THE EFFECT OF SUPERSONIC WAVES ON PHOSPHATE ROCK SUSPENDED IN WATER

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THE EFFECT OF SUPERSONIC WAVES ON PHOSPHATE ROCK SUSPENDED IN WATER

Summary

Purpose and Scope

The purpose of this investigation is to study the effects of supersonic waves on a suspension of phosphate rock in water. This study is to be the basis for the construction of a particle size analyzer which is to be used in the investigation of the separation of small phosphate rock particles from water. This analyzer is to be used on particles too small for the usual size separation equipment. The aim of the present work is to build and test apparatus which will introduce supersonic waves into a suspension of phosphate rock in water and to determine the effect of this motion on the rock particles.

Previous Work

There has been no previous work of a related nature on phosphate suspensions. Powdered quartz has been coagulated from organic liquids by waves at frequencies near 200,000 cycles per second [1]. The wave motion was obtained from a piezoelectric quartz crystal immersed in a bath of transformer oil. Particles which are several microns in diameter accumulate rapidly and settle out, but those less than a micron in diameter are not affected.

Present Work

A magnetostriction oscillator is the source of the supersonic waves used in the present investigation.

1. Sollner, Karl, J. Phys. Chem., 42, pp. 1071-1077 (1938)

The wave motion is translated to the phosphate suspension by means of a paddle which is screwed to the magnetostriction driving rod. The frequency of each magnetostriction rod is fixed; so stainless steel rods which gave frequencies of 300,000; 263,000; and 57,000 cycles per second were made. These rods were then used to find the effect of the wave motion on a number of different phosphate rock suspensions. Samples of the original suspension and of the clear solution from the top of both the normal and activated systems were taken. The particle sizes in these samples were determined by microscopic analysis.

Results and Conclusions

In general, the present work is not sufficiently adequate or accurate to use as the basis for the construction of a particle size analyzer. However, there were some definite results observed which may be of interest in future investigations. These conclusions are tabulated below.

1. Supersonic waves hold particles in suspension that would normally settle out.

2. The suspended particles are in the 5 to 10 micron range and are held up by all three wave frequencies.

3. Supersonic waves slow down the rate of settling.

4. Particles held suspended by wave motion settle out when the oscillator ceases to operate.

5. The wave motion obtained in this work affected only the smallest particles of the material used. Also,

only a small percentage of the total number of small sized particles present in the original suspension was affected. Therefore, the conclusion is drawn that the present wave motion is not in the right range nor strong enough to be used in the particle size analyzer.

6. The calibration of the wave lengths of the rods is not to be relied upon since the rods change in frequency when the capacitance of the air condenser is changed.

7. The data on the rates of settling are subject to many errors and are therefore only an indication of the effect of supersonic waves on settling of phosphate rock particles.

8. This work compares with that of Sollner[1], in the particle sizes affected by waves of the frequencies used.

9. The oscillator causes disturbances in neighboring radio sets.

Recommendations

Even though the present work was not completely successful, future work may be contemplated and for this reason the following recommendations are made in the hope that it will prove of value to future investigators.

1. Make magnetostrictive rods which will give a range of vibrations from 25,000 to 250,000 at intervals of 25,000 cycles per second.

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1. Op. Cit. p. 1077

2. Since each rod has different circuit characteristics, the proper size coil and condenser should be determined for each of the above mentioned rods so that a strong and stable oscillation can be obtained under operating conditions.

3. Investigate the change in frequency with change in capacitance of the variable air condenser.

4. Study the effect of increasing the depth to which the paddle is submerged on the particle size and the settling rate.

5. Determine the relationship between paddle area and intensity of vibration in the suspension.

6. Determine the relationship between the size, density, and frequency of vibration of the particles.

7. Investigate the possibility of separating particles of the same size which have different densities.

THE EFFECT OF SUPERSONIC WAVES ON PHOSPHATE ROCK SUSPENDED IN WATER

Introduction

Phosphate ore is sometimes found as fine particles of rock bonded together by a matrix. The size of these particles is such that recovery is difficult if not impossible in ordinary milling operations. The ore is usually low grade material and has had little commercial value because of the milling conditions. The Chemical Engineering Department of the University of Tennessee has undertaken an investigation of the recovery of this phosphate.

A particle size analyzer is needed in this investigation to cover the range of particle sizes below the smallest available test screens or similar sizing equipment. This analyzer, as originally planned, was to make use of supersonic wave motion in separating particles suspended in water.

Particles of like size, shape, and density should be settled out by waves of a fixed frequency and particles having different characteristics should be settled out by different wave frequencies. Therefore, it was hoped that a circuit could be set up in which the frequency could be altered by changing some of the circuit constants. Thus a calibration of the circuit variables in terms of particle sizes affected would give a satisfactory means of analyzing

samples of phosphate suspensions for particle size.

