THE GRINDING CHARACTERISTICS OF LABORATORY ROD MILL

by

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I. INTRODUCTION

In almost every chemical reaction that involves a solid or solids as one or more of the reactants, it is necessary to first crush the solid in order that the greatest amount of reacting surface may be obtained. There has been very little development in the field of fine grinding as compared to many other industrial operations. The factors that influence the grinding capacities of mills are many and they vary so greatly that no mathematical expression can be developed to give any accurate results. It would be well, if it were possible, to go to tables and obtain the crushing characteristics of the material to be crushed. Unfortunately, no such tables exist. In industry, any problems that develop in grinding a material have to be solved by experimentation.

The factors that influence the grinding capacity of a rod mill are the size of feed, size of product required, percentage of fines in the feed, size and number of rods, weight of charge, speed of mill, open or closed circuit grinding, rate of feed, nature of material, and the moisture in the feed. Grinding mills are designed to cope with several of these factors, but not with all of them. This is the main reason why the industrial mills have such poor capacities. There are many other mills that are far more efficient in fine grinding than the rod mill, but this work is to deal exclusively with the grinding characteristics of this mill.

The object of this work is to determine the grinding characteristics of a rod mill on air dry blue dolomite. This mill is a batch grinding mill located in the Chemical Engineering Unit Operations Laboratory at the Virginia Polytechnic Institute, Blacksburg, Virginia.

II. LITERATURE REVIEW

A review of the chemical and engineering literature of the grinding characteristics of the rod mill indicates that there are not many published articles on this subject. The existing articles on this subject are not complete and give little or no definite proof about the influencing factors on fine grinding. There has been considerable progress made along the mechanical aspects of grinding, but the theory and conceptions of the underlying principles have not advanced so rapidly. In the field of grinding, two laws have been advanced.

Rittenger[1,3,6,11] proposed a theory based upon the assumption that the energy required for a crushing process was proportional to the surface that was sheared.

Kick[1,3,6,11] proposed a theory that the energy necessary for crushing a material was proportional to the logarithm of the ratio between the initial and the final diameters.

Gross[3] showed from his experiments on crushing and grinding that Rittenger's law is more applicable to crushing than Kick's law. He said that Rittenger's law would be more accurate if there was a way of determining the size of the material ground which is less than two hundred mesh. The available screen sizes are inadequate in the determination of sizes of finely ground material. Gross also states that the experiments performed by the Bureau of Mines in surface determinations of crushed material confirmed Rittenger's law.

Taggart[11] stated that in certain types of material ground, Rittenger's and Kick's law could be applied and the results would be considerably accurate. In other experiments that he performed, neither law gave any accurate results as compared to the experimental results. He came to the conclusion that there are too many variable factors and these laws do not take them into consideration.

Perry[6] in his discussion of these laws does not come to any definite conclusions, but gives experimental data on the applications of both laws. From the experimental data found in his article, it was shown that Kick's law can be applied for crushing large particles and Rittenger's law can be applied to the size reduction of finer grinding.

The most important factors that influence the grinding capacity of a rod mill are as follows:

1. Rate of feed.
2. Nature of the material.
3. Size of the feed.
4. Size of the product.
5. Moisture in the feed.
6. Size and number of rods used.
7. Weight of charge.
8. Speed of mill.

In determining the capacity of the mill, all of the above factors should be taken into consideration, but in actual practice many of them are neglected. These eight factors are the most important and they will be taken up in detail.

In open circuit grinding,[3,11] the amount of a material of any given size produced by a single mill increases with the rate of feed.

The production of a mill reaches a maximum more quickly when the product has to be ground finer. When the feed rate in open circuit grinding is reduced to a point where all of the discharge product is of the desired size, the capacity of the mill is extremely low. Grinding under these conditions is not economical because power consumption is high and there is excessive wear on the mill lining and grinding media.

Batch grinding[8] is less efficient than all of the other types of grinding because when the product has to be ground to a maximum particle size, most of the material has been overground. Usually all mills are run in a closed circuit with a sizing device to return the oversized particles back to the mill to be reground. With a sizing device on the mill, power is not wastefully consumed in overgrinding the material.

The nature of the material or its physical characteristics[11] has a marked effect on size reduction by grinding. This characteristic has a greater effect upon fine grinding than it does upon coarser grinding. When a material is ground to less than two hundred mesh, its molecular structure makes grinding more difficult. The power required to reduce a material to this fineness is extremely high and other types of mills are far more efficient. If a rod mill is used to produce a product of less than two hundred mesh, it is usually carried out in stages, or steps in a closed circuit.

The size of the feed[8,11] is a very important factor in obtaining the highest capacity from any mill. For any given mill, there is a feed size that will give maximum grinding of a desired size. This factor is very rarely determined and the mill handles a given size of feed that is more often determined by less important factors. Therefore, the resulting efficiency of the grinding system is exceedingly less than it should be. The reason why this factor is so neglected is because there is not sufficient information available on this subject. Experiments have been run on this phase of grinding and the results have been convincing, but they have not been given much consideration by industry.

A change in the moisture content[3,4,11] of a material effects the grinding capacity of a mill. The moisture content controls the fluidity of the material. When the material is perfectly dry, it is very fluid and flows through the mill readily. It has a great transporting power, and can be easily discharged from a mill with horizontal axis. When the moisture content is between fifteen and eighteen percent, especially in clays and clayey materials, a stiff mud is formed and this prevents the operation of the mill. If the moisture content is increased to twenty percent, ordinary materials are sufficiently fluid to flow in a mill. The fluidity of a material[9] increases with the increase of moisture. For any given material and any given moisture content, the apparent wetness is greater when the material is coarse. Perry[6] states that in wet batch grinding, any variation in speed of the mill will have no effect upon the grinding because slow speeds are just as effective as higher speeds.

For maximum grinding of a material Richards[8] found that the rods in a rod mill should be from thirty to forty percent of the mill's volume. The rods should be of varying diameters and the most suitable diameters must be determined by experimentation. Maximum capacity and power consumption occurs when the mill is a little less than half full. This volume is composed of the rods and feed combined.

The speed[4,11] of a mill depends primarily upon the size of the feed and the inside diameter of the mill. In a rotating cylindrical mill the rods have two types of motion. They are rotating around their own axis that is parallel to the axis of the mill and a free falling motion. If the mill is operated at too fast a speed, the rods will tend to cling to the shell of the mill and there will be no crushing effect. The speed at which a mill should be operated is given by the following equation.[9]

$$N = 54.19/r$$

where:

N = revolutions per minute.

r = inside radius in feet.

The usual operating speed of the mill is from sixty to eighty percent of this figure.

