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A STUDY OF THE TRANSPORTATION OF MINE ROCK BY PUMPING

BY

HOWARD M. FOWLER

A

THESIS

submitted to the Faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

DEGREE OF

MASTER OF SCIENCE IN MINING ENGINEERING

Rolla, Missouri

1947

Approved by J. D. Forrester

Chairman, Department of Mining Engineering

ACKNOWLEDGEMENTS

This study of transporting mine rock by pumping was undertaken during the tenure of a Research Fellowship appointment at the State Mining Experiment Station, School of Mines and Metallurgy, University of Missouri.

I wish to acknowledge the assistance given me and express my appreciation to:

Dr. J. D. Forrester, Chairman of the Department of Mining Engineering of the School of Mines and Metallurgy for his cooperation in making possible this research work and for his suggestions and assistance in the preparation of this paper.

Professor Lysle E. Shaffer of the Mining Department for suggesting the problem and for his invaluable advice and ever-ready aid during this work.

The Mechanical Engineering Department, the Electrical Engineering Department, and the Buildings and Grounds Department for the use of equipment and shop facilities.

PREFACE

This thesis is submitted to the Faculty of the School of Mines and Metallurgy of the University of Missouri in partial fulfillment of the work required for the degree of Master of Science in Mining Engineering.

The conclusions arrived at in regard to the practicability of utilizing pumps instead of skip haulage for the removal of ore and waste from mines are entirely theoretical, as it was impossible to make actual comparative runs. These results were arrived at by comparing known or estimated costs for both types of operations.

The abrasion studies were conducted in the laboratory of the Mining Department at the School of Mines and Metallurgy.

The pressure tank was designed in an effort to counteract the present necessity for using single stage pumps in sand pumping, and to find a means for eliminating the high rate of abrasion in such pumps.

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INTRODUCTION

Relatively little work has been done on the possibility of pumping ore and waste from mines. Preliminary investigations indicated that two approaches to the problem offered the most likely solutions. The first approach suggested the use of a heavy media into which the crushed ore might be injected and circulated to the surface. This method has been discussed in some detail by C. Erb Wuensch,[1] Consulting Engineer, of San Francisco, California. The second approach called for the utilization of mine water as the transporting medium. This paper confines its efforts to this second method.

Aside from economic reasons, it soon became apparent that two principal factors would hamper the use of pumps to transport ore: First, the relatively low pumping heads - 80 to 120 ft. - for which present day sand pumps are designed; and second, the high rate of abrasion on the component parts of such pumps. In an effort to secure information concerning abrasion within sand pumps the author contacted manufacturers and was informed that no tests had ever been made to determine how pump abrasion varied with the percent of solids being pumped,[2] or in other words, what the most optimum solid-liquid ratio was from the standpoint of pump life. Because of the importance of this knowledge in reducing pump abrasion and because of need for increasing the effective head, the problem was divided into three parts: (1) abrasion studies, (2) pressure tank design, and (3) cost comparison of pump vs. skip haulage.

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[1] Wuensch, C. Erb, Pipeline ore transport may lower mining cost; Engr. and Min. Jour., Vol. 145, no. 4, pp. 91-93, 1944.

[2] Letter from Kimball-Krogh Pump Division of Victor Equipment Company, September 3, 1946.

ABRASION STUDIES

The pump set-up for the abrasion studies is illustrated in Figure 1. The pump used was a Model 100-R Kimball-Krogh rubber-lined sand pump with a $1\frac{1}{2}$ inch suction and a $1\frac{1}{4}$ inch discharge. The pump was powered with a 4 H.P. direct current motor wired into a 220 volt power line. The motor, rated at 1700 r.p.m., was connected to the pump with V-belts and a pulley designed to give a pump speed of 950 r.p.m. The pump speed was held constant by regulating the resistance in the power line with a slide-wire rheostat.

To measure the pressure a Helicoid pressure gauge was mounted above the pump discharge. In order to prevent the gauge from becoming fouled with material from the discharge line a Y-type Leslie self-cleaning strainer and a coil pipe siphon were connected into the gauge line as shown in Figure 1.

The material entered the pump through the return tank mounted above the center line of the pump suction. From the pump the material traveled in closed circuit back to the return tank, from which it again entered the pump. The return tank, which had a sloping bottom built up of concrete, was fitted with a drain through which the system could be flushed after each run. Power and pressure readings were taken every half hour during each run to insure constant conditions. During each run the gauge pressure fell below the initial reading. This is considered to be due, principally to the gradual grinding down of the solid particles from traveling in closed circuit. Table I shows how the readings and data were recorded.

