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OPERATING CHARACTERISTICS OF A VIBRATING MILL

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MINERAL PROCESSING DIVISION

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OPERATING CHARACTERISTICS OF A VIBRATING MILL

by

F.H. Hartman* and R.A. Wyman**

ABSTRACT

Variations in the operation of a vibrating mill were examined experimentally, and the various factors were related to the surface area of product as determined by the Lea and Nurse air-permeability apparatus. It was found that the product became finer as feed rate was decreased, or as amplitude and frequency were increased. The finest products were obtained when media of fused alumina cylinders, 1/2 by 1/2 inch, were used. These products contained approximately 70 per cent minus 10 microns material. Plus-325-mesh particles in various amounts were present in all products.

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Bulletin technique TB 94

Direction des Mines

CARACTÉRISTIQUES FONCTIONNELLES D'UN MOULIN VIBRATEUR

par

F.H. Hartman* et R.A. Wyman**

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RÉSUMÉ

Cette étude expérimentale a porté sur les variations dans le fonctionnement d'un moulin vibrateur; les divers facteurs qui l'influencent ont été étudiés en fonction de la surface de contact du produit fini, telle que déterminée par l'appareil Lea and Nurse de mesure de perméabilité à l'air. L'étude a démontré que la granulométrie du produit diminuait directement en fonction de la réduction de la vitesse d'alimentation ou de l'augmentation de l'amplitude et de la fréquence de vibration. Les particules les plus fines ont été obtenues en utilisant des cylindres d'alumine fondue (1/2 p x 1/2 p). Ces produits fins contenait environ 70 p. 100 de particules d'un diamètre inférieur à 10 microns. Dans tous les produits finis, on a trouvé en quantité variable des particules ne traversant pas le tamis de 325 mailles.

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*Préposé aux recherches scientifiques et **Chef, Section de l'usinage des minéraux industriels, Division du traitement des minéraux, Direction des mines, ministère de l'Énergie, des Mines et des Ressources, Ottawa, Canada.

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INTRODUCTION

The increasing demand by industry for raw materials ground to low-micron or sub-micron particle size prompted the Mines Branch to install equipment with which fine comminution studies on mineral commodities could be carried out. The design, performance claims, and cost of available equipment were weighed, and, in 1964, a "Palla 20 U" vibrating mill, manufactured by Klockner-Humboldt-Deutz A.G., of Cologne, Germany, was selected for the experimental programme.

This mill provides an extended exposure of the subject material to the action of a fluidized body of grinding media, and incorporates the advantages of continuous throughput and low power consumption with small space requirements.

In anticipation of requests for fine grinding experiments on a wide variety of industrial mineral commodities, the installation was designed to be as versatile as possible. A comprehensive experimental programme was devised to study its operation under various conditions and to indicate the necessary control settings to produce maximum fineness of product.

Data on vibration milling are scarce. Results of the experimental programme at the Mines Branch are offered as a contribution to the knowledge of this method of comminution..

DESCRIPTION OF EQUIPMENT

The Palla 20 U vibrating mill consists of a heavy base frame anchored to concrete, and of two horizontal cylindrical sections mounted one above the other, each 4 ft long and 8 in. in diameter, rigidly connected by two web plates and supported on the base frame by four pliable rubber cushions. These allow the mill to vibrate without undue transmission of energy to the base and thence to the building.

The mill is driven by a 5-horsepower Reeves Vari-Speed Moto-drive, direct-coupled through a universal joint to the area of balance. The speed can be varied between 1000 and 1500 rpm. Vibration is induced by eccentric weights opposing the weight of the mill and set on the drive axis. In Figure 1, which shows the main features of the Palla U system, the fan-shaped eccentric weights are exposed. The amplitude of vibration is established through the attitude of these weights, two at each end of the mill, one of which is fixed and the other free to rotate. Maximum amplitude (approximately 1/2 in. in both horizontal and vertical directions) is produced when the positions of fixed and movable weights correspond. By means of a