Of all the variable factors that exist in grinding, there are two that are agreed upon by different investigators. They are:

1. The characteristics of the different materials should be determined.
2. These characteristics are only applicable to the particular type of crushing equipment on which they are determined.

Therefore, to be of any value, they must be determined for each material and on each type of crusher and grinder.

III. EXPERIMENTAL

A. The purpose of this investigation is to determine the grinding characteristics of a laboratory size, batch operated rod mill.

B. Plan of Investigation:

1. To determine the maximum size reduction that is obtainable by the rod mill.
2. To determine the size of feed that produces maximum grinding in the rod mill.
3. To crush local blue limestone using various sizes of feed.
4. Plot curves of the representative sample screen analysis by two methods.
    a. Direct cumulative method.
    b. Logarithmic cumulative method.
5. From the experimental results obtained, determine the operating characteristics of the rod mill.

C. Materials:

Raw material used in this investigation is blue dolomite. This dolomite was obtained in the vicinity of Blacksburg, Virginia. This type of dolomite is dense with very slight changes in chemical composition. Inclusions of certain crystaline substances occurs in the rack and pieces containing large inclusions were not used in this investigation.

D. Apparatus:

1. Laboratory Jaw Crusher.

   a. Universal Crusher Company

      Cedar Rapids, Iowa.

   b. Overal Dimensions 26 by 23 inches.

   c. Power Requirements G. E. Motor 2 Hp

2. Laboratory Rod Mills.

   a. Inside dimensions 11 inches diamenter by 18 inches

   b. Lining Porcelain

   c. Power Requirements G. E. Motor 1 Hp

   d. Grinding media

      1) Cast iron rods

      2) Number used and size

         a) 3 1 inch diameter by 17 inches

         b) 4 $\frac{3}{4}$ inch diameter by 17 inches

         c) 6 $\frac{1}{2}$ inch diameter by 17 inches

         d) 9 1/8 inch diameter by 17 inches

3. Atmospheric Tray Dryer

   a. Proctor and Swartz, Inc.

      Philadelphia, Penn.

   b. Serial No. H 8122

4. Laboratory Analytical Balance

   a. Ohaus

   b. Newark Scale Works Co.

      Newark, New Jersey

5. Galvanized Iron Trays

   Dimensions 15 inches by 15 inches by 2 inches

6. Screen Analysis Equipment

   a. Combs Gyratory Riddle

      Great Western Manufacturing Co.

      Levenworth, Kansas.

      Serial No. S-101

   b. U. S. Standard Screens

      Size 8 inches in diameter

      Mesh No. 4, 8, 16, 40, 70, 100, and 200

7. Other Equipment Used

   a. 10 quart Galvanized buckets

   b. 1 quart steel containers

E. Procedure:

The following procedure was used in the preparation of the feed used in the operation of the rod mill:

1. The 6 - 12 inches in diameter pieces of dolomite were reduced to a maximum size of three inches by manually sledging with a sledge hammer.

2. The three inch pieces were washed with water to remove any extraneous material from the surface of them. They were allowed to drain and were stored in ten quart buckets.

3. The three inch pieces were then passed through the jaw crusher which was adjusted to approximately one quarter inch opening between the crushing plates. Two passes were necessary to reduce the limestone to sizes suitable to use as the feed.

4. The crushed limestone was placed in clean galvanized iron trays in the atmospheric tray dryer. The circulating air fan was started and the steam was adjusted to give a temperature of 240° F in the dryer. The limestone remained in the dryer until it was free of any retained moisture.
5. The dried dolomite was separated into sizes of 4 mesh, 8 mesh, 20 mesh, and 60 mesh by using U. S. Standard screens and a Combs Gyratory Riddle. The amount retained on the corresponding screens was assumed to be the size stated.
6. Thirty-two and one-half pounds of the various sizes (Table I) were ground in the rod mill for three hours. A representative sample was taken at the end of each hour and a screen analysis was made using 4, 8, 16, 20, 40, 70, 100 and 200 mesh U. S. Standard screens.
7. The weights retained on the screens were used to plot curves by the direct cumulative and the logarithmic cumulative methods.

F. Data:

TABLE I

Representative Screen Analysis of local blue limestone used as feed in the operation of the Rod Mill.

Run No.	Weight Retained in Grams on Screen Size				
	Minus 2 Mesh Plus 4 Mesh	Minus 4 Mesh Plus 8 Mesh	Minus 8 Mesh Plus 20 Mesh	Minus 20 Mesh Plus 60 Mesh	Total Wt.
1	14,482	--	--	--	14,482
2	--	14,479	--	--	14,479
3	--	--	14,491	--	14,491
4	4,820	9,665	--	--	14,485
5	--	--	6,923	7,545	14,468
6	2,453	1,047	8,223	1,970	14,691

TABLE II

Representative Sample of Screen Analysis of local blue limestone of feed containing 14,482 grams minus 2 mesh - plus 4 mesh. A representative sample of the product was taken at 60 minute intervals for three hours grinding in the rod mill.

SCREEN	TIME OF GRINDING								
MESH	A = 60 Minutes			B = 120 Minutes			C = 180 Minutes		
	Wt. Retained Grams	% Retained	Cum. %	Wt. Retained Grams	% Retained	Cum. %	Wt. Retained Grams	% Retained	Cum. %
4	51.5	8.95	8.95	20.5	3.11	3.11	3.0	0.63	0.63
8	159.0	27.70	36.65	90.0	13.49	16.60	19.5	3.81	4.44
16	99.5	17.30	53.95	48.5	7.25	23.85	33.5	6.50	10.94
20	56.0	9.80	63.75	28.0	4.18	28.03	29.5	5.64	16.48
40	44.5	7.75	71.50	70.0	10.00	38.03	32.5	6.33	22.81
70	34.5	6.00	77.50	94.0	14.10	52.13	84.0	16.19	39.00
100	30.5	5.31	82.81	115.5	16.65	68.78	75.0	14.4	53.40
200	80.0	13.95	96.76	150.0	23.0	91.78	180.0	34.6	88.00
-200	19.0	3.24	100.0	65.0	9.30	100.08	65.0	12.0	100.00
Total	574.5	100.00	100.0	478.0	100.0	100.08	517.0	100.0	100.00

TABLE III

Representative Sample of Screen Analysis of local blue limestone of feed containing 14,479 grams of minus 4 mesh - plus 8 mesh. A representative sample was taken at sixty minute intervals for three hours of grinding.

