run. Recirculation information shows results obtained when these same middlings were fed back to a following primary run with the same conditions as the original primary.

Results

Tables 3 (a), 3 (b), and 3 (c) give results on the "high grade" sample. Weight percent distribution figures for CO_2 in Table 3 (b) equal those for cleaner 4 and 5 Table 3 (a). A combination of products from the primary and side circuits (Primary Conc. + Side Conc. + Side Cl 2 and 3 Tails) gives a grade of 50.4% CO_2 at 80.8% recovery.

TABLE 3(a)

Primary Circuit System for Pilot Plant Treatment of "High Grade"

Product	% Weight Distribution	% CO_2	% CO_2 Distribution	Temp. °C of Cell	pH of Cell	% Solids in Cell
No. 5 Cleaner Concentrate	53.8	50.4	57.1			
No. 5 Cleaner Tailings*	11.7	49.2	12.1	14	10.7	9.9
No. 4 Cleaner Tailings*	12.9	48.0	13.0	16	10.7	10.4
No. 3 Cleaner Tailings	8.2	44.8	7.7	17	10.6	10.7
No. 2 Cleaner Tailings	5.7	39.8	4.8	20	10.6	11.6
No. 1 Cleaner Tailings	2.8	33.2	2.0	26	10.2	14.6
Rougher Tailings	4.9	32.1	3.3	38	10.1	11.3

*These products used as feed for side and recirculation circuits.

TABLE 3(b)

Side Circuit System for Pilot Plant Treatment of "High Grade"

Product	% Wt. Distribution of Primary Feed	% CO_2	% CO_2 Distribution	Temp. °C of Cell	pH of Cell	% Solids in Cell
No. 3 Cleaner Concentrate	18.8	50.8	19.7			
No. 3 Cleaner Tailings	2.1	48.8	2.2	18	10.7	14.9
No. 2 Cleaner Tailings	1.8	46.5	1.8	20	10.7	14.3
No. 1 Cleaner Tailings	1.0	41.0	0.8	27	10.4	14.5
Rougher Tailings	0.9	34.4	0.6	44	10.3	13.5

TABLE 3(c)

Recirculation System for Pilot Plant Treatment of "High Grade"

Product	% Weight Distribution	% CO_2	% CO_2 Distribution	Temp. °C of Cell	pH of Cell	% Solids in Cell
No. 5 Cleaner Concentrate	53.5	50.4	56.5			
No. 5 Cleaner Tailings	12.9	49.0	13.2	13	10.6	13.1
No. 4 Cleaner Tailings	17.6	47.4	17.4	15	10.5	14.2
No. 3 Cleaner Tailings	7.0	42.6	6.2	17	10.4	12.1
No. 2 Cleaner Tailings	5.0	39.4	4.1	20	10.4	12.0
No. 1 Cleaner Tailings	2.2	32.8	1.5	27	10.2	14.1
Rougher Tailings	1.8	29.4	1.1	39	10.0	13.4

TABLE 4

Comparison Between Side Circuit and Recirculation Systems for "High Grade"

	Side Circuit	Recirculation
Feed, % CO_2	47.69	47.69
Concentrate Grade, % CO_2	50.4	50.4
Actual CO_2 Recovery	80.8	81.4
CO_2 Recovery by Formula	80.5	80.6
Total Harfat 231, lb/ton	2.8	2.4
Total Sodium Silicate, lb/ton	12.2	12.0

Application of the two product formula to recirculation shows an indicated recovery of 80.6% at 50.4% CO_2 grade. The "actual recovery" figure for recirculation is percent CO_2 in conc. expressed as a fraction of percent CO_2 in feed based on weight of feed and weight of conc. Highlights of the two systems are compared in Table 4.

It may be noted that further cleaning of the 50.4% products gave grades of up to 51.8% CO_2 but with an overall recovery drop to 44.7%.