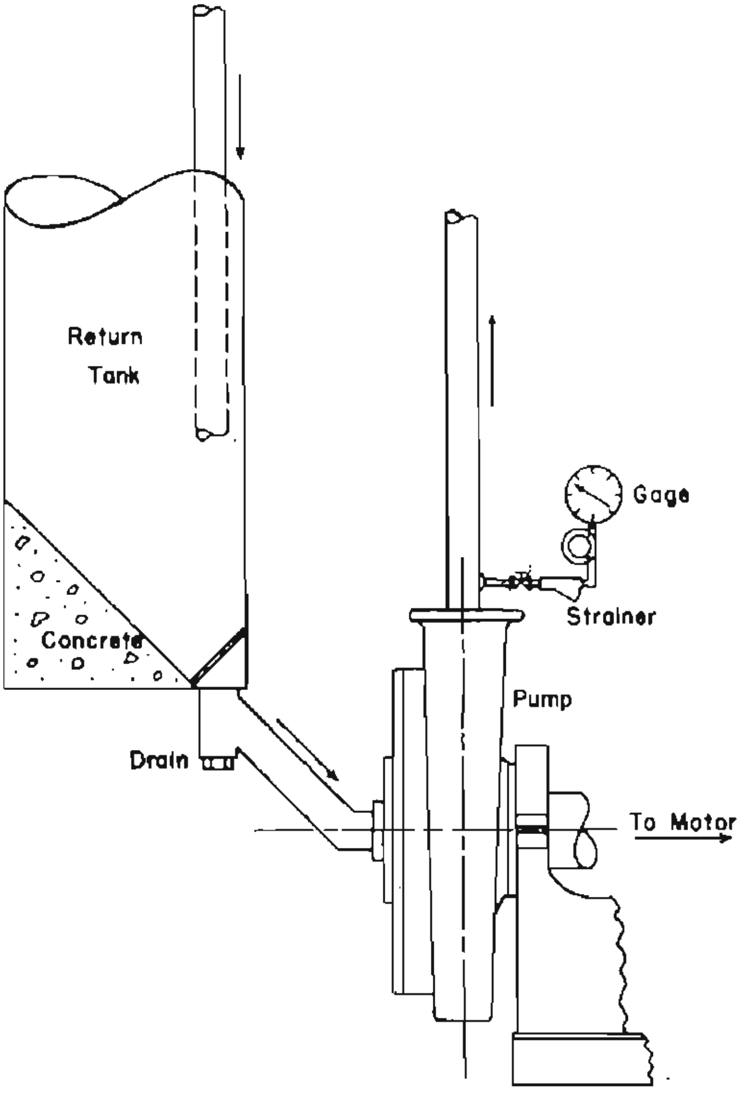


Fig.1

Table I

Granite: 10% Solids (Volume)
January 13, 1947

Granite: 2,088 gms.
Water: 7,200 Ml.

Time	Volts	Amps.	Gauge lb. per sq. in.	RPM
6:00 P.M.	219	5.25	7.75	960
6:30	219	4.47	7.75	950
7:00	218	4.60	7.50	950
7:30	219	4.50	7.75	945
8:00	210	4.50	7.25	950
8:30	215	4.50	6.75	950
9:00	213	4.25	6.50	950
9:30	214	4.30	6.50	950
10:00	223	4.50	5.50	960
10:30	220	4.50	5.25	950
11:00	216	4.50	5.0	950
11:30	217	4.50	5.0	950
12:00 M.	217	4.30	5.0	950

Pump Part	Wt. Before Run (Gms.)	After (Gms.)	Loss (Gms.)
Face Plate	11,351	11,350	1
Impeller	7,070	7,063	7
Casing	30,129	30,108	21

Tests were run with granite, dolomite, and hematite. Large pieces of the individual rocks were crushed, and a screen analysis was made of each type. The specific gravity of each material was determined by a Jolly Balance and a hardness test for each was made. Tabulated in Tables II, III, and IV are the screen analyses for the three types of rock used.

Table II

GRANITE

Sp. Gr. = 2.61
Hardness = 6.0

Screen Analysis

Wt. Sample: 720 gms.   Screen Ratio 1.414

OPENINGS					
Inches	Millimeters	Mesh	Dia. Wire Inches	Wt. Grams	0/0
.185	4.699	4	.065		
.131	3.327	6	.036	152	21.1
.093	2.362	8	.032	97	13.5
.065	1.651	10	.035	92	12.8
.046	1.168	14	.025	63	8.8
.0328	.833	20	.172	51	7.1
.0232	.589	28	.0125	49	6.8
.0164	.417	35	.0122	50	6.9
.0116	.295	48	.0092	35	4.9
.0082	.208	65	.0072	29	4.0
.0058	.147	100	.0042	23	3.2
.0041	.104	150	.0026	21	2.9
.0029	.074	200	.0021	18	2.5
.0029	.074	200	.0021	39	5.4

Table III

HEMATITE

Sp. Gr. = 4.40
Hardness = 5.5

Screen Analysis

Wt. Sample: 578 gms. Screen Ratio = 1.414

OPENINGS					
Inches	Millimeters	Mesh	Dia. Wire Inches	Wt. Grams	0/0
.185	4.699	4	.065		
.131	3.327	6	.036	205	35.8
.093	2.362	8	.032	104	18.0
.065	1.651	10	.035	72	12.4
.046	1.168	14	.025	38	6.6
.0328	.833	20	.0172	29	5.0
.0232	.589	28	.0125	25	4.3
.0164	.417	35	.0122	17	2.9
.0116	.295	48	.0092	12	2.1
.0082	.208	65	.0072	10	1.7
.0058	.147	100	.0042	9	1.6
.0041	.104	150	.0026	9	1.6
.0029	.074	200	.0021	9	1.6
.0029	.074	200	.0021	42	7.3

Table IV

DOLOMITE

Sp. Gr. = 2.68
Hardness = 4.0

Screen Analysis

Wt. Sample: 290 gms.