SCREEN	TIME OF GRINDING								
MESH	A = 60 Minutes			B = 120 Minutes			C = 180 Minutes		
	Wt. Retained Grams	% Retained	Cum. %	Wt. Retained Grams	% Retained	Cum. %	Wt. Retained Grams	% Retained	Cum. %
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	83.5	13.26	13.25	0.00	0.00	0.00	0.00	0.00	0.00
16	197.0	31.40	44.66	89.5	17.3	17.3	7.0	1.09	1.09
20	71.5	11.30	55.90	43.5	8.42	25.72	24.0	3.72	4.81
40	40.0	6.35	62.21	57.0	11.00	36.72	12.0	1.80	6.61
70	31.5	5.01	67.22	74.0	14.25	50.97	55.5	8.47	15.08
100	59.0	9.38	76.6	57.0	11.0	61.97	132.5	20.3	36.78
200	146.5	23.4	100.0	165.0	30.4	92.47	333.0	50.5	85.88
-200	0.0	0.0	100.0	31.5	7.6	100.07	92.0	14.2	100.08
Total	629.0	100.0	100.0	517.5	100.07	100.07	653.0	100.08	100.08

TABLE IV

Representative Sample of Screen Analysis of local blue limestone feed containing 14,491 grams minus 8 mesh - plus 20 mesh material. A representative sample of the product was taken at 60 minute intervals for three hours grinding in the rod mill.

SCREEN	TIME OF GRINDING								
MESH	A = 60 Minutes			B = 120 Minutes			C = 180 Minutes		
	Wt.Retained Grams	% Retained	Cum. %	Wt.Retained Grams	% Retained	Cum. %	Wt.Retained Grams	% Retained	Cum. %
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	10.0	2.04	2.04	0.00	0.00	0.00	0.00	0.00	0.00
20	32.5	6.67	8.71	12.0	1.9	1.9	4.5	0.75	0.75
40	81.0	16.55	25.26	20.5	3.18	5.08	6.0	1.08	1.83
70	51.0	10.45	35.71	33.0	5.20	10.28	24.5	4.37	6.20
100	130.0	26.5	62.21	179.5	28.00	38.28	131.0	23.60	29.80
200	94.5	21.4	83.61	215.0	34.6	72.88	225.0	40.50	70.3
-200	80.5	16.4	100.01	180.0	27.2	100.08	165.0	29.7	100.00
Total	489.5	100.01	100.01	640.0	100.08	100.08	555.0	100.0	100.00

TABLE V

Representative Sample of Screen Analysis of local blue limestone of feed containing 4,820 grams of minus 2 mesh - plus 4 mesh and 9,665 grams of minus 4 mesh - plus 8 mesh. A representative sample was taken at sixty minute intervals for three hours grinding.

SCREEN	TIME OF GRINDING								
MESH	A = 60 Minutes			B = 120 Minutes			C = 180 Minutes		
	Wt. Retained Grams	% Retained	Cum. %	Wt. Retained Grams	% Retained	Cum. %	Wt. Retained Grams	% Retained	Cum. %
4	18.0	1.97	1.97	0.00	0.00	0.00	0.00	0.00	0.00
8	155.5	17.00	18.97	13.5	3.5	3.50	0.00	0.00	0.00
16	291.5	32.00	50.97	87.5	14.3	17.80	7.5	1.25	1.25
20	70.0	7.60	58.63	63.0	10.30	28.10	1.0	0.15	1.40
40	80.0	8.75	67.38	82.0	13.42	41.52	12.0	2.05	3.45
70	64.0	7.00	74.38	73.0	10.95	52.47	75.0	12.55	16.0
100	39.0	4.28	78.66	69.0	11.3	63.77	127.0	21.25	37.25
200	120.0	13.2	91.86	122.5	21.1	84.87	251.0	42.25	79.50
-200	75.0	8.2	100.06	93.0	15.20	100.07	123.0	20.5	100.0
Total	913.5	100.06	100.06	610.5	100.07	100.07	597.0	100.0	100.0

TABLE VI

Representative Sample of Screen Analysis of local blue limestone of feed containing 6,923 grams of minus 8 mesh - plus 20 mesh and 7,545 grams of minus 20 mesh - plus 60 mesh. A representative sample was taken at sixty minute intervals for three hours of grinding.

SCREEN	TIME OF GRINDING								
MESH	A = 60 Minutes			B = 120 Minutes			C = 180 Minutes		
	Wt. Retained Grams	% Retained	Cum. %	Wt. Retained Grams	% Retained	Cum. %	Wt. Retained Grams	% Retained	Cum. %
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	2.5	0.83	0.83	0.00	0.00	0.00	0.00	0.00	0.00
20	3.0	0.97	1.80	1.00	0.19	0.19	0.00	0.00	0.00
40	7.0	2.28	4.08	4.00	0.76	0.95	291.0	57.8	57.8
70	18.0	6.87	10.95	141.0	26.8	27.75	67.0	13.31	71.11
100	78.0	26.40	37.35	118.0	22.4	50.15	3.0	0.59	71.70
200	195.0	62.70	100.05	262.5	49.8	99.95	141.5	28.30	100.30
Total	307.5	100.05	100.05	526.5	99.95	99.95	502.5	100.00	100.30

TABLE VII

Representative Sample of Screen Analysis of local blue limestone of feed containing 2,453 grams minus 2 mesh - plus 4 mesh, 1,047 grams minus 4 mesh - plus 8 mesh, 8,223 grams minus 8 mesh - plus 20 mesh, and 1,970 grams minus 20 mesh - plus 60 mesh. A representative sample of product was taken at 60 minute intervals for three hours of grinding in the rod mill.

SCREEN	TIME OF GRINDING								
MESH	A = 60 Minutes			B = 120 Minutes			C = 180 Minutes		
	Wt. Retained Grams	% Retained	Cum. %	Wt. Retained Grams	% Retained	Cum. %	Wt. Retained Grams	% Retained	Cum. %
4	9.5	1.89	1.89	0.00	0.00	0.00	0.00	0.00	0.00
8	54.0	10.45	12.34	10.5	2.10	2.10	0.00	0.00	0.00
16	43.0	8.4	20.74	17.0	3.50	5.60	3.0	0.95	0.95
20	141.0	27.4	48.14	55.5	11.15	16.75	6.0	1.88	2.83
40	45.5	8.9	57.04	74.05	15.05	31.80	24.5	7.42	10.25
70	37.0	7.2	64.24	36.5	7.30	39.10	35.5	10.75	21.00
100	64.5	12.5	76.74	103.0	20.50	59.60	51.0	15.30	36.30
200	97.0	18.9	95.64	106.5	21.30	80.9	148.0	40.70	77.00
-200	22.5	4.4	100.04	95.5	19.10	100.00	77.0	23.0	100.00
Total	514.0	100.04	100.04	499.5	100.00	100.00	335.0	100.00	100.00