Although a rather more complicated treatment, as described earlier, was necessary for the "low grade" feed, results may be presented in similar fashion. Table 5 (a) presents primary run data, Table 5 (b) side circuit data, and Table 5(c) recirculation data. Primary circuit conc. (Table 5(a)), side circuit conc. (Table 5(b)) and side circuit cleaner 5 tails when combined form a 48.6% CO_2 product for a recovery of 73.9%. In tests incorporating recirculation the return middlings were introduced to the No. 6 cleaning stage.

A comparison between side circuit and recirculation systems is given in Table 6. Recovery figures were determined as described for the "high grade" sample.

Among the primary runs on "low grade" results obtained include one of 50.7% CO_2 grade at 26.5% recovery, and one at 49.5% CO_2 grade at 54.5% recovery. Although this is a little better than the example presented in full, complete data are not available for other phases of the side and recirculation operations.

TABLE 5(a)

Primary Circuit System for Pilot Plant Treatment of "Low Grade"

Product	% Weight Distribution	% CO_2	% CO_2 Distribution	Temp. °C of Cell	pH of Cell	% Solids in Cell
No.11 Cleaner Concentrate	31.8	47.7	51.3			
No. 11 Cleaner Tailings*	9.0	43.9	13.3	20	10.9	9.4
No. 10 Cleaner Tailings*	11.4	31.2	12.0	20	10.9	11.4
No. 9 Cleaner Tailings*	3.4	18.2	2.1	21	10.8	11.8
No. 8 Cleaner Tailings*	4.0	8.8	1.2	23	10.7	12.0
No. 7 Cleaner Tailings	3.0	8.2	0.8	28	10.6	12.0
No. 6 Cleaner Tailings	3.5	8.1	0.9	41	10.2	12.2
No. 5 Cleaner Tailings*	7.6	26.6	6.9	19	10.6	22.8
No. 4 Cleaner Tailings*	9.7	16.1	5.3	20	10.6	17.7
No. 3 Cleaner Tailings	4.5	12.6	1.9	23	10.5	19.5
No. 2 Cleaner Tailings	5.7	10.4	2.0	26	10.4	17.5
No. 1 Cleaner Tailings	3.6	10.5	1.3	31	10.1	18.3
Rougher Tailings	2.8	10.3	1.0	41	9.8	18.8

*Products used as feed for side circuit, and recirculation into No. 6 Cleaner Cell.

TABLE 5 (b)

Side Circuit System for Pilot Plant Treatment of "Low Grade"

Product	% Weight Distribution	% CO_2	% CO_2 Distribution	Temp. °C of Cell	pH of Cell	% Solids in Cell
No. 5 Cleaner Concentrate	9.6	50.3	12.5			
No. 5 Cleaner Tailings	7.9	49.7	10.1	21	10.5	10.5
No. 4 Cleaner Tailings	10.5	43.7	11.9	21	10.5	14.6
No. 3 Cleaner Tailings	3.6	33.9	3.2	21	10.5	16.5
No. 2 Cleaner Tailings	4.5	18.5	2.1	23	10.4	17.7
No 1 Cleaner Tailings	4.0	4.9	0.5	29	10.2	18.6
Rougher Tailings	5.0	3.8	0.5	44	10.1	13.7

TABLE 5 (c)

Second Stage of Recirculation System for Pilot Plant Treatment of "Low Grade"

Product	% Weight Distribution	% CO_2	% CO_2 Distribution	Temp. °C of Cell	pH of Cell	% Solids in Cell
No. 11 Cleaner Concentrate	60.0	46.2	78.6			
No. 11 Cleaner Tailings	8.6	38.8	9.5	18	11.0	13.5
No. 10 Cleaner Tailings	12.0	22.5	7.7	20	11.0	14.0
No. 9 Cleaner Tailings	4.0	13.4	1.5	21	11.0	14.1
No. 8 Cleaner Tailings	5.9	5.8	1.0	24	10.9	15.5
No. 7 Cleaner Tailings	3.0	7.5	0.7	29	10.6	16.0
No. 6 Cleaner Tailings	6.5	5.9	1.0	39	10.4	16.4