The present problem is to introduce wave motion into a phosphate suspension and to study the effect on the solid particles. A magnetostriction oscillator is the equipment used in this work to introduce supersonic waves into the phosphate rock suspension.

Previous Work

There are two main parts to the present problem. The first is the construction of the oscillator and the second is the determination of the effect of supersonic waves on phosphate suspensions. Therefore, there are two lines of investigation that have to be studied from previous work. This section is therefore, divided and listed under two section heads.

Ultrasonic Waves in Colloid Chemistry

Sollner(1) found that a quartz crystal 7 centimeters in diameter and 1 centimeter thick, when placed in an alternating circuit, oscillated at a frequency in the neighborhood of 200,000 cycles per second. The crystal he used was placed on a lead electrode and was covered with a brass ring electrode and the whole assembly was then placed in transformer oil. When an alternating current was then applied to the electrodes, the crystal, being piezoelectric, vibrated. This vibration was transmitted to the oil and a fountain of vibrating oil was obtained. Particles of quartz

1. Op. Cit., pp. 1071-1078

powder suspended in organic liquids were placed in test tubes and the test tubes were immersed in the fountain of vibrating oil.

The quartz particles which were several microns in diameter accumulated practically instantaneously and settled out in a few seconds. The smaller particles, less than one micron in diameter, were hardly affected by the frequency employed.

Sollner describes the action of the ultrasonic waves on the quartz suspension as follows[1]:

> "The coagulating action of the ultrasonics is now easily understood; firstly, the particles are accumulated and, as one knows, the rate of spontaneous coagulation increases rapidly as the concentration increases; secondly, particles of different size migrate with different velocities towards the zones of accumulation, thus being liable to additional collisions, a kind of orthokinetic coagulation; thirdly, the particles do not migrate only in one direction, their macroscopic movements merely being the result of the assymetry of the oscillations which they perform according to their (different) size; this too causes a kind of orthokinetic coagulation".

The Magnetostriction Oscillator

One method of introducing supersonic waves into a liquid is by transferring energy to the body of the liquid from an external oscillator. One of the most feasible plans for getting the necessary high frequency vibrations is to use radio oscillator tubes. The apparatus chosen uses a radio circuit with a magnetostriction driving rod in the tank coils

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1. Op. Cit. p. 1077

of a modified Hartley circuit.

The principle of the magnetostriction oscillator depends upon the relation between mechanical stresses in a rod of magnetostrictive material and the magnetic field in a surrounding coil. The magnetization of magnetostrictive materials (monel metal, invar, stoic metal, nichrome, and stainless steels) will cause a change in length of the material. The change in length is a function of the amount of magnetization. The frequency at which the rod oscillates varies inversely with the length.(2)

The simplest circuit is essentially a Hartley series radio system. The polarity of the tank coils is reversed and a magnetostrictive rod is inserted through the coils. A small condenser is placed across the source of direct current, and the tube filament is heated by an external A.C. circuit. A variable air condenser is placed across both plate and grid circuits instead of just one.

Pierce(1) says that the alloys of nickel and iron are good vibrators; the best being 36 percent nickel and 64 percent iron. Commercial nichrome is another good magnetostrictive material. If a small horseshoe magnet be held near the end of a monel metal rod, this also will be a very powerful oscillator. All of the vibrators are made more powerful by annealing.

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2. Eastman, A.V., Fundamentals of Vacuum Tubes, McGraw-Hill Book Co., Inc., N.Y. (1937) Chapter VIII pp. 291-293.

1. Pierce, G.W., Magnetostriction Oscillators, Proc.Ins. Radio Eng., 17 (January, 1929) pp. 42-88.

The highest frequencies are hard to obtain with ordinary rods because they must be very short. Pierce also found that a beaded rod of stainless steel 1.26 centimeters in diameter and 9 centimeters long with each bead and each groove 1 centimeter long and the grooves turned to half the diameter of the rod would give a stable oscillation at 295,480 cycles per second. The tank coils used with this rod were composed of 200 turns of wire and were placed over adjacent beads or had one bead between them. The rod was free within the coils and could have a clearance as large as its own diameter.

Principles of Operation

Brown[1], an English botanist, found that very fine particles of solids suspended in water were constantly in motion due to the bombardment of the water molecules. The motion occurs because the bombardment by the water molecules is not the same on all sides. This Brownian movement causes some particles to collide with others, and under certain conditions, the colliding particles stick together. If enough collisions occurred, the particles would be built up until they became large enough to settle out. This is not the exact basis for the present study, but is perhaps the nearest related theory to the effect of supersonic waves on fine particles. The present work is an attempt to increase the motion of phosphate rock particles by a mechanical addi-

1. Getman & Daniels, Outlines of Theoretical Chemistry Chapter X, p. 201.

tion of wave motion in the liquid and thus increase bombardment of the particles by waves derived from supersonic oscillations.