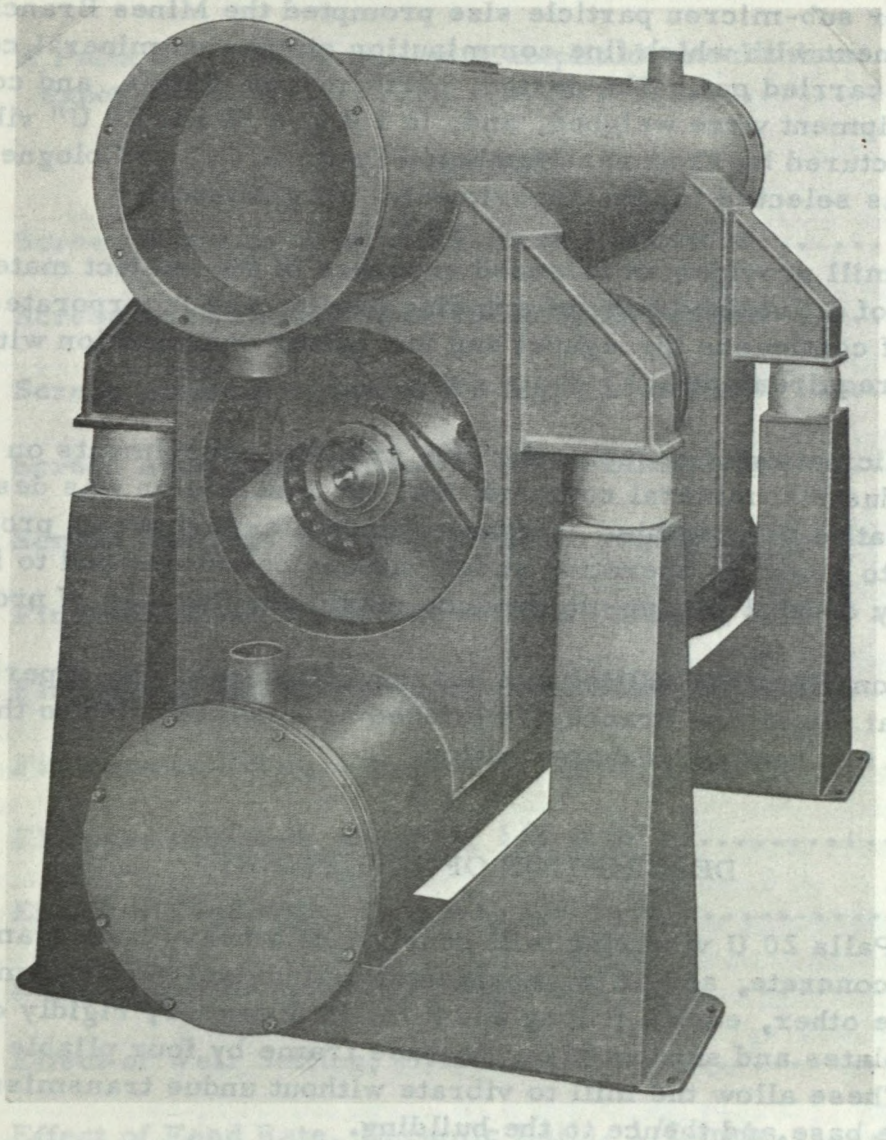

Figure 1. A Palla U vibrating mill with amplitude mechanism exposed.

series of seven holes through both fixed and movable weights, the two may be spread apart from this maximum position and securely bolted together in a series of settings. There are thus seven possible amplitudes available, including maximum and minimum. The designation "2 off maximum" would indicate bolting through the second hole from the maximum position, and "2 off minimum" through the fourth hole from a maximum position. Minimum amplitude is obtained when bolting is done through the seventh hole.

The two sections are normally filled to 70 per cent of their volume with grinding media. The feed can be passed through the mill in three flow patterns:

1) Series - feed is introduced at one end of the upper section, flows to the opposite end, passes to the lower section, and returns in reverse flow.

2) Parallel - feed is introduced at the same end of both sections and discharges at the opposite ends.

3) Split parallel - feed is introduced at the centre of each section and discharges at both ends.

The longest exposure of the feed to the mill action is obtained in (1), about one-half of this exposure in (2), and one-fourth in (3). The capacity should increase in proportion to the decrease in exposure time, and the product should be proportionately coarser. Since the finest product was an objective of the experiments performed, only the series flow pattern was used.

Grinding media are prevented from leaving the sections through the outlets by perforated plates. Flow of material may be regulated, to some extent, by weirs at the discharges. Replaceable linings in both steel and plastic (for iron-free grinding) were purchased with the equipment. Flexible inlet and discharge connections are provided.

Two sizes of stainless steel balls, 3/4 in. and 1/2 in.; two sizes of "cylpebs" (high-density alumina cylinders), 3/4 in. diameter by 3/4 in. long, and 1/2 in. by 1/2 in.; and 1/2-in. high-density alumina "balls" were used. These "balls" were actually 1/2-in. cylpebs with spherical ends. It is necessary, in all cases, to have the same weight of grinding media in both upper and lower sections of the mill.