Inches	Millimeters	Mesh	Dia. Wire Inches	Wt. Grams	0/0
.185	4.699	4	.065		
.131	3.327	6	.036	97	33.4
.093	2.362	8	.032	65	22.4
.065	1.651	10	.035	61	21.0
.046	1.168	14	.025	41	14.3
.0328	.833	20	.0172	26	9.0

The dolomite was considerably softer than the other materials run. It also had a higher percentage of small sizes. Therefore, in order to insure sufficient wear on the pump parts during the dolomite runs, all sizes below -20 mesh were screened out.

The material being pumped was not sized, because in actual practice this would not be feasible. The percent of solids was calculated on the basis of volume displacement and was the only variable factor during the runs. All other conditions were held as constant as possible. A sample calculation for percent solids by volume is shown below:

Granite: 10% Solids (Volume)

System: 8000 Ml. H_2O

$8000 \times .10 = 800$ Ml. H_2O to be displaced

$800 \times 2.61 = 2{,}088$ gms. granite

8000 Ml. $- 800$ Ml. $= 7{,}200$ Ml. H_2O

Because of the uncertainty of how long a pump run would be necessary to effect a measurable amount of abrasion within the pump, two trial runs of 12 hours were made. The abrasion in 12 hours was found to be enough to warrant cutting the runs to 6 hours. Originally, the material pumped included everything that passed a 3-mesh screen. This worked well for 10 percent solids and 20 percent solids; however, when an attempt was made to pump 30 percent solids, the high concentration of large particles attempting to enter the throat openings of the impeller caused it to clog. This was solved by eliminating all material over 4-mesh. In order to insure adequate abrasion when pumping relatively soft dolomite, only plus 20-mesh material was pumped.

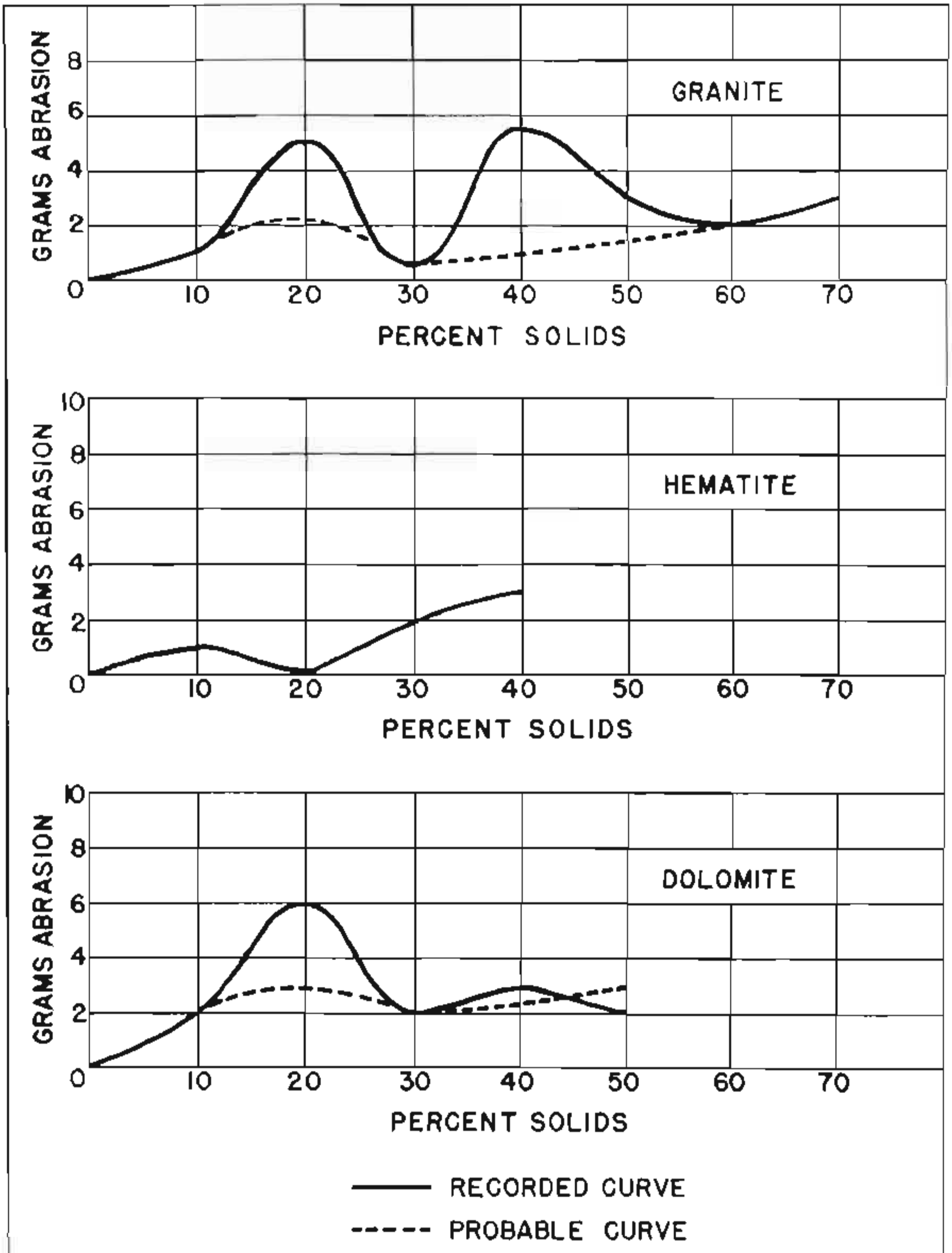
Some trouble was experienced at first by air locks forming in the pump. These were caused by entrapped air being carried into the pump from the return tank. The installation of a baffle plate at the bottom of the return tank eliminated this source of trouble.