Brown found that different particles move with different velocities and that the finest moved the most rapidly. He also found that the velocity is inversely proportional to the size. In the present work it was expected that particles of different sizes would be activated by different wave frequencies and there would be a relationship between the particle size and the wave frequency.

Description of Equipment

The equipment may be grouped into three general classes: (1) The electrical equipment which is used in the oscillator circuit. This circuit and arrangement of equipment is shown in Figure 1 of this report. (2) The mechanical equipment used to transform the electrical oscillations into mechanical motion in the liquid and thus impart motion to the phosphate rock particles suspended in the liquid. Auxiliary laboratory equipment is also included in this group. The assembly of this equipment and the detailed drawings of the special equipment is shown in Figure 2 of this report. (3) The description of the starting suspensions of phosphate rock and water. The description of the samples of original material and fractions of the resulting suspensions from normal and activated settling will be found in Table 1 and the particle size analysis of these samples is listed in Table 2.

Electrical Equipment

1. Two way, two pole switch. This switch has copper poles and a 4 by 1-3/4 in. porcelain base.

2. Weston milliammeter. Model 301 of the Weston Electrical Equipment Company.

3. General Electric Capacitor Model DL3905756. Maximum voltage - 450 volts D.C. Capacitance 0.100 microfarads

4. A 21 plate variable condenser having a maximum capacitance of about 300 micro-microfarads.

5. Tube base. Type 158 of the General Radio Co.

6. Tube. No. 10 of Hygrade Sylvania Corporation.

7. Voltmeter. General Electric Company Type A0-21 Model 8A021VALT.

8. "Truetest" transformer Type 2584 of the Lafayette Radio Manufacturing Company.

9. Power unit which will deliver 375 volts of direct current at no load. The normal current drawn from this unit is 8.8 milliamperes.

10. The coils are composed of 200 turns of 0.012 in. diameter copper wire wound on a fiber cylinder. The wire is insulated with a cloth cover and each layer of wire is insulated from the next by a coat of insulating varnish. The fiber cylinder is 3/8 in. long, 5/8 in. inside diameter, and 1/8 in. thick. The outside diameter of the coil is approximately 1-1/4 in.

11. Fixed resistance coil of 56 Ohms resistance.

12. Variable resistance. This is connected in series with No. 11 and is used in the tube heater circuit to control the voltage.

Mechanical Equipment

13. Magnetostrictive Rods These rods are used in this investigation to translate electrical energy into mechanical motion. Each rod oscillates at one frequency so a number of rods were made so that a variety of frequencies could be obtained. These rods are designated by number and will hereafter be referred to in that manner. Detail drawings of the rods are shown in Figure 2.

a. Number 1. This is the beaded rod made to the specifications of Pierce[1]. It is made of 18-8 stainless steel round bar stock. The outside diameter is 0.495 in. This is the diameter of the beads, each of which is 0.393 in. long. The five beads are joined by four cylinders each 0.393 in. long and 0.247 in. in diameter. One of the end beads has 1/2 by 20 NF threads turned the whole length of the bead. The overall length of the rod is 3.541 in. It oscillates at 300,000 cycles per second.

b. Number 2. This rod was turned from heat-treated stainless steel round bar stock like that used for rod number 1. This one is 1.505 in. long and 0.496 in. in diameter. A 1/2 by 20 NF thread is turned 0.281 in. long on one end. A slot 0.093 in. wide and 0.084 in. deep is turned between the

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1. See page 9.

threaded section and the main part of the rod.

c. Number 3. This rod is exactly the same as number 2 except that the overall length is 2.002 in. and the width of the slot is 0.115 in.

14. Connecting Rod. This rod was turned from 3/4 inch round cold-rolled steel. It is 3.5 in. long. The diameter is reduced to 0.375 in. 0.125 in. from the lower end and 0.500 in. from the other end. The latter end is bored and threaded for 1/2 by 20 NF threads to a depth of 0.393 in. The opposite end is drilled and tapped for 1/4 by 20 NC threads to a depth of 0.750 in.

15. Paddle. This is a two inch square plate cut from a piece of 1/8 inch thick steel. A 1/4 inch hole is drilled through the center of the paddle. It is fastened to the connecting rod by a 1/4 by 20 machine screw which is 5/8 inch long.

16. Auxiliary Equipment included a laboratory ringstand, clamps, adapter clamps, a 400 cubic centimeter beaker, a watch, a 25 cubic centimeter pipette, and a scale graduated in 1/16 of an inch.

Phosphate Suspensions

About 1,000 grams of phosphate rock from the Voorheis Tract (Sample MV-1 F.S. Osborne 11/30/39) was screened and all material was ground on a steel plate with a bucker until it passed through a 325 mesh Tyler screen. This phosphate was

then mixed with about two liters of distilled water. The suspension was allowed to stand for five minutes and then 400 cubic centimeters of the liquid at the top was siphoned off. This suspension is known as number 1. At five minute intervals three more samples were drawn off and these are designated as II, III, and IV, respectively. Suspension number V was made from 0.5 pound of the dry phosphate rock (-325 mesh) and 5.0 pounds of distilled water. Suspension number VI was made by adding number II and number III after they had been used for earlier runs.