Attrition of media and linings is slight, and power consumption is comparatively low. The equipment is essentially dust-proof. It is possible to vent the sections or to employ a controlled atmosphere. Maximum safe operation is considered to be that with settings somewhat below those causing dangerously violent motion. Build-up of static electricity is prevented by grounding.

Auxiliary equipment consisted of a vibrating disc feeder, a vibrating screw feeder, and vacuum arrangements to collect light incident dust and material air-swept from the mill through the vents during certain experiments.

VARIABLES OF OPERATION

The equipment can be operated with the following variables:

Frequency. The number of vibrations per minute can be varied between 1000 and 1500.

Amplitude. The amount of displacement can be varied from almost 0 to 1/2 in.

Media type. For the purpose of this investigation, five media types were used.

Media load. Normally 70 per cent of the internal volume of each section, the load can be varied as long as the weight is kept the same in each section.

Liner type. Both steel and plastic-covered liners were used.

Weirs. The rate of discharge from both sections, and hence the height within the mill of material being ground, can be varied by raising or lowering the weirs.

Venting. Light, air-borne material can be drawn off through vent ports at the discharge end of each section.

PARTICLE SIZE ANALYSIS

Sizing analyses were carried out by:

1. Screens

   a) Tyler standard sieves

   b) Micro-mesh sieves (1), which provide a new method of carrying out sieve analyses to as low as five microns.

2. A Modified Lea and Nurse Air-Permeability Apparatus (2)

Within limits, the Lea and Nurse apparatus provides a simple and rapid means for determining the specific surface area of powders having a wide range of particle sizes. It is based on a method of Carman (3), but Lea and Nurse (4) substituted a gas for a liquid as the medium for permeability measurements.

Results are given as surface area in units of cm^2/g. Any plus-65-mesh material was removed prior to Lea and Nurse analysis.

3. "EEL" Photo-Extinction Sedimentometer

The EEL Sedimentometer is designed for the determination of the size frequency curves of granular material within the sub-sieve range, with an accuracy adequate for industrial control and similar purposes. The photo-extinction technique depends on the measurement of the projected cross-sectional area of the material as it falls between certain assigned limits of size. This method is time-consuming and was used to correlate results.

DESCRIPTION OF SAMPLES

Work was done with two materials, viz:

1. Limestone

A local grey limestone was selected because of its availability. Feed lots for the experiments were prepared as indicated below:

a) Minus 4 mesh

b) Minus 10 mesh

c) Minus 28 mesh

d) Minus 65 mesh.

Screen analyses of these four feeds, Tyler series, are given in Tables 1 to 4.

It was found necessary, during the course of the work, to prepare additional lots of minus-10 and minus-28-mesh material. The screen analyses of these lots were substantially the same as for the original.

TABLE 1

Screen Analysis of Minus-4-Mesh Limestone

Fraction	Weight %
- 4 + 10 m	18.3
- 10 + 14 m	25.3
- 14 + 20 m	11.8
- 20 + 28 m	8.6
- 28 + 35 m	7.3
- 35 + 48 m	5.9
- 48 + 65 m	5.0
- 65 + 100 m	4.1
-100 + 150 m	3.0
-150 + 200 m	1.7
-200 + 325 m	2.9
-325 m	6.1
Total	100.0

TABLE 2

Screen Analysis of Minus-10-Mesh Limestone

Fraction	Weight %
- 10 + 14 m	5.7
- 14 + 20 m	16.6
- 20 + 28 m	15.7
- 28 + 35 m	13.2
- 35 + 48 m	10.8
- 48 + 65 m	8.6
- 65 + 100 m	6.9
-100 + 150 m	5.4
-150 + 200 m	3.0
-200 + 325 m	4.1
-325 m	10.0
Total	100.0

TABLE 3

Screen Analysis of Minus-28-Mesh Limestone

Fraction	Weight %
+ 28 m	1.9
- 28 + 35 m	8.7
- 35 + 48 m	19.8
- 48 + 65 m	15.3
- 65 + 100 m	11.3
-100 + 150 m	8.5
-150 + 200 m	4.8
-200 + 325 m	8.1
-325 m	21.6
Total	100.0

TABLE 4

Screen Analysis of Minus-65-Mesh Limestone

Fraction	Weight %
+ 65 m	4.9
- 65 + 100 m	21.8
-100 + 150 m	19.6
-150 + 200 m	8.4
-200 + 325 m	15.2
-325 m	30.1
Total	100.0

2. Nepheline Syenite

A commercial nepheline syenite, which is sold with the nominal screen analysis given in Table 5, was used.