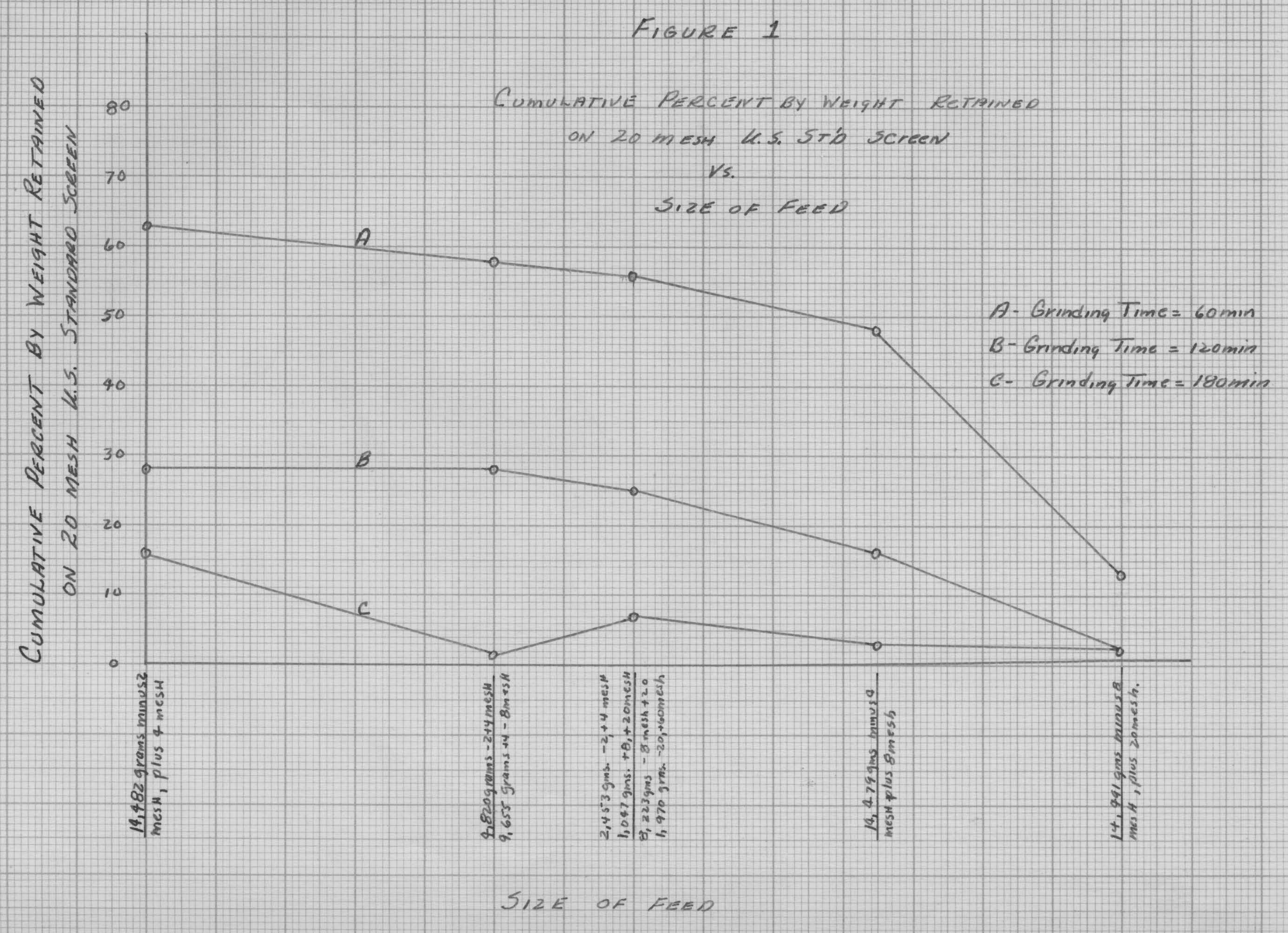


FIGURE 1
CUMULATIVE PERCENT BY WEIGHT RETAINED
ON 20 MESH U.S. ST'D SCREEN
VS.
SIZE OF FEED
A- Grinding Time = 60min
B- Grinding Time = 120min
C- Grinding Time = 180min
A
B
C
CUMULATIVE PERCENT BY WEIGHT RETAINED
ON 20 MESH U.S. STANDARD SCREEN
0
10
20
30
40
50
60
70
80
14,482 grams minus 2 mesh, plus 4 mesh
9,820 grams -2+4 mesh
9,655 grams +4 - 8 mesh
2,453 gms. -2,+4 mesh
1,047 gms. +8,+20 mesh
8,223 gms - 8 mesh +20
1,970 gms. -20,+60 mesh
14,479 gms minus 4 mesh plus 8 mesh
14,991 gms minus 8 mesh, plus 20 mesh.
SIZE OF FEED