Procedure

Heat-treatment of Rods

A bar of 18-8 stainless steel 1/2 inch in diameter and 4 inches long was placed in a furnace whose temperature was regulated at 1065 degrees centigrade. Twenty minutes later the rod was quickly thrust into cold water and stirred around to insure uniform cooling.

Measurement of Rod Frequencies

The Chanalyst of the RCA Dynamic Demonstrator was used to measure the frequency. The wavemeter connection was hooked into the plate circuit. The dial was set at the lowest frequency and then readings were taken at the maximum points of the voltmeter reading as the frequency was increased. From these readings the fundamental frequency of the rod was determined.

Settling Data

The two coils were clamped in a horizontal position with one above the other. A piece of rubber about 3/8 inch long was put on the end of the rod and this end was then clamped with a laboratory clamp so that the rod was in a vertical position and through the coils. The beaded rod was so adjusted that the coils were over the second and fourth beads. Then the paddle was fastened to the connecting rod and the connecting rod was screwed on the magnetostriction driving rod. The 400 cubic centimeter beaker was placed under the paddle and the whole unit was adjusted so that the liquid suspension could cover the paddle.

The 110 volt current was turned on the filament circuit and the variable resistance adjusted until the AC voltmeter reading was 7.5. The 110 volt current was turned on the power unit and the line switch at the unit was turned to the oscillator circuit feed. When the run was started the two-pole switch was closed and the variable air condenser was changed until a maximum milliammeter reading was obtained. The oscillator circuit was then operating under test conditions.

When the run was started, the well-mixed phosphate suspension was poured into the beaker until it covered the paddle 3/8 inch, and more suspension was poured into a similar beaker until the liquid level was approximately the same as that in the other beaker. The height of the liquid in each was taken at zero time and then the height of the interface between

the clear liquid on top and the suspension in the bottom was recorded for both beakers at regular intervals. When the height of the interface became constant, the run was terminated and samples were taken.

Sampling

Samples of the liquid above the interface were taken by pipetting small amounts of the liquid from the part under the paddle. Samples of the original material were taken in the same way from the well mixed phosphate suspensions. The slides for the microscopic measurement of the particle sizes were made by putting drops of the sample on a clean slide and drying them over a small flame. In the case of the very dilute samples, more than one drop was used, but the slide was dried between drops.

Particle Size Measurement

The slides were placed on the mechanical stage of a petrographic microscope whose scale had been previously calibrated with a standardized scale slide. Then all the particles of one of the sizes in the size scale were counted in a definite area. The particles of all the other selected sizes were also counted and then all were reported as the percent of the total number. Particles less than a half size larger were counted as the next lowest size, but those more than a half size larger were counted as the next larger size. All particles less than five microns were grouped together. The size scale was selected from a study of the actual sizes found in one of the original samples.

Results and Conclusions

A study of Table 3 shows that in 71 percent of the runs the activated suspensions had a slower settling rate. The two runs which were exceptions to this statement had the paddle against the beaker and this may have had some bearing on the results. Therefore, it seems that the beaker itself may have vibrated and thus settled the denser portion of the suspension more rapidly. In the run marked (d) in Table 3-C the one inch diameter disc was used as the paddle and by comparing it with (c) it can be seen that the smaller paddle had less effect on the settling rate.

It was found that the frequencies of the two cylindrical rods changed with small changes of the variable air condenser. Since no readings of the setting of this condenser during runs were made, it would be incorrect to state that the rods were vibrating at the values found at the end of the investigation in the calibration by the Chanalyst. The frequency of the beaded rod seemed to be much more stable, but was in the range of 300,000 cycles per second. The threads on one bead may have caused this slight discrepancy. The previous work on magnetostriction[1] showed that changing the condenser, plate current, and even the tube itself was not enough to alter the frequency more than a few cycles in 100,000.

1. Pierce, G.W., Proc. Ins. Radio Eng., 17, pp. 63-64

Therefore, the circuit must be studied and a thorough understanding of the operation and limitations is the most important point in any subsequent investigation.

Since the frequencies are not too well known, it is almost impossible to state that one frequency affected any one size of particle. It can be seen from Table 3 and Figure 4 that all activated suspensions had more particles left in the top than the perfectly clear liquid from the top of the normal settling samples. It may also be seen that some mutual activation occurred because a sample was taken from the top of each of the first four solutions under conditions of normal settling and the one having the most color (sample No. 7) was reported to have only foreign organic matter and dried soluble material which in all probability came from the water. The normal settling samples taken when the normal was run with the activated showed some particles in the five micron range. The activated samples had from one to forty-five percent more particles in suspension than even these normal samples so it may be definitely stated that the range of frequencies used held up particles of the 5 to 10 and even 15 micron sizes. Samples 9 and 10 (Table 2) show that soon after vibration ceases the particles held up by the supersonic waves settle out. Sample 9 was taken after 60 minutes of activation, and then the supersonics were cut off and the suspension was allowed to settle normally for 30 minutes. Sample 10 was taken then after 60 minutes of activated and 30 minutes of normal settling. The range of sizes found to be affected by these

frequencies compares with Sollner's, "particles a few microns in diameter" and thus show that the present work is fairly accurate.