TABLE 5

Screen Analysis of Minus-30-Mesh Nepheline Syenite

Fraction		Wt
U.S. Series	Equivalent Tyler Series	%
+ 25 m	+ 24 m	0.01
- 25 + 30 m	- 24 + 28 m	1.1
- 30 + 40 m	- 28 + 35 m	17.9
- 40 + 50 m	- 35 + 48 m	24.1
- 50 + 100 m	- 48 + 100 m	40.3
-100 + 200 m	-100 + 200 m	13.4
-200 m	-200 m	3.2
Total		100.0

EXPERIMENTAL WORK

1) Steel Balls and Steel Liners

a) 3/4 in.-stainless steel balls

To fill the two sections to approximately 70 per cent of their volume with 3/4-in. balls, a total charge of 440 lb was added, 220 lb to each.

With limestone as the feed, the mill was run with the weirs at their maximum opening, under various settings, and with different sizes of feed and rates of addition. Two samples were cut for each experimental run, one after 40 minutes of operation (top line in table for each feed size), the other after 50 minutes (bottom line in table for each feed size). Results from these are shown separately and have not been averaged, because their differences are significant in judging the end product.

The amount of material retained on a 325-mesh screen and the surface area of product as determined by the Lea and Nurse permeability apparatus are given for each sample.

Sampling was done manually by cutting the discharge stream during a measured interval.

Results are shown in Table 6.

b) 1/2-in. stainless steel balls

The two sections were filled to approximately 70 per cent of their volume with 1/2-in. balls, again using the same total weight, 440 lb, 220 lb to each section.

The mill was operated in a similar manner to that with the heavier 3/4-in. balls except that the minus-4-mesh feed was not used. In a few cases the screen size of product was checked at 20 microns as well as at 325 mesh (1). In certain cases, which are indicated, samples were cut after 30 and after 40 minutes.

Results are given in Table 7.

2) Ceramic Media and Plastic Liners

For grinding with a minimum of iron contamination, the mill was lined with plastic material bonded to a removable steel insert. Grinding was done with 3/4-in. and 1/2-in. cylpebs, and with alumina "balls".

a) 3/4 in.-Cylpebs

With the plastic linings the inside diameter of each section is reduced. In addition, the sp gr of alumina media is 3.65, much less than steel's. Thus the weight of media required to fill each section to 70 per cent of its volume was found to be only 78 lb, or a total of 156 lb.

Limestone from the minus-10-mesh and minus-28-mesh feed lots was used. The minus-4-mesh feed was too coarse to be handled with the reduced media load, and little information had been derived with the minus-65-mesh feed and steel balls. Comparison was made between feed rates of 75 and 25 pounds per hour. Amplitudes of maximum, 2 off maximum, and 2 off minimum were employed. The weirs were kept at maximum opening. Samples were cut at 20 and at 30 minutes after the start of each run.

Results for these experiments are shown in Table 8.

b) 1/2-in. Cylpebs

Limestone Feed

The mill was filled with 186 lb of 1/2-in. cylpebs, 93 lb to each cylinder. Experiments were made under similar conditions to those with the 3/4-in. cylpebs. Results are given in Table 9.

TABLE 6

Fineness of Grind,
Stainless Steel Balls, 3/4-in.

Top Section - 220 lb. Bottom Section - 220 lb
Weirs - maximum. Feed - limestone.
Top line - 40-min sample. Bottom line - 50-min sample.

Rpm		1000				1200				1500			
Amplitude Setting		2 Off Minimum		2 Off Maximum		2 Off Minimum		2 Off Maximum		2 Off Minimum		2 Off Maximum	
Size Analysis		+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g
Feed Rate, 75 lb/hr	- 4m					5.8	6261	8.3	6621				
						7.5	7055	8.5	6950				
	-10m	8.5	6850	7.3	7490	5.3	7315	8.2	7450	5.8	7740		
		8.8	6900	7.8	7575	6.0	7300	8.4	7880	6.5	7900		
	-28m	12.6	5950	8.4	7480	5.8	6390	9.3	6990	7.6	7250		
		12.2	6120	8.7	7435	6.3	6840	9.5	7175	8.4	7250		
	-65m					4.4	7250	9.2	6614				
						5.6	7500	9.6	7460				
Feed Rate, 150 lb/hr	- 4m					22.4**	5509***	12.8	5999				
						16.2	5945***	12.4	6460				
	-10m	30.8	4365	12.1	6350	17.1	5260	13.5	6280	15.4	5570		
		34.5*	4005	12.2	6185	17.8	5250	14.0	6130	16.2	5470		
	-28m	23.2	4725	12.8	6010	14.4	5500	12.5	6250	12.3	6100		
		29.2*	4195	12.4	6245	16.5	5330	12.7	6400	12.4	6150		
	-65m					12.0	5911	12.3	6181				
						11.2	6100	12.1	6450				

* Overload.
** Unground material in discharge.
*** Plus-65-mesh material removed prior to S/A determinations.