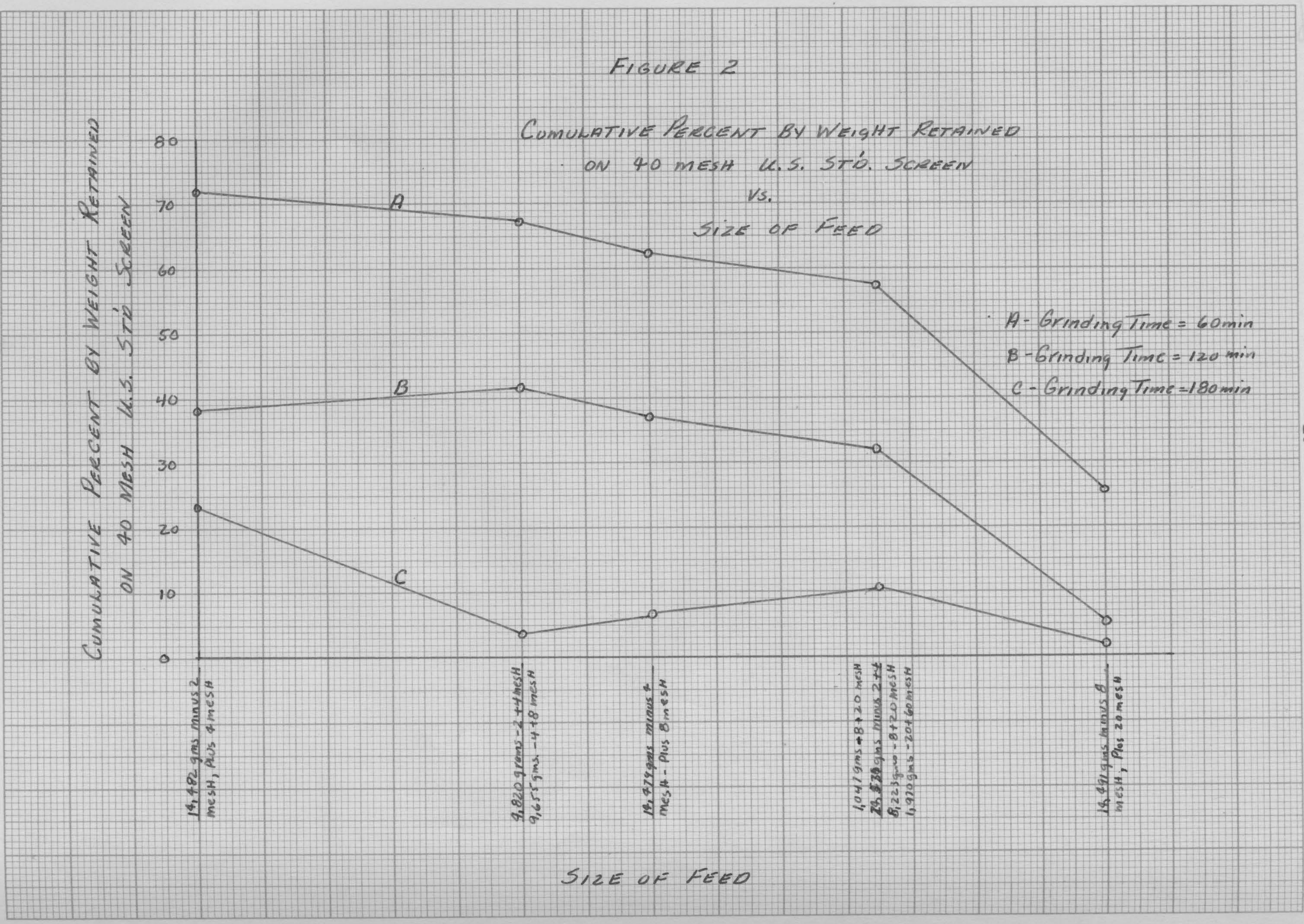


FIGURE 2
CUMULATIVE PERCENT BY WEIGHT RETAINED
ON 40 MESH U.S. STD. SCREEN
VS.
SIZE OF FEED
A - Grinding Time = 60 min
B - Grinding Time = 120 min
C - Grinding Time = 180 min
A
B
C
CUMULATIVE PERCENT BY WEIGHT RETAINED
ON 40 MESH U.S. STD SCREEN
80
70
60
50
40
30
20
10
0
14,482 gms minus 2 mesh, Plus 4 mesh
9,820 grams -2+4 mesh
9,655 gms. -4+8 mesh
14,474 gms minus 4 mesh - Plus 8 mesh
1,041 gms +8+20 mesh
8,223 gms -8+20 mesh
1,920 gms -20+60 mesh
14,491 gms minus 8 mesh, Plus 20 mesh
SIZE OF FEED