The main difficulty in the investigation is the fact that the particles affected are only a very small portion of the original suspension. Therefore, the frequencies used were too high and the energy in the liquid is not enough for use as a particle size analyzer. Another fault of these suspensions is that the ratio of liquid to solid is too low and the suspended particles interfere with each other.

One very serious fault with the oscillator is that it causes bands of static on neighboring radios. The RCA Dynamic Demonstrator picked up disturbances from the fundamental and ten harmonics of rod number two. This set is only twelve feet from the oscillator, but radio sets much further away will probably be affected. If this is true, it may mean that the oscillator type of analyzer may have to be abandoned.

Bibliography

(1) Eastman, A.V., Fundamentals of Vacuum Tubes, McGraw-Hill Book Co., Inc., 1937. Chapt. VIII, pp. 291-293.

(2) Getman and Daniels, Outlines of Theoretical Chemistry, Chapt. X, p. 201.

(3) Pierce, G.W., Magnetostriction Oscillators, PROC. INS. RADIO ENG., 17, (January, 1929), pp. 42-88.

(4) Ramsey, R.R., Fundamentals of Radio, (1935) Chapt. XV.

(5) Sollner, Karl, J. PHYS. CHEM., 42, 1938, pp. 1071-1077.

Acknowledgment

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TABLE 1

Description of Samples

Sample Number	Suspension Number	State of Activation	Time of Sample	Remarks
1	I	300,000	90 min.	Liquid just under paddle
2	I	300,000	90 min.	Rock layer in bottom
3	I	Original	-	Well mixed before sample
4	II	Original	-	Well mixed before sample
5	III	Original	-	Well mixed before sample
6	IV	Original	-	Well mixed before sample
7	I	Normal	110 min.	Liquid at top of beaker
8	IV	300,000	100 min.	Liquid just under paddle
9	III	263,000	60 min.	Liquid just under paddle
10	III	Normal	30 min.	This is a continuation of the run in which No.9 was taken. Total time 90 min.
11	II	57,000	90 min.	Liquid just under paddle
12	III	263,000	96 min.	Liquid just under paddle
13	III	Normal	96 min.	Liquid at top of beaker

TABLE 1,CONT'D

Sample Number	Suspension Number	State of Activation	Time of Sample	Remarks
14	VI	Original	-	Well mixed before sample
15	VI	Normal	70 min.	Liquid at top of beaker
16	VI	57,000	70 min.	Liquid under paddle

TABLE 2

Particle Sizes in the Samples

Sample Number	Percent of Sample in Size Group*				
	20 mu	15 mu	10 mu	5 mu	Less than 5 mu
1	-	-	5%	5%	90%
2	10%	10%	20	20	40
3	1	4	10	20	65
4	-	1	30	15	54
5	10	20	20	20	30
6	-	1	10	15	74
7	mostly extraneous organic material				
8	-	-	-	5	95
9	-	-	10	20	70
10	-	-	-	5	95
11	-	-	-	2	98
12	-	5	20	20	55
13	-	-	-	10	90
14	-	5	10	20	65
15	-	-	-	1-2	98
16	-	-	-	2-4	96

*Based on number of particles

1 mu equals 0.001 millimeter.

A

TABLE 3

Settling Data for Suspension No. 1

Time in Minutes	Distance Between Liquid Surface and Interface* in 1/16 in.	
	Normal	Activated (300,000)
0	0	0
15	9	-
30	17	18
40	22	24
50	27	28
55	-	30
60	30	32
65	-	33
70	30.5	34
75	-	34.5
80	31	34.5
85	-	35
90	31.5	-

B

Settling Data for Suspension Number II

Time	Normal	Activated (57,000)
0	0	0
5	-	0
15	4	2
30	10	8
35	-	10
40	15	-
45	-	14
50	19	16
55	-	18

*Note: It may be seen in Figure 4 that there is a very definite line between top and bottom parts of the suspension. This line moves down as time increases. It will be known as the interface in this thesis.