TABLE 7

Fineness of Grind,

Stainless Steel Balls, 1/2-in.

Top Section - 220 lb. Bottom Section - 220 lb.
Weirs - maximum. Feed - limestone.
Top line - 40-min sample. Bottom line - 50-min sample.

Rpm		1000				1200				1500				
Amplitude Setting		2 Off Minimum		2 Off Maximum		2 Off Minimum		2 Off Maximum		2 Off Minimum			2 Off Maximum	
Size Analysis		+325m, %	Surface Area, cm²/g	+325m, %	Surface Area, cm²/g	+325m, %	Surface Area, cm²/g	+325m, %	Surface Area, cm²/g	+325m, %	+20 mu	Surface Area, cm²/g	+325m, %	Surface Area, cm²/g
Feed Rate, 75 lb/hr	-10m	5.7 6.2	7049 6910	5.0 4.9	6812** 6780**	1.9 2.0	7370 7970	4.5 4.2	8017 9025	4.6 4.7	26.8 26.9	7626 7332		
	-28m	3.0 3.3	6609 7195	3.6 3.9	7310 7885	2.3 2.1	7050 8020	4.2 4.5	7606 8260	3.0 2.9		9375 8597		
	-65m					1.4 1.7	8328 7500	3.5 3.6	7637 7525					
Feed Rate, 150 lb/hr	-10m	*		12.9 12.7	5260** 7310**	11.2 25.8	6044 4333	5.9 6.1	7013 7270	11.7 12.4	36.4 38.8	6045 5578		
	-28m			6.4 6.9	5841 6230	* 20.9	4556 4570	6.9 7.4	6613 6460	8.1 8.6		6000 5730		
	-65m					5.2 5.6***	6083 6400	5.0 4.3***	- 7000					

* Overload.
** Plus-325-mesh material removed prior to S/A determinations.
*** 40-min run - not 50-.

TABLE 8

Fineness of Grind, Cylpebs, 3/4-in.

Top Section - 78 lb. Bottom Section - 78 lb.
Weirs - maximum. Feed - limestone.
Top line - 20-min sample. Bottom line - 30-min sample.

Rpm		1000						1200						1500					
Amplitude Setting		2 Off Minimum		2 Off Maximum		Maximum		2 Off Minimum		2 Off Maximum		Maximum		2 Off Minimum		2 Off Maximum		Maximum	
Size Analysis		+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g
Feed Rate, 25 lb/hr	-10m	11.5	6256	9.9	6376	3.9	7332	2.0	8607	3.8	7780	3.5	7969	4.7	7282	3.0	8976		
		10.8	6596	5.0	7315	4.2	7490	3.4	7885	3.6	7591	3.1	8338	2.3	8175	3.3	8666		
	-28m	5.8	6555	1.9	8009	2.2	7820	3.4	6619	2.2	7710	2.9	8208	1.7	7272	2.6	8228	3.8	8547
		7.0	6693	2.1	7859	2.4	8134	3.2	7042	2.4	7710	3.0	7799	2.0	7211	2.7	8650	4.8	8257
Feed Rate, 75 lb/hr	-10m	12.3	6335	16.7	5578	13.7	5877	34.3	--	12.7	5997	8.4	6555	26.0	4562	15.8	5778		
		20.6*	6025	13.9	6375	14.7	6069	37.6*	--	16.7	6053	10.2	6845	32.4	--	16.0	6140		
	-28m			9.8	5718	9.4	5917	14.4	5021	10.0	5758	7.3	6256	12.1	5280	8.5	6196	8.0	6355
				8.5	6135	7.9	6155	21.0	4721	11.0	5897	6.9	6252	11.1	5498	9.1**	6405	**	--

* Overload.
** Discharge hose hot.

TABLE 9

Fineness of Grind,
Cylpebs, 1/2-in.