TABLE 6

Comparison Between Side Circuit and Recirculation Systems for "Low Grade"

	Side Circuit	Recirculation
Feed, % CO_2	26.3	26.3
Concentrate Grade, % CO_2	48.6	46.2
Actual CO_2 Recovery	73.9	89.5
CO_2 Recovery by Formula	60.6	81.1
Total Harfat 231, lb/ton	4.0	4.0
Total Sodium Silicate, lb/ton	32.3	26.0

Among the runs made using 40% "high grade" and 60% "low grade" mixed as feed it was found that no single primary run had developed enough middlings to allow both side circuit and recirculation procedures to follow. For this feed, therefore, two primary runs, as similar in all respects as it was possible to make them, were used, one followed by recirculation of the middlings and the other by side circuiting of the middlings. Tables 7(a) and (b) record the latter and 8(a) and (b) the former. A combination of the primary concentrate, Table 7(a), with the side circuit concentrate and No. 5 Cleaner Tails,

TABLE 7(a)

Primary Circuit for Pilot Plant Treatment of 60 "Low"/40 "High" Mixture (Side Circuit System)

Product	% Weight Distribution	% CO_2	% CO_2 Distribution	Temp. °C of Cell	pH of Cell	% Solids in Cell
No. 11 Cleaner Concentrate	50.9	49.7	75.0			
No.11 Cleaner Tailings*	6.0	39.7	7.1	21	10.8	13.8
No.10 Cleaner Tailings*	6.8	30.6	6.2	21	10.8	14.7
No. 9 Cleaner Tailings*	3.9	21.0	2.4	22	10.8	15.3
No. 8 Cleaner Tailings*	4.3	12.5	1.5	25	10.7	16.0
No. 7 Cleaner Tailings	2.6	10.0	0.9	30	10.5	16.6
No. 6 Cleaner Tailings	3.3	10.8	1.2	44	10.4	11.6
No. 5 Cleaner Tailings*	3.8	14.5	1.5	23	10.7	16.2
No. 4 Cleaner Tailings	6.4	9.2	1.8	23	10.6	16.0
No. 3 Cleaner Tailings	2.9	8.1	0.6	26	10.6	16.8
No. 2 Cleaner Tailings	3.6	6.5	0.6	29	10.5	16.9
No. 1 Cleaner Tailings	2.0	8.0	0.6	33	10.2	19.1
Rougher Tailings	3.5	5.8	0.6	42	9.2	18.4

*These products used as feed for side circuit.

TABLE 7 (b)

Side Circuit System for Pilot Plant Treatment of 60 "Low"/40 "High" Mixture

Product	% Weight Distribution	% CO_2	% CO_2 Distribution	Temp. °C of Cell	pH of Cell	% Solids in Cell
No. 5 Cleaner Concentrate	10.9	50.3	12.3			
No. 5 Cleaner Tailings	2.7	49.7	3.2	21	11.0	11.9
No. 4 Cleaner Tailings	1.5	35.8	1.1	21	10.8	13.6
No. 3 Cleaner Tailings	1.4	28.3	0.9	22	10.8	14.6
No. 2 Cleaner Tailings	1.8	9.8	0.5	25	10.8	16.0
No. 1 Cleaner Tailings	2.2	2.8	0.1	29	10.5	17.0
Rougher Tailings	4.3	0.0	0.0	43	10.4	12.5

TABLE 8 (a)

Primary Circuit for Pilot Plant Treatment of 60 "Low"/40 "High" Mixture (Recirculation System)