B

TABLE 3,CONT'D

Time	Normal	Activated(57,000)
60	22	20
65	-	23
70	22.5	24
75	-	25
80	23	25.5
85	-	26
90	24	26.5
100	24	-
110	25	-
120	25	-

C

Settling Data for Suspension No.III

Time in Minutes	Distance Between Liquid Surface and Interface in 1/16 in.				
	Normal(a)	Normal(b)	263,000(c)	263,000(d)	263,000(e)
0	0	0	0	0	0
5	1	-	0	0	0
10	2	-	0	1	0
15	3	4.5	0	2	1
20	4	-	1	3	1.5
25	5	-	2	4	2
30	8	11	3	8	2
35	-	-	5	-	2.5
40	10	14	8	14	3
45	12	-	-	15	3
50	14	19	11	17	3.5
55	15	-	-	18	4
60	16	22	14	20.5	4.5

C

TABLE 3,CONT'D

Time in Minutes	Distance Between Liquid Surface and Interface in 1/16 in.				
	Normal(a)	Normal(b)	263,000(c)	263,000(d)	263,000(e)
65	18	-	-	23	-
70	19	23	17	25	-
75	21	-	-	26	-
80	23	24	20.5	27	-
85	23.5	-	-	28	-
90	23.5	24	25	28	-
95	24	-	-	28.5	-

a. These data were taken on a solution in a small bottle 4 inches high by 1-3/4 inches in diameter placed 5 feet from the oscillator.

b. These data were taken on a sample in a 400 cubic centimeter beaker with no nearby source of disturbance.

c. Suspension in 400 cubic centimeter beaker with a 2 inch paddle. This run showed some eruptions along the outlines of the paddle.

d. Suspension in a bottle the same as in (a) with a 1 inch diameter disc as the paddle.

e. Similar to (c) except that 50 cubic centimeters of top liquid had been withdrawn as samples in two previous runs.

D

TABLE 3, CONT'D

Settling Data for Suspension No. IV

Time in Minutes	Distance Between Liquid Surface and Interface in 1/16 in.	
	Normal	Activated (300,000)
0	0	0
15	2	2
30	10	7
40	14	11
50	18	15
60	24	18
70	25	22
80	26	25
90	27	27
100	27	27

E

Settling Data for Suspension No. V

Time in Minutes	Distance Between Liquid Surface and Interface in 1/16 in.	
	Normal	Activated (263,000)
0	0	0
1	6	7
2	9	9
3	11	11
4	15	14
5	16	16
6	18	18
7	20	20
9	24	24
12.5	32	29
15	32	32