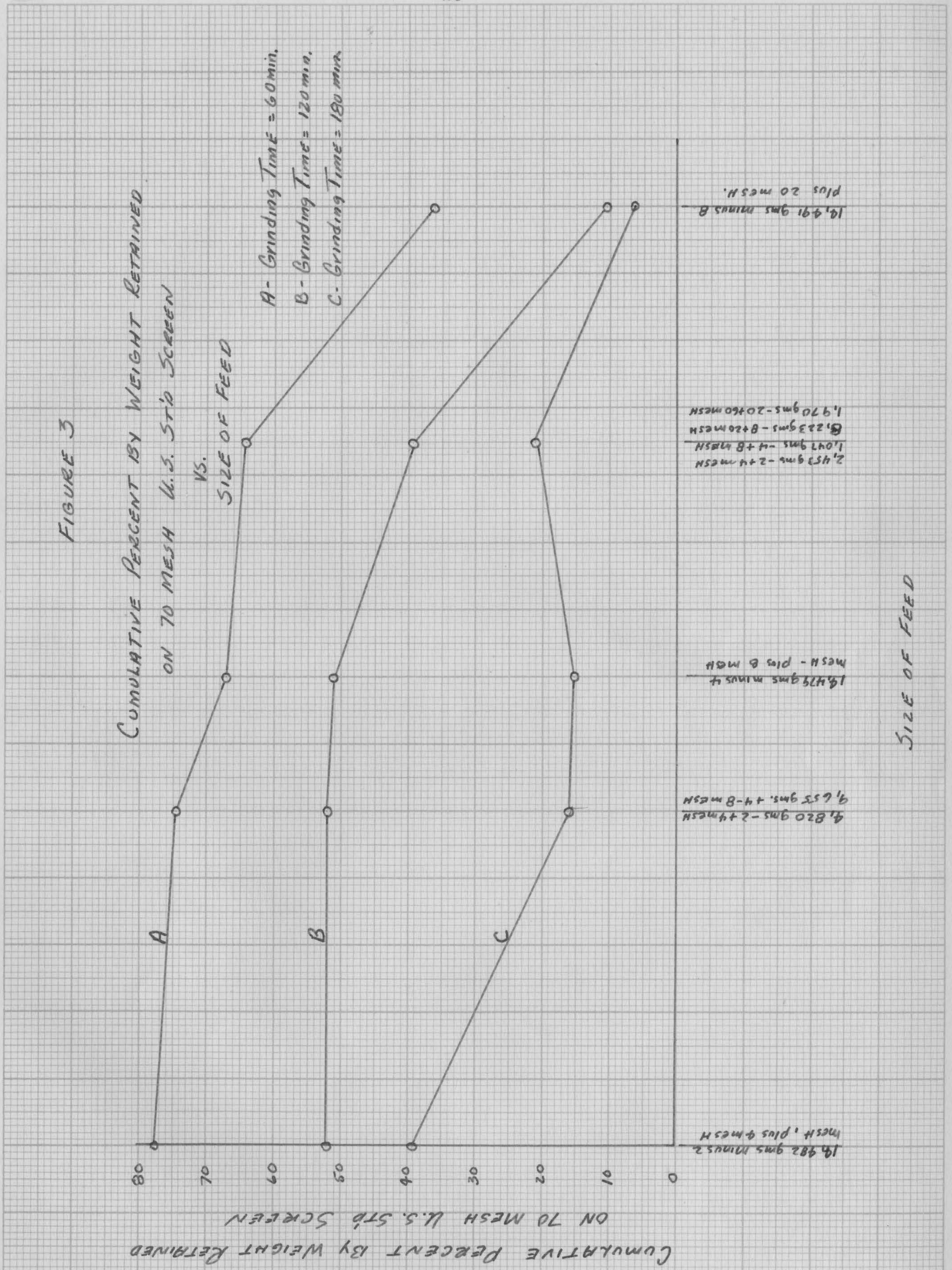
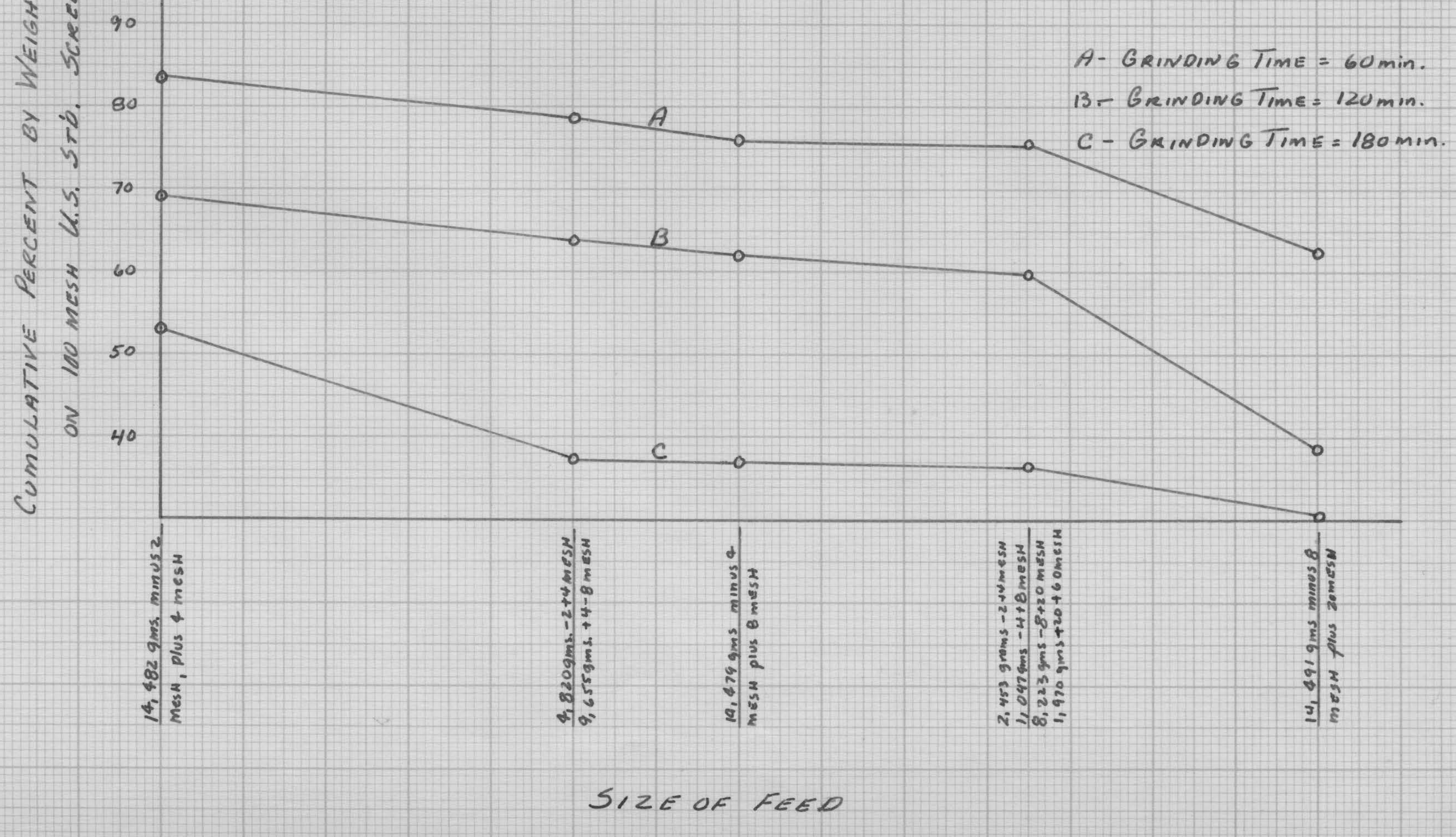


FIGURE 3
CUMULATIVE PERCENT BY WEIGHT RETAINED
ON 70 MESH U.S. STD SCREEN
VS.
SIZE OF FEED
A- Grinding Time = 60 min.
B- Grinding Time = 120 min.
C- Grinding Time = 180 min.
A
B
C
0
10
20
30
40
50
60
70
80
CUMULATIVE PERCENT BY WEIGHT RETAINED
ON 70 MESH U.S. STD SCREEN
19,482 gms minus 2 mesh, plus 4 mesh
4,820 gms -2+4 mesh
9,655 gms. +4-8 mesh
19,479 gms minus 4 mesh - plus 8 mesh
2,457 gms -2+4 mesh
1,047 gms -4+8 mesh
8,223 gms -8+20 mesh
1,970 gms -20+60 mesh
19,491 gms minus 8 plus 20 mesh.
SIZE OF FEED

FIGURE 4

CUMULATIVE PERCENT BY WEIGHT RETAINED
ON 100 MESH U.S. STD. SCREEN
VS.
SIZE OF FEED.