Top Section - 93 lb. Bottom Section - 93 lb
Weirs - maximum. Feed - limestone,
Top line - 20-min sample. Bottom line - 30-min sample

Rpm		1000						1200						1500					
Amplitude Setting		2 Off Minimum		2 Off Maximum		Maximum		2 Off Minimum		2 Off Maximum		Maximum		2 Off Minimum		2 Off Maximum		Maximum	
Size Analysis		+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m; %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g	+325m, %	Surface Area, cm^2/g
Feed Rate, 25 lb/hr	-10m	20.2 8.3	4781 6116					-- 7.5	-- 9842					14.6 15.1	-- 9692	13.6** 8.6	7705 10678		
	-28m	4.0 2.7	6096 6773	0.4 0.5	9075 9861	0.6 0.8	9324 10409	0.5 0.3	7391 7939	0.5 0..3	9921 10887	-- 2.3	-- 11734	0.3 0.3	10539 10458			**	
Feed Rate, 75 lb/hr	-10m	*												6.6 12.0	-- 6634	** --	6634		
	-28m	*	6733	2.4 1.9	6837 6674	1.0 1.3	7163 6933	7.5 16.0	5499 4781	1.3 1.0	6873 7062	2.7 1.1	7332 7112	1.0 3.4	6854 6136	**			

* Overload.
** Discharge hose whipping badly.

Nephelline Syenite Feed

Operation with a frequency of 1200 rpm at maximum amplitude, using 1/2-in. cylpebs, had given the finest product on limestone feed. Experiments were made with the nepheline syenite feed, using these same conditions at feed rates of 25, 50, 75 and 100 pounds per hour. For these experiments, samples were obtained by riffling from the product collected after the mill had reached equilibrium. Results are given in Table 10.

TABLE 10

Effect of Feed Rate,
Cylpebs, 1/2-in.

Top Section - 93 lb. Bottom Section - 93 lb.
Weirs - maximum. Feed - nepheline syenite.
Frequency - 1200 rpm. Amplitude - maximum.

Feed Rate, lb/hour	Screen Analysis* - Cumulative %						Surface Area, cm^2/g
	+70	+100	+140	+200	+270	+325	
25	nil	0.01	0.03	0.10	0.22	0.42	8403
50	tr	0.01	0.02	0.12	0.91	2.64	5477
75	nil	0.01	0.10	1.05	4.69	10.06	3941
100	0.01	0.03	0.31	2.60	9.10	16.72	3460

*U.S. Standard, provided by Industrial Minerals of Canada Limited.

A series of experiments was run in which the mill charge of 1/2-in. cylpebs was progressively increased. Feed rate was 30 lb per hour, frequency 1200 rpm, and amplitude maximum. Except for the experiment in which the mill became overloaded, the length of run was 30 minutes.

During operation, fine dust fills the small space not occupied by charge. For this series of experiments, the vent over the discharge of the lower section was opened and the dust collected by vacuum. It was noted that a considerable amount of the vent material appeared as tiny balls or agglomerates.

Results are given in Table 11.

TABLE 11

Effect of Media Loading,
Cylpebs, 1/2-in.

Feed Rate - 30 lb/hr.
Weirs - maximum. Feed - nepheline syenite.
Frequency - 1200 rpm. Amplitude - maximum.

Charge, lb	Bottom Vent			Discharge		
	Wt (lb)	+325m, %	Surface Area, cm^2/g	Wt (lb)	+325m, %	Surface Area, cm^2/g
93x2 = 186	0.43	0.11	7682	16	0.9	7233
98x2 = 196	0.65	0.17	6856	14	0.5	8654
103x2 = 206	0.79	0.20	5707	12	0.7	7233
108x2 = 216	Overload - mill charge hot					

To check the effect of the weir openings, experiments were run with the settings at 1/4 and 1/2 maximum. These results are compared to those with the weirs set at maximum.

Results are given in Table 12.

TABLE 12

Effect of Weir Setting,
Cylpebs, 1/2-in.

Top Section - 98 lb. Bottom Section - 98 lb.
Feed Rate - 30 lb/hr. Feed - nepheline syenite.
Frequency - 1200 rpm. Amplitude - maximum.

Weir Opening	+325 m, %	Surface Area, cm^2/g
Maximum	0.5	8654
1/2	0.2	7630
1/4	0.5	7525

c) 1/2-in. balls

To compare the grinding characteristics of 1/2-in. ceramic balls with those of 1/2-in. ceramic cylinders, the series of runs with nepheline syenite (Table 10) was repeated, using 93 lb of balls in each cylinder.

Results are shown in Table 13.

TABLE 13

Effect of Feed Rate,
Ceramic Balls, 1/2-in.

Top Section - 93 lb. Bottom Section - 93 lb.
Weirs - maximum. Feed - nepheline syenite.
Frequency - 1200 rpm. Amplitude - maximum.