After each six-hour run the pump was dismantled into three parts: the face plate, the impeller, and the casing. The face plate and the back plate on the casing were rubber lined. The case itself was made of an unhardened semi-steel similar to Mechanite. The impeller was made of white cast iron. After each run the parts were throughly washed and dried. The abrasion on each part was then measured by weighing on an O'Haus scale to determine the loss of weight in grams. The loss of weight in grams for each part of the pump is tabulated in Table V.

Table V

Percent Solids	Impeller	Face Plate	Casing
	GRANITE		
10	7	1	21
20	13.5	5	21
30	9	0.5	43
40	11.5	5.5	40
50	14	3	57
60	20	2	63
70	51	3	70
	HEMATITE		
10	15	1	28
20	35	0	61
30	42	2	71
40	57	3	69
	DOLOMITE		
10	5	2	24
20	7	6	6
30	6	2	18
40	11	3	25
50	21	2	39

The abrasion curves in Figure 2 illustrate the recorded and probable paths of abrasion of the face plate when pumping granite, hematite, and dolomite.



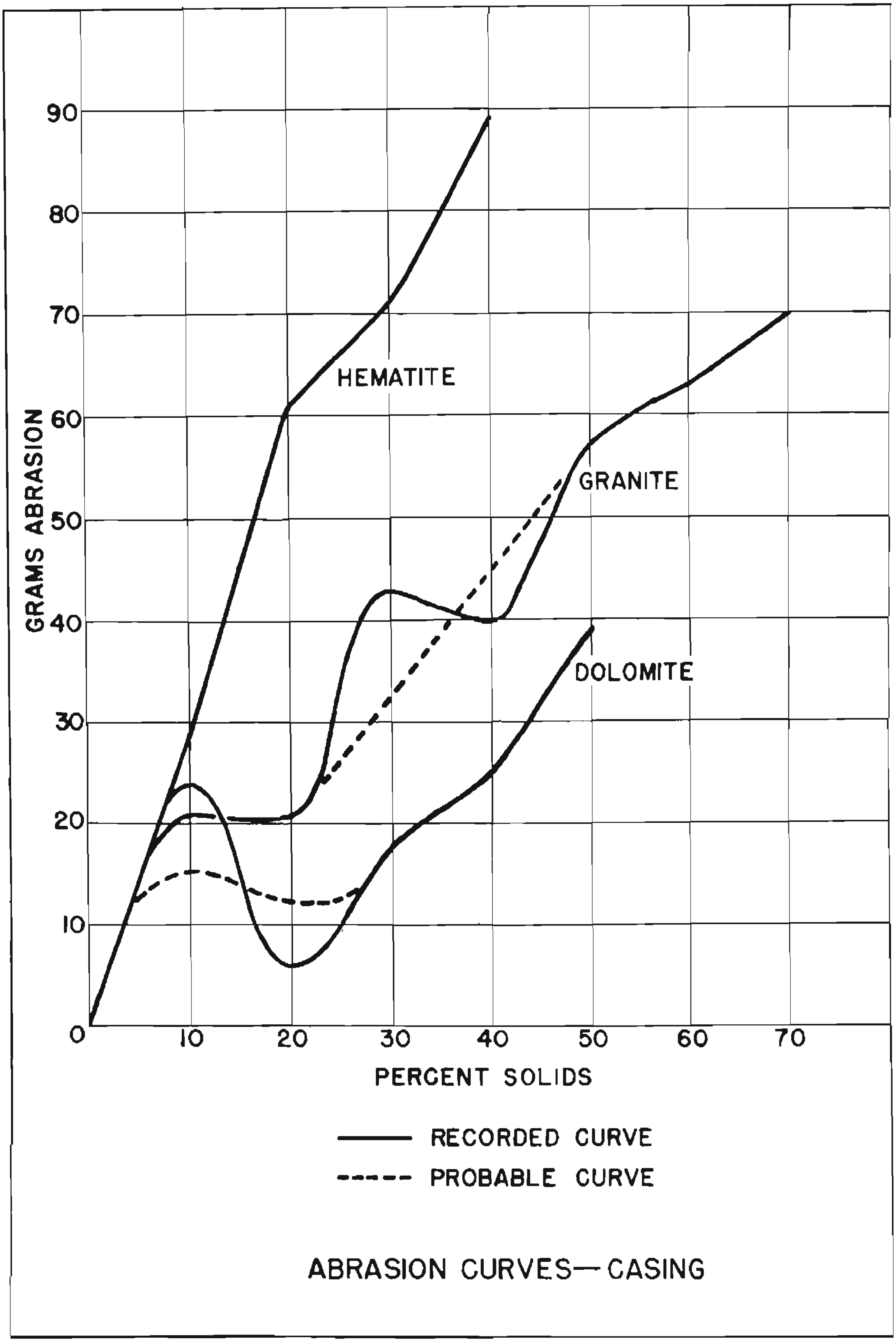
ABRASION CURVES—FACE PLATE

Fig. 2

The ordinates of the curves in Figure 2 are purposely exaggerated in comparison to the abscissas because of the small amount of lose of weight incurred by the face plate. This small loss is due in part to the hard rubber with which the face plate is coated and in part to the lack of contact with abraiding particles. Not only does the hard rubber tend to absorb shocks from the particles, but the location of the face plate with relation to the impeller makes it difficult for large particles to collect between the face plate and the impeller. The irregularities in the curves apparently represent distorted abrasion and will be explained in further detail with relation to Figure 5. If, however, the lines of the probable curve are followed, it will be noted that the optimum percent solids for pumping from the view-point of wear on the face plate is at 30 percent solids for both granite and dolomite. For hematite the optimum is 20 percent solids. This variance is due possibly to accidental lack of normal particle concentration next to the face plate during the hematite runs. Actually, for practical purposes, all three curves are similar. Moreover, when we consider that abrasion on the face plate is negligible in comparison to wear on the other pump parts, the face-plate curves can be disregarded except for check purposes.