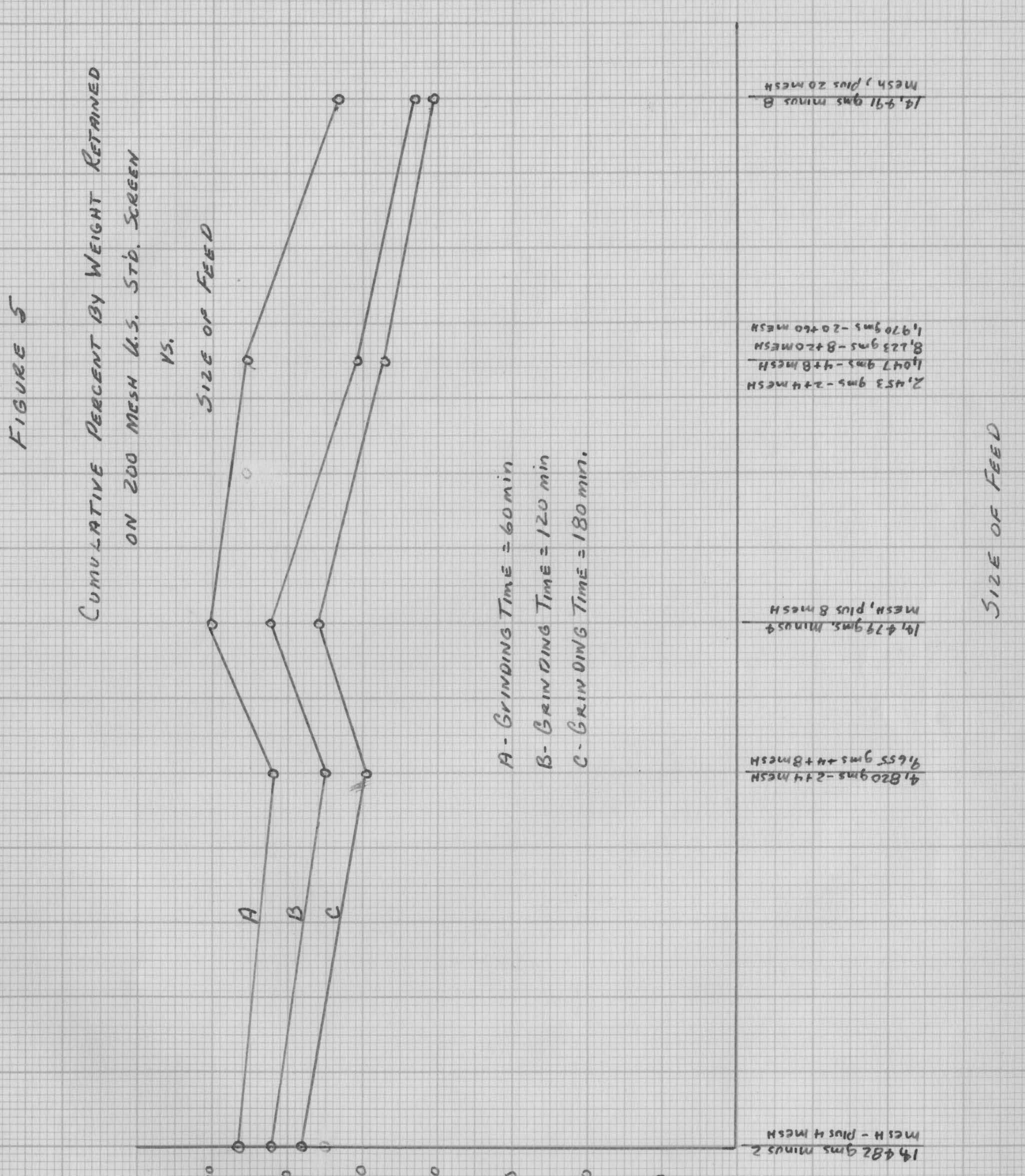


FIGURE 5
CUMULATIVE PERCENT BY WEIGHT RETAINED
ON 200 MESH U.S. STD. SCREEN
VS.
SIZE OF FEED
A - GRINDING TIME = 60 min
B - GRINDING TIME = 120 min
C - GRINDING TIME = 180 min.
A
B
C
100
90
80
70
60
50
40
CUMULATIVE PERCENT BY WEIGHT RETAINED
ON 200 MESH U.S. STD. SCREEN
14,482 gms minus 2 mesh - plus 4 mesh
4,820 gms -2+4 mesh
9,655 gms -4+8 mesh
14,479 gms. minus 4 mesh, plus 8 mesh
2,453 gms -2+4 mesh
1,047 gms -4+8 mesh
8,223 gms -8+20 mesh
1,970 gms -20+60 mesh
14,491 gms minus 8 mesh, plus 20 mesh
SIZE OF FEED