Feed Rate, lb/hour	Screen Analysis* - Cumulative %						Surface Area, cm^2/g
	+70	+100	+140	+200	+270	+325	
25	0.01	0.09	0.40	0.91	2.10	3.52	7666
50	tr	0.02	0.10	0.46	1.47	3.34	6522
75	nil	0.01	0.11	0.80	2.84	6.80	4766
100**	0.02	0.11	1.21	5.22	10.70	21.22	3272

* U.S. Standard, provided by Industrial Minerals of Canada Limited.
**Close to 125 lb/hour.

The experiments reported on in Table 11 employed removal of material from the vent at the discharge end of the bottom section. To study the prospects for recovering an extra fine product further, experiments were made in which dust from the top vent was collected first and then dust from the bottom vent. Tiny agglomerates were again present and were found to include relatively coarse particles.

Results are given in Table 14.

TABLE 14

Effect of Venting.
Ceramic Balls, 1/2-in.

Top Section - 93 lb. Bottom Section - 93 lb.
Weirs - maximum. Feed - nepheline syenite.
Frequency - 1200 rpm. Amplitude - maximum.
Feed rate - 25 lb/hr.

Vacuum Location	Vent Sample			Discharge Sample		
	Wt, lb	+325m, %	Surface Area, cm^2/g	Wt, lb	+325m, %	Surface Area, cm^2/g
Top*	0.29	1.4	2707	6.5	2.0	9039
Top*	0.40	3.0	2717	5.5	3.3	9397
Bottom	0.46	0.6	3575	16.0	1.6	8382

*Two samples taken at different times.

3) Steel Balls and Plastic Liners

The experiments performed with plastic liners and ceramic media were made with lower feed rates than those with steel balls and steel liners. A number of experiments were performed to relate these two areas of operation. For these experiments the plastic liners were used with a charge of 1/2-in. steel balls. Because of the reduced volume of the sections when lined with plastic, it was found that 185 lb of the 1/2-in. steel balls was sufficient to fill each section to 70% of its volume (in contrast to the 220 lb used with steel liners). The highest surface area with 1/2-in. steel balls and steel liners had been produced with minus-28-mesh limestone feed at a frequency of 1500 rpm and amplitude 2 off minimum. These settings were therefore chosen. Feed rates of 75, 50 and 25 pounds per hour were used. Results are given in Table 15.

TABLE 15

Transition Experiments,
Stainless Steel Balls, 1/2-in.; Plastic Liners

Top Section - 185 lb. Bottom Section - 185 lb.
Weirs - maximum. Feed - limestone (-28 m).
Frequency - 1500 rpm. Amplitude - 2 off minimum.

Feed Rate, lb/hr	Sampled after min	+325m, %	Surface Area, cm^2/g
75	20	4.2	7262
	30	4.1	7202
50	20	5.0	9623
	30	4.0	8517
25	20	1.0	8607
	30	1.6	8945
	40	2.2	9583
	50	3.8	10977
	60	4.0	9882
25 (Top vent open)	20	3.8	9722
	30	2.8	9643

There was an indication, from the results in Table 14, that a finer product is obtained when a small amount of material is removed through the top vent. The final run at 25 lb/hr (Table 15) was also made with the top vent open and under vacuum suction. It continued the preceding run at 25 lb/hr. In comparison with the results for 50- and 60-minute samples, vent closed, the surface area of the product obtained showed a slight decrease.

4) General

To check surface area determinations against particle size distributions, coarse, fine and intermediate samples were run through the "EEL" Photo-Extinction Sedimentometer. Results are given in Table 16.

TABLE 16

Size Distribution:

Surface Area: Limestone Particle Size

Sample Identification	Surface Area, cm^2/g	Particle Size Distribution, microns			
		+10	-10+5	-5+1	-1
1/2-in. cylpebs; -28 mesh (75 lb/hr), 1200 rpm, 2 off min	4781	43	26	29	2
3/4-in. cylpebs; -28 mesh (75 lb/hr), 1200 rpm, 2 off min	4721	35	33	31	1
3/4-in. cylpebs; -28 mesh (25 lb/hr), 1000 rpm, maximum	8134	34	28	37	1
3/4-in. cylpebs; -10 mesh (25 lb/hr), 1500 rpm, 2 off min	8175	36	28	34	2
1/2-in. cylpebs; -28 mesh (25 lb/hr), 1000 rpm, maximum	10409	30	26	42	2
1/2-in. cylpebs; -28 mesh (25 lb/hr), 1500 rpm, 2 off min	10458	30	30	40	0

DISCUSSION

The settings were chosen to cover a broad range and to give representative results. An examination of Table 16 will disclose that, although products containing up to 70 per cent minus 10 micron may be made, there is virtually no minus-1-micron content. Moreover, even the finest products contain some plus-325 mesh. Thus, while the equipment is capable of producing micron-size products, it does not differ from other fine grinding devices in respect to a range of sizes in the product.