F

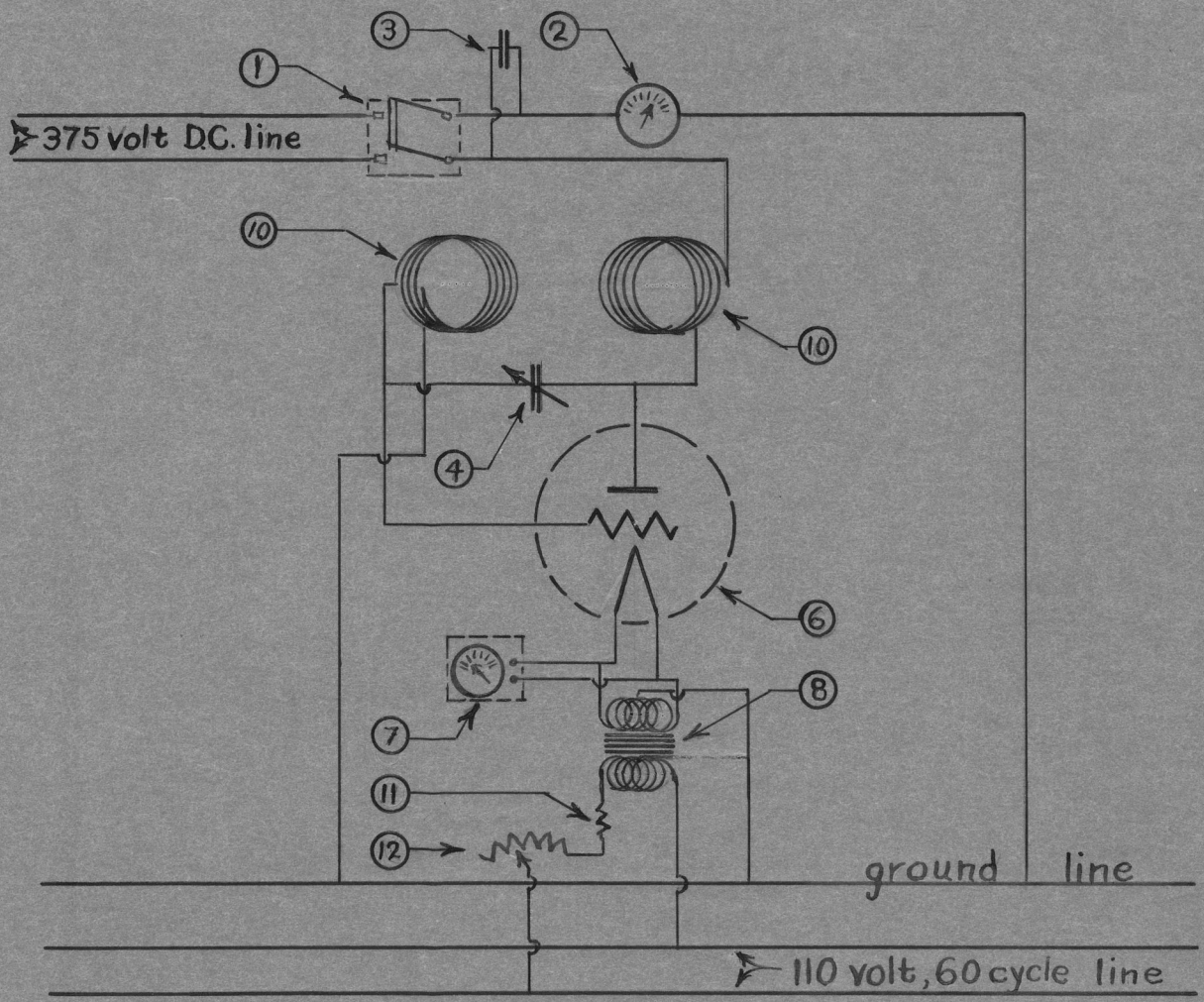
TABLE 3,CONT'D

Settling Data for Suspension No. VI

Time in Minutes	Distance Between Liquid Surface and Interface in 1/16 in.	
	Normal	Activated (57,000)
0	0	0
5	1	4
10	7	9
15	9	11
20	11	14
25	13	16
35	17	21
40	20	24
45	23	26
50	25	28
55	28	31
60	30	32
65	32	33
70	33	33

FIGURE 1

Note: Numbers refer to items listed in the section on description of equipment.



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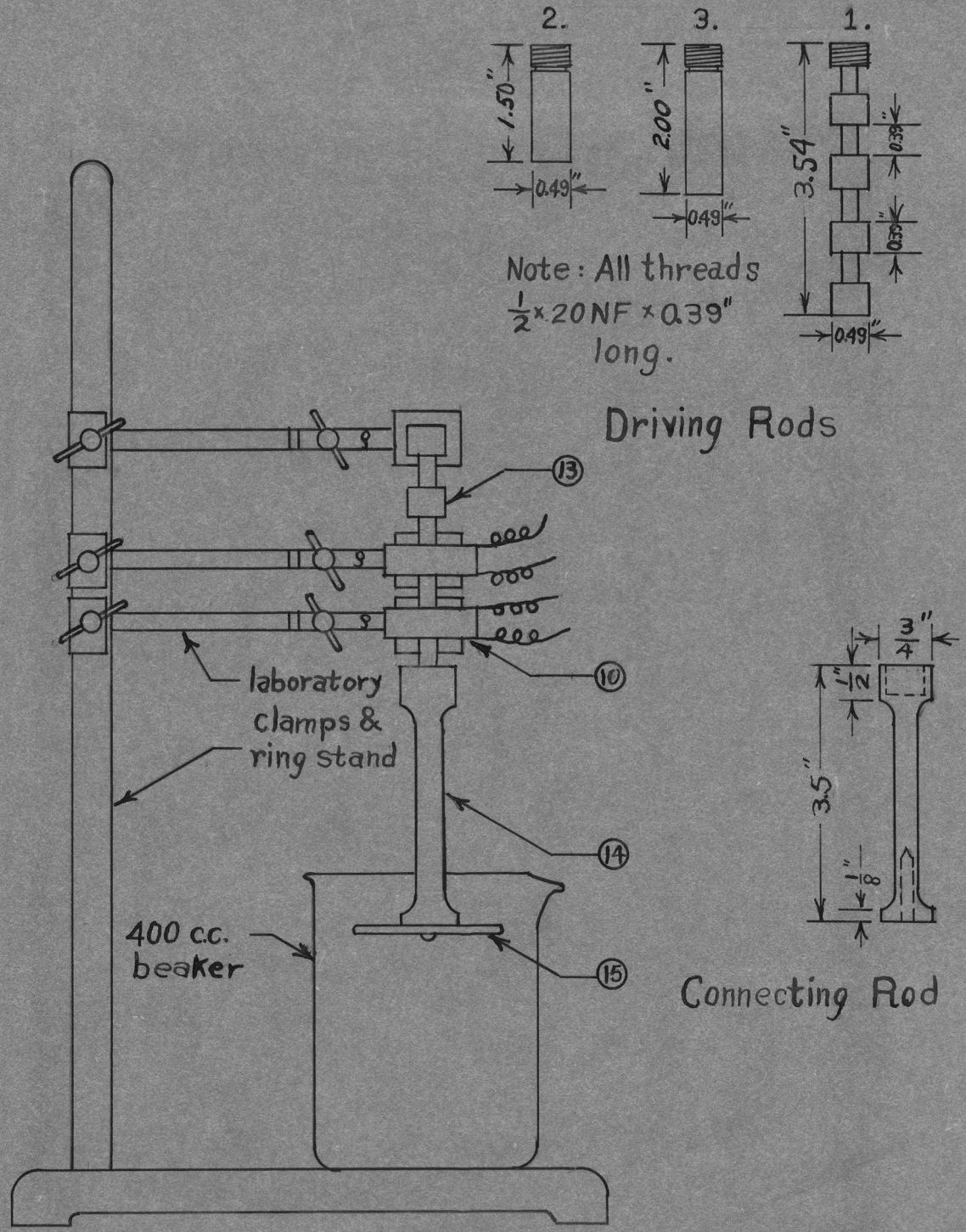
MAGNETOSTRICTON OSCILLATOR CIRCUIT