Figures 3 and 4 illustrate the recorded and probable abrasion curves for the pump casing and impeller respectively. In general these curves follow a pattern similar to those in Figure 2, showing an optimum solid - liquid ratio in the 20 percent to 30 percent range of solids.

Figure 5 illustrates the recorded, probable, and distorted curves for granite. When a fluid containing 40 percent granite solids was pumped the measured abrasion for the casing and impeller made a decided jump. This was particularly apparent for the impeller. When the pump was dismantled



ABRASION CURVES— CASING

Fig. 3

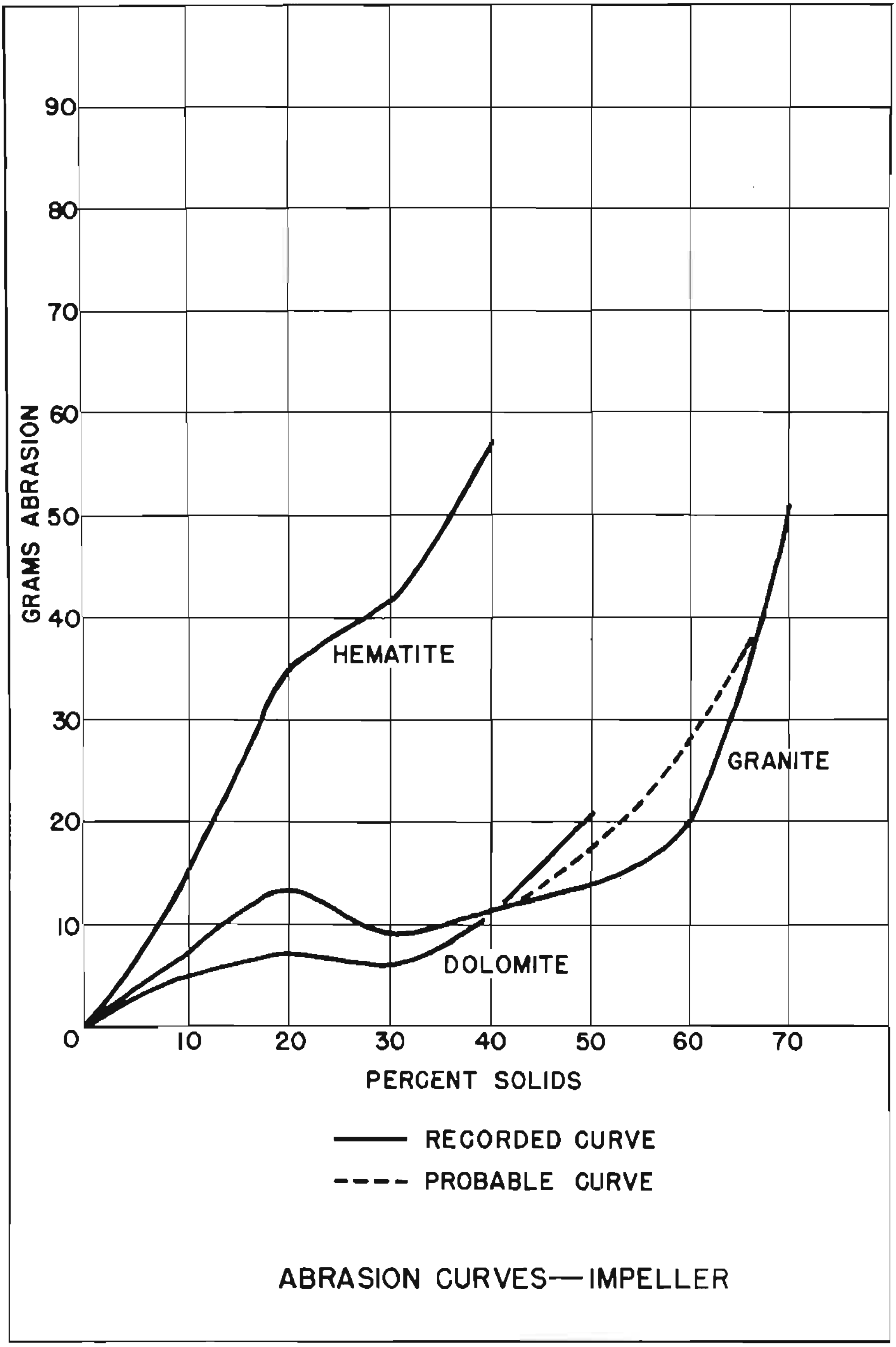

GRAMS ABRASION
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
PERCENT SOLIDS
HEMATITE
GRANITE
DOLOMITE
RECORDED CURVE
PROBABLE CURVE
ABRASION CURVES—IMPELLER