Correspondence from a representative of the manufacturer (5) states: "To our knowledge, there is no device as yet on the market which, applicable in continuous feed operation, would lend itself to producing products of this degree of fineness (minus 10 micron) with theoretically perfect avoidance of any stray oversize particles".

To obtain products of a specific micron size with this equipment, it would be necessary to use a suitable classification system.

Data below have been lifted from Tables 6, 7, 8, 9 and 15, which give results for experiments on limestone feeds. These data show the operating combinations which produced the highest surface area of product in each group of experiments.

TABLE 17

Operating Combinations for Finest Products

Lining	Media	Feed Rate, lb/hr	Feed Size, mesh	Amplitude	Frequency, rpm	Surface Area, cm^2/g
Steel	3/4-in. steel	75	-10	2 off min	1500	7820
Steel	1/2-in. steel	75	-28	2 off min	1500	8986
Plastic	1/2-in. steel	25	-28	2 off min	1500	10430
Plastic	3/4-in. cylpeb	25	-10	2 off max	1500	8821
Plastic	1/2-in. cylpeb	25	-28	max	1200	11734

Whether steel or ceramic media were used, the combination of low feed rate, high frequency, and medium-to-high amplitude gave a product with the highest surface area. Interestingly, with 3/4-in. media (steel or ceramic), the highest surface areas were produced on minus-10-mesh feed. With 1/2-in. media (steel or ceramic), the highest surface areas were produced on minus-28-mesh feed. For both steel and ceramic media, the highest surface areas were produced with the 1/2-in. size. Although this suggests that it might be appropriate to use even smaller media, say 1/4 in., such media are difficult to obtain, and discharge grids for the mill sections would have to be made up with smaller openings. Such a project is under consideration for future investigation.

High surface area of product was coupled with low plus-325 mesh. The lowest plus-325 mesh in product was obtained with the finest feeds and with settings which created slightly less activity in the charge than those settings which produced the highest surface areas.

In most respects the results followed predictable trends. As frequency and amplitude are increased, the activity of the charge (media plus feed) increases. It would be expected that new surface would be created more rapidly at the higher than at the lower activity levels. This is confirmed by the data. It also conforms with that well-known rule of comminution: higher energy input, more work done.

Similarly, it would be expected that lower feed rates would yield finer products. This is also confirmed by the data.

Finer starting sizes of feed might be expected to yield correspondingly finer products. This, however, did not always follow, particularly with the 3/4-in. media.

Work with nepheline syenite, using 1/2-in. cylpebs, confirmed that the finest products are obtained with low feed rates (Tables 10). It also indicated that the optimum cylpeb load would be approximately 98 lb per section (Table 11), and that maximum weir opening is preferable (Table 12). Ceramic balls (Table 13) were shown to be less effective than cylpebs.

Table 14 indicated that a product with higher surface area might be obtained when dust was removed from the top vent. The vent samples were comparatively coarse. Results were similar, but not as good, when the bottom section was vented. Less positive indications were obtained on experiments recorded in Table 11, and an additional trial reported in Table 15 gave reverse results. The value of venting, if any, is not clearly established by the experiments performed.

A factor of possible interest is that the ceramic balls became coated with product whereas the cylpebs did not.

The surface area figures used in this study can only be considered as relative. They represent the determinations provided by Lea and Nurse air-permeability equipment. However, having these determinations made by the same operator, in duplicate, and using the averaged result, ensures that all figures are amenable to comparison. Accuracy checks on the Lea and Nurse equipment were made by the longer, sedimentation method.

Wear on grinding media and liners is slight with this equipment. Space requirements are comparatively small, and, aside from start-up, the power requirements are modest.

CONCLUSIONS

(1) To obtain the finest products, the major variables in order of their influence are: Feed rate (the slower the feed the finer the product); amplitude (the higher the amplitude the finer the product); frequency (the higher the frequency the finer the product); grinding media (1/2-in. cylpebs produced the finest products).

(2) The finest products developed in the experimental work were obtained with 1/2-in. cylpebs at high amplitudes and low feed rates. These were approximately 70 per cent minus 10 microns, 40 per cent minus 5 microns, and with a little minus 1 micron, according to the measuring systems employed.

(3) Plus-325-mesh particles, in varying amounts, appeared in all the products.

(4) It would be necessary to classify the discharge in order to obtain uniform products in the low micron range.

(5) It would be necessary to work out experimentally the optimum conditions for producing a specified product for each material.

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