Side View - Assembly Drawing

FIGURE - 2

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DIAGRAM OF EQUIPMENT

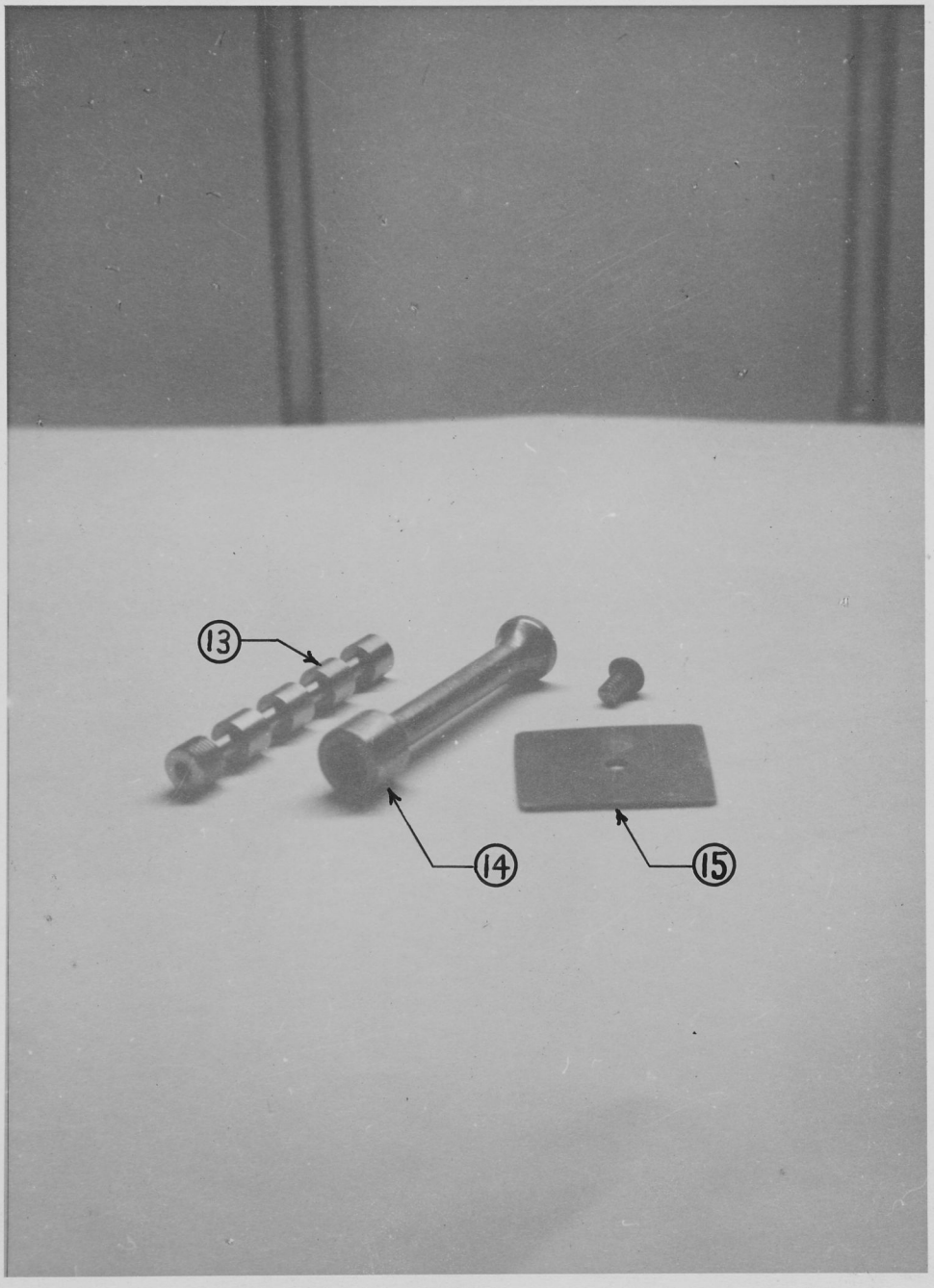

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FIGURE - 3

MECHANICAL EQUIPMENT



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FIGURE - 4

PHOSPHATE SUSPENSIONS UNDER TEST

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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Date June 1, 1941