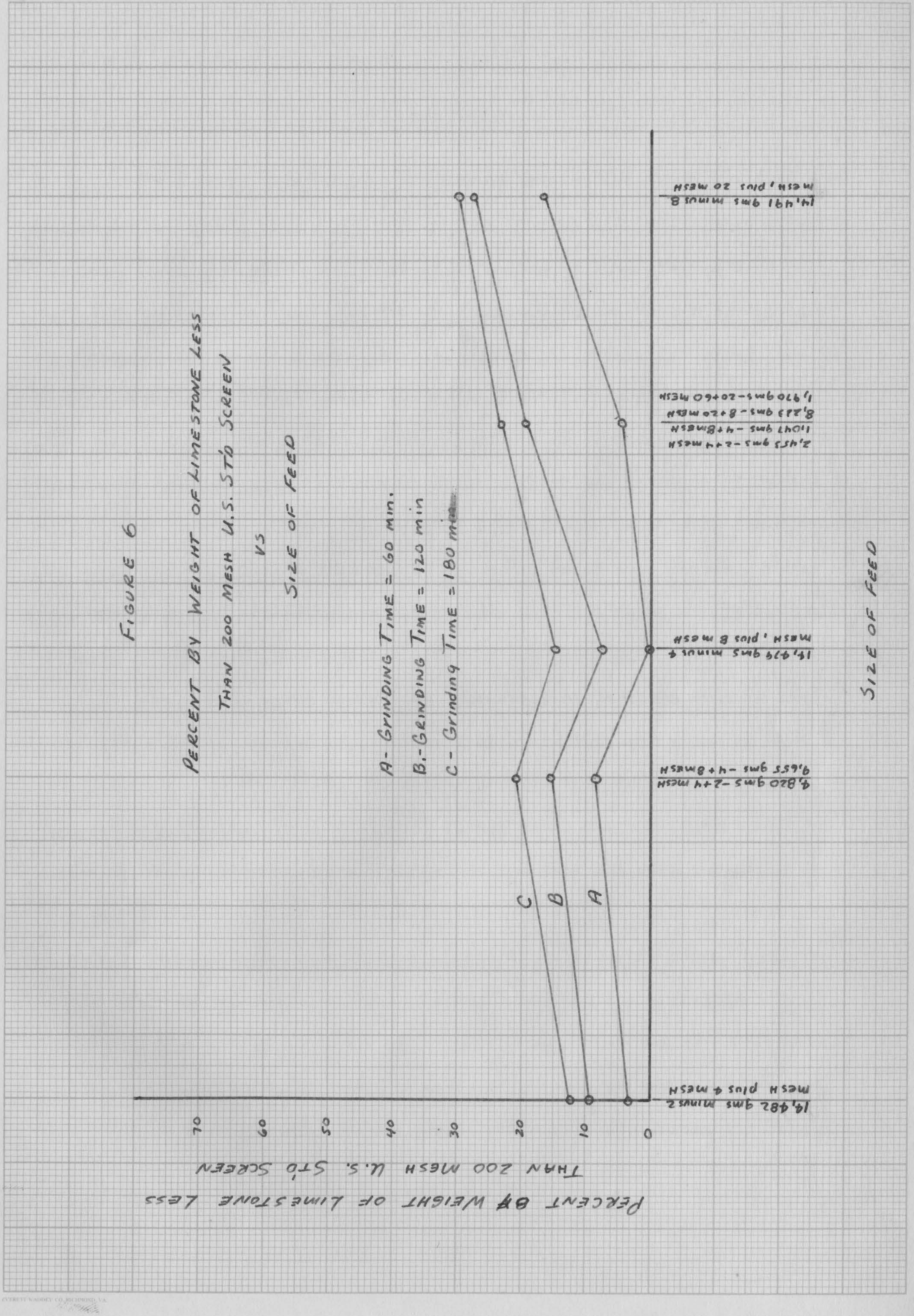


FIGURE 6
PERCENT BY WEIGHT OF LIMESTONE LESS
THAN 200 MESH U.S. STD SCREEN
VS
SIZE OF FEED
A- GRINDING TIME = 60 min.
B.- GRINDING TIME = 120 min
C - Grinding TIME = 180 min
C
B
A
70
60
50
40
30
20
10
0
PERCENT BY WEIGHT OF LIMESTONE LESS
THAN 200 MESH U.S. STD SCREEN
SIZE OF FEED
14,482 gms minus 2 mesh plus 4 mesh
4,820 gms -2+4 mesh
9,655 gms -4+8 mesh
17,474 gms minus 4 mesh, plus 8 mesh
2,453 gms -2+4 mesh
1,047 gms -4+8 mesh
8,223 gms -8+20 mesh
1,970 gms -20+60 mesh
14,491 gms minus 8 mesh, plus 20 mesh

IV. DISCUSSION

The screen analysis of the representative sample on the feed containing 6,923 grams of minus 8 mesh - plus 20 mesh and 7,545 grams of minus 20 mesh - plus 60 mesh is not correct. Packing of the finely ground material occurred on the 70 mesh U. S. Standard screen during screening of the sample. To enable a more accurate screen analysis of grinding, the samples should have been screen wet or on a Roto-top shaker instead of a gyratory riddle. The material that passed the two hundred mesh screen had to be assumed as minus 200 mesh because there was no means of determining the particle sizes. The size of this material should be determined by using finer screens and screening wet or by using elutriation. With the determination of particle sizes of less than 200 mesh, a more accurate picture of the grinding characteristics of the rod mill will be obtained.

The power imput versus the reduction of particle size in the rod mill does not confirm with either Kick's or Kittinger's law on crushing and grinding. From previous determinations by using a watt-meter on the grinding system of the rod mill, it was found that the power imput remained the same providing the weight of the feed and rods remained constant.

From the graphical interpertations of the experimental results, there is a uniform size reduction for the first two hours of grinding depending upon the size of the feed that is used. Maximum grinding occurs in the first two hours of grinding and a cushioning or packing effect of the finely ground material on the grinding media occurs during the final period of grinding. A certain amount of the finely ground material adhered to the rods thus producing a certain degree of cushioning.

The rod mill is well adapated to grinding material that does not have to be finer than 200 mesh. From the range sizes of 20 to 100 mesh, there is a high degree of uniform size reduction that could be easily duplicated provided that the initial conditions of the size of feed number and sizes of rods and the time of grinding are observed. This type of mill is desirable in industries where exact particle sizes are a necessity in the production of their product. For example, the manufacture of glazes in the ceramic field.

Limitations: This investigation was carried out on local blue limestone that was obtained at Blacksburg, Virginia. The experimental results will not correspond to any other types of limestone because it varies in physical and chemical composition depending upon the locality. Other materials should be ground in the rod mill before its grinding characteristics can be accurately determined.

V. CONCLUSIONS

The following conclusions are based upon the experimental data obtained from the investigation on the grinding characteristics of a laboratory batch-type rod mill.

1. The variation in the size of feed from 4 to 20 mesh has the greatest effect on the particle size after being ground for three hours.
2. Using a feed size of minus 8 mesh - plus 20 mesh, a more uniform product was obtained. After three hours of grinding the following percentages was obtained by weights retained on the corresponding screen. 0.75 percent on 20 mesh, 1.08 percent on 40 mesh, 4.37 percent on 70 mesh, 23.6 percent on 100 mesh, 42.2 percent on 200 mesh, and 29.0 percent minus 200 mesh.
3. Maximum size reduction of the limestone ground in the rod mill occurred in the first two hours of grinding. During the third hour of grinding in the mill, the fines had a cushioning or packing effect upon the grinding media that decreased the grinding capacity of rods in the mill.
4. The mill produces a uniform size reduction in particles from 20 to 100 mesh. For sizes finer than 200 mesh, the mill is not suitable. It is recommended to use a feed of 20 mesh or finer if the mill is to produce a product of 200 mesh or finer in a minimum grinding time.
5. In order to obtain a product of 200 mesh or finer in the rod mill, a large percentage of the material will be overground and the batch-type rod mill is undesirable.

VI. SUMMARY

In almost every chemical reaction that involves a solid or solids as one or more of the reactants, it is first necessary to crush the solid in order that the greatest amount of reacting surface may be obtained. When a solid can be reduced to micron size, the reaction takes place more readily with a higher increase in the percentage of the final product. In the ceramic field, there is an extensive use of rod and ball mills for the fine grinding of glazes and clays.

It was decided to determine the grinding characteristics of the rod mill and its value in the field of fine grinding. The experimental results obtained in this investigation was on local blue limestone that was obtained in the vicinity of Blacksburg, Virginia. There is a uniform size reduction in particle size from 20 to 70 mesh and the amount of material obtained is a relationship of the size of feed used as shown in the graphical interpretation of the results. The size of feed used is a deciding factor in determining the product desired in unit time from the rod mill.

When using a feed size of minus 8 mesh - plus 20 mesh, a uniform size of product is obtained. From Table IV it was shown after three hours of grinding, the following percentages by weight of limestone retained on the corresponding screens were obtained. 0.75 percent on 20 mesh, 1.08 percent on 40 mesh, 4.37 percent on 70 mesh, 23.6 percent on 100 mesh, 40.50 percent on 200 mesh. At the time of screen analysis of the product of grinding, there was no means available for determining the sizes of particles less than 200 mesh.

The amount of material less than 200 mesh is approximately a straight line relationships of the size of feed used in the rod mill. From Figure 6 this is shown by plotting graphically the percent by weight per unit time versus the size of the feed used.

From Figure 5, the percent of material retained by weight on a 200 mesh screen remains constant even in varying the size of feed from minus 2 mesh - plus 8 mesh to minus 8 mesh to plus 20 mesh. This is due to the fact that the percent of fines increase with increased grinding.

This mill is well adapted for the ceramic field because from the experimental results obtained from this investigation on local limestone, it can be assumed that these results can be duplicated providing the conditions of grinding are followed.

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