Product	% Weight Distribution	% CO_2	% CO_2 Distribution	Temp. °C of Cell	pH of Cell	% Solids in Cell
No.11 Cleaner Concentrate	50.7	49.5	74.8			
No.11 Cleaner Tailings*	5.9	42.3	7.4	20	10.8	13.6
No.10 Cleaner Tailings*	3.9	30.5	3.5	21	10.8	15.7
No. 9 Cleaner Tailings*	3.9	26.3	2.9	24	10.8	15.9
No. 8 Cleaner Tailings*	3.5	21.7	2.1	29	10.7	14.4
No. 7 Cleaner Tailings	2.2	13.5	0.8	45	10.5	15.4
No. 6 Cleaner Tailings	2.9	11.0	0.9	19	10.4	11.3
No. 5 Cleaner Tailings*	5.5	20.5	3.3	21	10.7	14.6
No. 4 Cleaner Tailings	6.8	8.0	1.6	22	10.7	15.1
No. 3 Cleaner Tailings	3.7	6.8	0.7	25	10.6	16.4
No. 2 Cleaner Tailings	4.6	6.1	0.8	27	10.5	16.9
No. 1 Cleaner Tailings	2.5	7.1	0.5	31	10.3	19.3
Rougher Tailings	3.9	6.4	0.7	40	10.0	19.4

*These products used for recirculation.

TABLE 8 (b)

Second Stage of Recirculation System for Pilot Plant Treatment of 60 "Low"/40 "High" Mixture

Product	% Weight Distribution	% CO_2	% CO_2 Distribution	Temp. °C of Cell	pH of Cell	% Solids in Cell
No. 11 Cleaner Concentrate	71.5	50.0	86.5			
No. 11 Cleaner Tailings	5.1	39.5	4.9	20	10.9	22.0
No. 10 Cleaner Tailings	4.6	30.5	3.4	21	10.9	21.2
No. 9 Cleaner Tailings	4.2	22.0	2.2	22	10.8	21.0
No. 8 Cleaner Tailings	5.4	12.3	1.6	24	10.8	19.7
No. 7 Cleaner Tailings	4.3	6.5	0.7	31	10.6	19.8
No. 6 Cleaner Tailings	4.9	6.5	0.7	44	10.5	15.2

TABLE 9

Comparison Between Side Circuit and Recirculation Systems for Mixture of 60 "Low"/40 "High"

	Side Circuit	Recirculation
Feed, % CO_2	33.2	33.2
Concentrate Grade, % CO_2	49.8	50.0
Actual CO_2 Recovery	90.5	92.5
CO_2 Recovery by Formula	90.2	92.1
Total Harfat 231, lb/ton	3.5	3.1
Total Sodium Silicate, lb/ton	29	26

Table 7(b), gives a 49.8% CO_2 product for a recovery of 90.5%. A comparison, on the same basis of recovery calculation as for the other feeds is given in Table 9. With this feed grades of up to 50.8% were obtained on certain primary runs, but with some sacrifice of recovery.

In Table 10 the results from all the tests presented have been drawn together for ease of overall comparison.

TABLE 10

Concentrate Grade and Recovery

Feed	System	% CO_2	CO_2 Recovery (Actual)*	CO_2 Recovery (Formula)
High Grade	Side Circuit	50.4	80.4	80.5
"	Recirculation	50.4	81.4	80.6
Low Grade	Side Circuit	48.6	73.9	60.6
"	Recirculation	46.2	89.5	81.1
60 Low/40 High	Side Circuit	49.8	90.5	90.2
"	Recirculation	50.0	92.5	92.1

*See page 16, paragraph one.

A chemical analysis of two typical concentrates is given in Table 11.

TABLE 11

Chemical Analysis of Magnesite Concentrates

CO_2 %	49.51	48.50
CaO %	0.97	1.92
SiO_2 %	1.24	2.92
R_2O_3 %	1.38	1.70
MgO by diff	46.90	44.96

Pelletizing

Considerable test work was carried out in order to obtain a product that would be strong enough to withstand serious breakage during calcination in a rotary kiln.