Fig.4

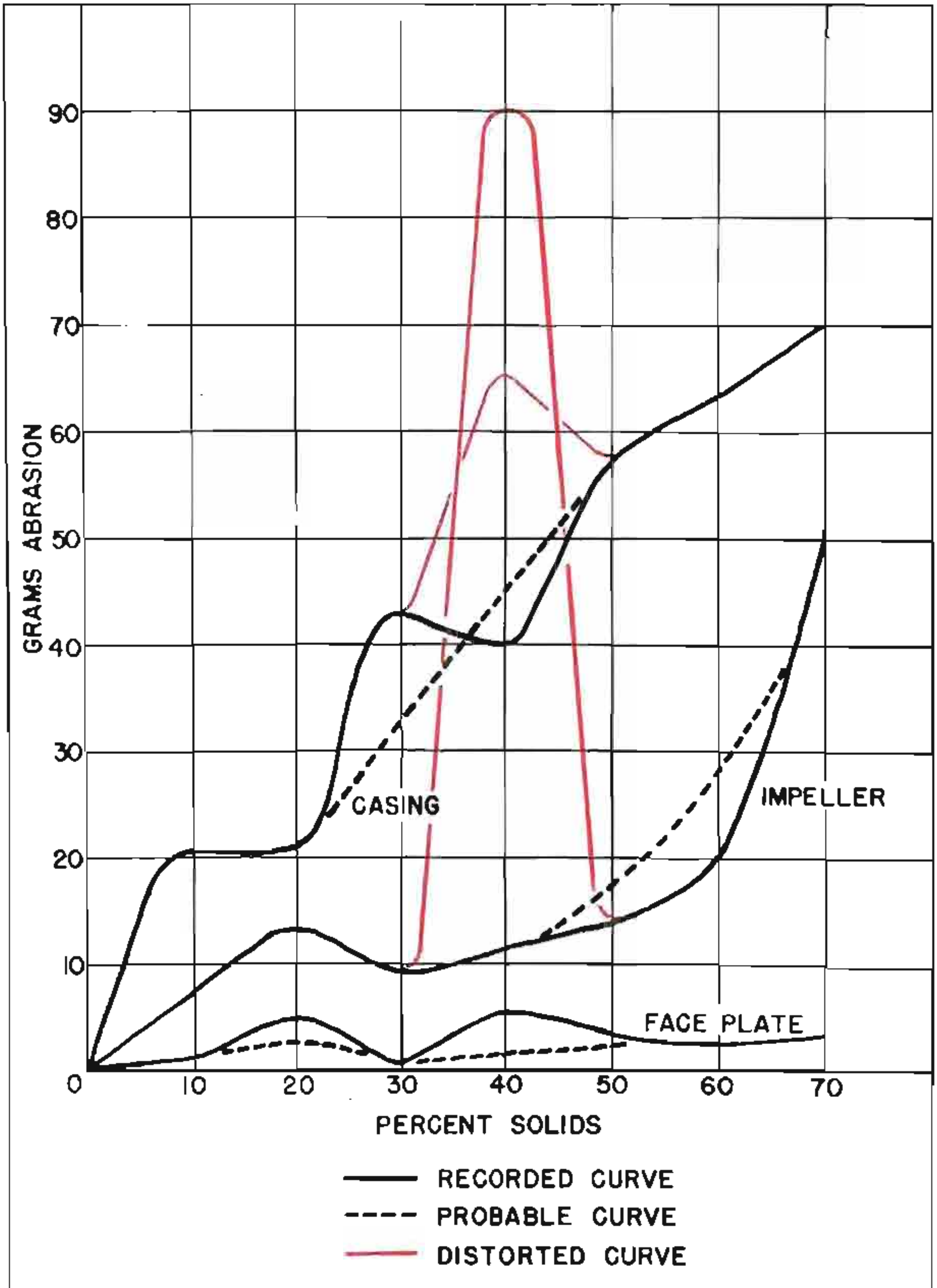

GRAMS ABRASION
0
10
20
30
40
50
60
70
80
90
PERCENT SOLIDS
0
10
20
30
40
50
60
70
CASING
IMPELLER
FACE PLATE
RECORDED CURVE
PROBABLE CURVE
DISTORTED CURVE
ABRASION CURVES—GRANITE

Fig. 5

after that run it was noted that the impeller and rubber facing on the casing had several deep circular grooves cut into each part. This was considered to be due to large particles becoming lodged between the two parts. Realizing that the measured abrasion on these parts was undoubtedly abnormal, a re-run was made. The results of the re-run were accepted as approximating the correct value and were recorded as such. The principal significance of the re-runs was to illustrate the ease with which an abrasion curve might be distorted from the normal. The test also shows how pump life would be materially shortened if particles became lodged between the parts during commercial pumping. It should however be pointed out that much of the danger from this source would be eliminated if the material was ground finer.

Ideally, the different abrasion curves should be expected to follow a definite pattern similar to the ones actually followed. Abrasion should rise rapidly until a fluid containing approximately 20 percent solids is being pumped. From zero to 20 percent is the range of relatively free movement of particles in the liquid medium. In this range abrasion is caused by the impinging of fast moving particles against the pump parts. When the percent of solids is, however, further increased the particle concentration becomes so high that free movement of the particles is restricted. When particle movement is restricted, particle velocity decreased, and, as a result, the rate of abrasion decreases. If particle concentration is increased beyond this percentage a point is reached where abrasion by grinding takes place. Hence beyond this point the curve should behave as a straight line and rise rapidly as the percentage of solids is increased. Neglecting distortion, it will be seen that the curves of Figures 2 to 5 behave exactly as should be expected.