Numerous tests were conducted on pellets made by hand and pelletizing equipment using various concentrations of "copacite" as a binder. These were fired in a stationary kiln, and in a 12 in. x 12 ft rotary kiln. The kiln temperature range was from 1230 to 1260 °C. A large percentage of fines was produced and very few whole pellets came from the kiln.

Firing tests in a stationary kiln showed that the copacite burned off at about 300°C. Pellets fired at 600°C, 900°C and 1200°C were found to be very soft.

Magnesite briquettes were made by a constant volume standard double roll press. The briquettes were almond shaped and 1 1/8 x 3/4 x 1/2 in. in size. The binder consisted of 2 parts per 100 of copacite and 4 parts per 100 of water. The briquettes were dried at 108°C, and fired in a 5 in. x 5 ft rotary kiln at 1200 to 1230°C. Although some of the briquettes tended to split during the calcining process, no fines were produced.

Calcination

Calcination tests were performed on various concentrates from flotation. For this, the only equipment available was a stationary gas-fired furnace capable of temperatures of up to 1700°C maximum. Tests were performed by pressing the concentrates into small plaques at 8000 psi and breaking them up into approximately 1/2 inch lumps prior to firing. Actual calcination took place in zirconia crucibles. Temperature was raised over the usual time period to a predetermined maximum and soaked at that temperature. A few tests were made on flotation concentrates as powder, and satisfactory sintering was achieved. Such tests were, however, considered to be of interest only since some form of pelletizing or briquetting would be necessary for rotary kiln work, and would probably aid in achieving desired density of product.

All calcined products were shades of brown in colour. Results of three typical firings are given in Table 12.

TABLE 12

Firing Characteristics of Some Magnesite Flotation Concentrates

	High Grade	Medium Grade	Low Grade
% CO_2 before firing	50.6	49.8	49.1
Firing temp (°C)	1685	1650	1650
Soaking time (hr)	1 1/2	1	1 1/2
Product Density (g/cm^3)	2.80	3.04	3.25
Product Analysis			
SiO_2	3.10	4.12	4.96
CaO	2.11	3.26	4.16
Fe_2O_3	2.06	2.16	2.26
MgO (oxine)	95.85	92.74	91.11
" (EDTA)	94.27	-	90.32
" (Diff)	92.73	90.46	88.62

Discussion

Results obtained in the pilot plant runs are not considered to represent the optimum but do illustrate clearly that grade products may be produced at reasonable recoveries. As originally requested by the principals, a good working process was sought, rather than the best possible process. In addition there was a demand for pilot plant concentrates to be used as samples in market development. This necessitated some emphasis on production of grade products at the expense of experimentation. It is reasonable to assume that a working plant would effect improvements on reagent consumption, number of cleaning stages, and other factors, which will be indicated in this discussion.

The average input of collector, Harfat 231, was 3 to 4 lb/ton. We believe this would be reduced on continuous operation with the fineness of feed, temperature and other factors subject to close adjustment.

Similarly the sodium silicate consumption was high. In laboratory tests up to 16 lb/ton of this reagent was used for pH control. In the pilot plant approximately 4 lb/ton was fed to the conditioner and 2 lb/ton to each cleaner. As a result pH was maintained at a somewhat higher level than necessary. The fact that most of the runs had to be made in two sections was also wasteful of silicate as the pH had to be reestablished on repulping. Recovery and recirculation of tailings water, in a commercial plant, would reduce the overall silicate input a great deal.

The effect of the two section operation is well illustrated in Table 5(a) where the tailings from cleaner 5, last stage of the first section, contain 26.6% CO_2, while those from cleaner 6, first stage of the second section, contain 8.1% CO_2. It is not until cleaner 10 that the CO_2 value in tails exceeds that of cleaner 5. This suggests strongly that had the circuit been continuous throughout all the cleaning stages, grade would have been achieved with several fewer steps, and possibly with higher overall recovery.