PRESSURE TANK

When this investigation of ore and waste pumping was undertaken it soon became apparent that high abrasion on pump parts, and the relatively low head of 80 to 120 ft. attainable by sand pumps would render the problem impractical. Although high heads could be obtained by pumping in stages, this would require the installation of extra pumps and increase the number of parts undergoing heavy wear. High-pressure water pumps that are capable of pumping against high heads might be used but none of these pumps are designed to handle solids. The most obvious solution is the use of some sort of pressure tank to inject the feed into the pump line under pressure after the water has left the pump. This solution would make possible the use of high pressure water pumps capable of pumping against high heads and would also eliminate the high wear on pump parts from particles passing through the pump. The desirability of a pressure tank coupled with the pump soon became obvious; otherwise a separate pump would be necessary to obtain the required pressure for operation of the tank. With these factors in mind, the pump-pressure tank arrangement as illustrated in Figure 6 was developed. The most optimum-size relationship of pressure tank to pump was not worked out. The principles involved are however, illustrated, and when tested the arrangement proved to be a complete success. To operate the pressure tank, valves A, B, C, and D are first closed. In the pump the water from the water tank attains a high velocity head. Upon leaving the pump this velocity head is largely converted into pressure head. However, when the water reached the venturi the velocity head again rises, with a consequent localized reduction in pressure head. After the pump is in operation valve A is opened and the pressure tank is partly filled with feed. Valve A is then closed. Valves B and D are then opened simultaneously. The tank fills with water immediately and the pressure head in the tank becomes equal to that at the pump discharge. Inasmuch as this pressure head is greater than that in the venturi, the feed in the tank is immediately forced out through valve D into the main line. When the tank is empty, valves B and D are closed and valve C is opened so that the water level in the pressure tank can be lowered to admit more feed through valve A. The cycle is then repeated. In practice it was found that material could be fed into the tank and the tank emptied into the line as fast as it was possible to operate the valves manually. Two or three such tanks arranged in series along a line and with valves operated automatically would eliminate the intermittent flow of feed present when only one tank is used.

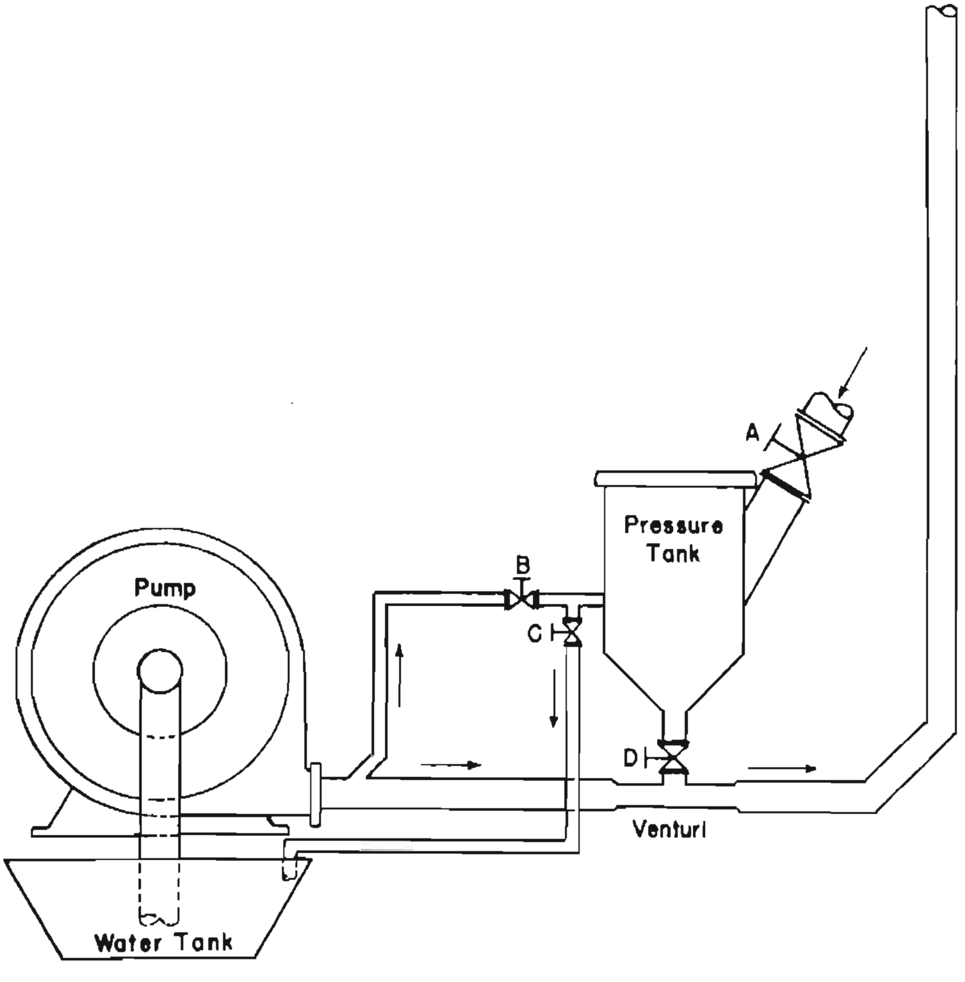


Fig. 6

COST COMPARISON OF PUMP VS. SKIP HAULAGE

Any economic analysis of pumping vs. skip hoisting must also include a general discussion of the related problems involved. The various factors involved in skip haulage have been well worked out in the past. Such is not the case for pumping. Only a general cost analysis is possible here because the pumping of each ore considered will, of necessity, be a separate problem. For any ore, however, the general considerations will be the same. It must be remembered that the velocity of the water must be greater than the settling velocity of the largest or heaviest particles being pumped. The entails a study of the hindered settling characteristics of the particular ore in question. The settling velocities of the particles in question are determined for the most part by the specific gravity, the size, and the shape of the particles. Of two particles having different specific gravities, that having the higher will fall faster. Also, with two particles of different size, the settling velocity of the larger will be greater. Round particles will settle faster than long narrow particles or flat particles. Inasmuch as it is necessary to increase the velocity of the liquid medium as the size and weight of particles increases, power costs rise rapidly. It therefore becomes economical to crush to smaller sizes underground. The logical development of this would be the installation underground of equipment with which a rough concentrate of the ore could be made. This might be accomplished by sink-float, Humphrey's spiral, or other equipment suited to the nature of the ore. The tailing resulting from the rough concentration could then be returned to the stopes for fill. With such an arrangement, it is probable that many mines would find it practical to raise less than half the volume of material to the surface than is now necessary. Other benefits resulting from such an arrangement would include: (1) lower shaft sinking costs because of the elimination of large shafts; (2) utilization of slower speed, less expensive hoists; (3) smaller headframes; (4) the elimination of skip pockets; and (5) continuous feed to the treatment plant; and (6) no interference from hoisting men and supplies.

An adequate supply of water would be necessary. The quantity required will vary with the amount of material to be pumped, but it should approximate 70 percent of the total volume. If an insufficient amount of mine water is available, water could be brought in from the surface. The pressure from the static head of the column of water from the surface actually would aid the pump and reduce the amount of work necessary for the pump to perform. This would be true, of course, only if the static column was connected into the pump suction.

In those properties where pumping is already a problem, the cost of installing an ore pumping system would be relatively low. The principal expense would be the costs of crushers, rough ore concentration equipment, and pressure tanks. At properties where pumping is at present a minor problem, the construction of larger pumping units probably would be necessary.

Pipeline abrasion would be a definite factor to be reckoned with. Pumping through drill holes might be possible in some types of ground; in that event abrasion would not matter. The use of rubber lines pipes gives very satisfactory results.

Friction heads for rubber lined pipes are about one third less than friction heads for smooth pipe. Efficient transportating velocities for material 8 mesh or under ranges from 3 feet per second for 1 inch pipe to 9 feet per second for 32 inch pipe. At the efficient transporting velocity the loss of head due to friction is approximately given by the formula: Total loss of head in feet per 1000 feet = loss of head due to water alone at the efficient transporting velocity plus a constant times the percent of sand carried. The constant ranges from 2 for a 10 inch pipe to 3 for a 4 inch pipe.

Indicated direct costs:

Pumping:

Rubber lined pipe approximately $12.00/ft.

Pump cost ≠ pipe and equipment = $2500.00 (100' head)

Pump cost ≠ pipe and equipment = 15,000.00 (1000' head)

Cost of pumping = 2¢ to 5¢/ton

Hoisting:

Hoist cost ≠ equipment = $5000 to $25,000

Cost of hoisting = 8¢ to 15¢/ton

These costs are approximate. Because of unsettled economic conditions today prices are difficult to estimate accurately. Cost advantages are however definitely in favor of pumping. Lower shaft sinking costs for pumping, lack of expense in cutting skip pockets, etc., are factors difficult to evaluate but are considerations that must be weighed by an operator for a problem of this nature. Crushing expense would be slightly greater for pumps. These costs would naturally vary widely with the nature of the ground, timber costs, etc., present at individual properties.

CONCLUSIONS

Several worth-while conclusions can be drawn from the results of the foregoing work.

1. From the viewpoint of abrasion on pump parts, approximately 30 percent solids by volume is the most economical solid-liquid ratio.

2. Elimination of abrasion on pump parts can be obtained by means of a pressure tank.

3. A pressure tank makes possible the use of multistage pumps by means of which high heads can be obtained.

4. Pumping of ore or waste from mines is not practical unless a form of pressure tank is used for injecting the feed into the pump line on the discharge side of the pump.

5. A decided savings is indicated where pumps are used in place of skips.

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VITA

The author was born on October 10, 1918 at Muskagee, Oklahoma. His elementary school education was completed at Tacoma, Washington. He was graduated from Stadium High School, Tacoma, Washington in June 1937. After graduation from high school he went to work in the mines. In order to gain well rounded experience he worked as a "tramp miner" and was employed at many mines in Alaska and most of the western states. He is familiar with many different systems of mining. He has worked as a mucker, a drift miner, a raise miner, a stope miner, a shaft miner, a timberman, and a millman. He attended Washington State College at Pullman, Washington for two years. He was graduated from the Missouri School of Mines at Rolla, Missouri in June 1946. He is a Junior Member of A.I.M.E.