From the laboratory results it was intended to operate the pilot plant at 20% solids in the roughers, decreasing to about 15 in the final cleaner. Due to the fact that large volumes of make-up water were required to transport froth, the actual % solids achieved in cleaners was lower than desired in the greater portion of the tests. Roughers on the other hand were easily controlled by metered water input. The best density control was obtained on runs with the 60-40 mixture as feed. These were the last runs made and operating skill acquired through the earlier runs could be applied.

This acquired operating skill and better density control may also account for the fact that the best overall results appear to have been made on the 60-40 mixture (Table 10).

Grades of over 50% CO_2 (95% Magnesite) were achieved on all three feeds, but usually at the expense of recovery. On the other hand it was generally possible to obtain recovery of over 80% if somewhat lower grades were accepted. Even on the "low grade" feed, 80% recovery of 48% CO_2 (92% Magnesite) was shown to be possible.

Results for runs incorporating recirculation were generally better than those employing the side circuit. The recirculation system developed was the best that could be achieved with available equipment; however, true continuous recirculation conditions were not established. The runs performed indicate that recirculation of middlings does not reduce selectivity. In continuous operation it is quite possible that there might be a detrimental build up of slimes, a tendency for lag in clearing back to tails for discard, difficulty in density control, and other such effects. For these reasons, it is considered that the side circuit results are probably more reliable than those for recirculation.

By using dry grinding it was possible to employ the same personnel on feed preparation, between runs, as were used on flotation. It also allowed a close control of feed input to the flotation circuit and constant density in the conditioner. On a wet grinding circuit with a feed rate to flotation of 1 1/2 lb/min it is difficult to maintain constant density. Although it was assumed that grinding in a commercial plant would probably be wet, the design of such a circuit to produce the desired grind would be standard and should not require pre-testing on a small scale.

Tests made on pelletizing indicate that briquetting by rolls press using a little copacite binder would produce sufficient hardness to withstand subsequent drying and passage through a rotary kiln. It is possible that briquetting with higher pressure and no binder would produce sufficient strength to withstand the subsequent handling.

The higher grades of magnesite concentrate produced were sufficiently refractory that firing below 1700°C failed to develop 3.0 g/cm^3 density, although up to 2.9 density was achieved at 1685°C. With slightly lower grades density of above 3.0 g/cm^3 was easily obtained at 1650°C. It appears from the amount of work done on calcining that grades in the order of 50-50.2% CO_2 would fire to 3.0 g/cm^3 density at 1650°C.

CONCLUSIONS

With close control of pulp density, temperature, pH, and fineness of grind it should be practical to produce flotation concentrates grading 50% CO_2 (95% Magnesite) with 90% or better recovery from "high grade" magnesite feeds or from mixtures composed of 40% "high grade" and 60% "low grade". With "low grade" feeds alone similar grades of flotation concentrate may be produced at lower recovery, or lower grades (48% CO_2) at 80% or better recovery.

The number of cleaning stages necessary to produce flotation concentrates is roughly in reverse proportion to the grade of feed, the smallest number being required for the highest grade feed and the largest number for the lowest grade feed. A final concentrate of less than 50% CO_2 grade requires correspondingly fewer cleaning stages.

Recirculation of middlings does not cause loss of selectivity, however such factors as density control, slimes build up, etc., would be likely to make side circuiting of middlings a more favourable operation than recirculation on a commercial basis.

Within limits increasing fineness of grind, increasing temperature of pulp, increasing collector concentration, and increasing pH all produce higher recoveries of flotation concentrate for a slight lowering of grade.

With flotation concentrates grading 50% or lower CO_2 pressure pelletizing should produce bodies of sufficient toughness to withstand rotary kiln firing. A fired product of 3.0 g/cm^3 or better density should be obtained at 1650°C.

Gravity beneficiation of the "low grade" sample could not be achieved on a practical basis.

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