0-196

0-196
AN-7205
RN-3158

Quality Control of Liquids and Suspensions

To be Presented at

Indiana Plant Food and Agricultural Chemicals Conference
Purdue University
West Lafayette, Indiana
December 11-12, 1984

by

Hubert L. Balay, Chemical Engineer
Field Engineering Staff
Division of Agricultural Development
National Fertilizer Development Center

TENNESSEE VALLEY AUTHORITY
Muscle Shoals, Alabama

Quality Control of Liquids and Suspensions

Introduction

For many years there have been problems with the analysis of solid fertilizer (1, 2, 3) and much effort has been put into solving the problem. It has been assumed that since liquids and suspensions are relatively homogeneous, compared to solid fertilizers, quality control problems do not occur very often. However, reports by control officials show that this is far from the case (4). Some clue as to why this happens can be obtained from the impurities in the raw materials used. This is particularly true of the phosphate raw materials. Studies by TVA (5, 6) show that a number of insoluble compounds which are combinations of the impurities found in phosphate rock and the reaction products of wet-process phosphoric acid production are found in the raw materials used to produce fluid fertilizers. Methods are available for coping with these impurities.

Basic Fundamentals

A quality control program cannot be successful without a thorough understanding of the basic fundamentals of liquid and suspension fertilizers. While the curve shown in figure 1 is familiar to most people in the fluid fertilizer industry, its significance is sometimes misunderstood. It shows the relative solubility of ammonium phosphates formed as phosphoric acid is reacted, or neutralized, with ammonia. When ammoniation begins, the mixture is very soluble. But when one hydrogen on the phosphoric acid molecule is replaced with ammonia (monoammonium phosphate), the solubility becomes very low and only about 30 pounds of the salt can be dissolved in 100 pounds of water. This point is referred to chemically in several ways. It is the point where monoammonium phosphate (MAP) is formed. It is also referred to as the ammonia phosphoric acid mole ratio of 1.0:1; or the $N:P_2O_5$ ratio of 0.2:1; or an ammoniation ratio of 4.8 pounds of ammonia per unit (20 lbs) of P_2O_5 from the phosphoric acid. All mean the same.

If ammonia is added at this point, it begins to react with the second hydrogen on the phosphoric acid and the solubility of the ammonium phosphate mixture begins to increase again. At about mole ratio 1.45:1 a maximum solubility point is reached. This point, referred to as the eutectic point, is also the 0.3:1 $N:P_2O_5$ ratio and 7.2 pounds of ammonia per unit of P_2O_5. One grade in the ortho system made by ammoniating phosphoric acid to this point is 9.1-29.7-0. In the polyphosphate system the grades are the familiar 10-34-0 and 11-37-0. These are higher in the polyphosphate system because of the high solubility of polyphosphates.

The grade 9.1-29.7-0 or grades in that ratio in the ortho system are not very familiar to plant operators. A 1:3:0 fertilizer ratio, for example 8-24-0 solution or 10-30-0 suspension, is usually the grade made because the pH of the 9.1-29.7-0 is about 5.8. Orthophosphate is fairly corrosive to mild steel at this pH and a compromise was made in the early days of solution fertilizers between solubility and an acceptable corrosion rate. Early research also showed that if polyphosphate was present, the mixture was less corrosive and the highest solubility point (0.3:1 N:P_2O_5 ratio) could be used. Normally, then, to produce an ammonium phosphate product a producer should use the 0.33:1 N:P_2O_5 ratio i.e. 8-24-0, but to provide an ammonium polyphosphate product, he can use the 0.30:1 N:P_2O_5 ratio i.e. 10-34-0. If these ratios aren't used, problems with corrosion, solids precipitation or ammonia loss can occur.

Using the 0.33:1 N:P_2O_5 ratio can be even more important with suspensions. If the 0.30:1 ratio is used, the solid, or suspended phase, will likely be MAP. If the 0.33:1 ratio is used, the solid phase will likely be diammonium phosphate (DAP). DAP crystals are lighter and better shaped for suspensions.

Only recently have fluid fertilizer plant operators dared to try other N:P_2O_5 ratios. Both acid fertilizers (where no ammonia is added to phosphoric acid) and low pressure suspensions (where all of the nitrogen comes from ammonia) are being made. These concepts, however, involve special handling and equipment (7, 8).

A good pH meter, or at least pH paper, should be used during operation of a fluid fertilizer plant when phosphoric acid is being reacted with ammonia. This is because pH is the best guide for determining if the proper N:P_2O_5 ratio has been reached. There is a direct relationship between pH and N:P_2O_5 ratio. The proper pH must be used. Most pH's listed in the literature are for fertilizers based on electric furnace phosphoric acid. Wet-process phosphoric acid contains impurities which can tie up phosphates and change the pH which would normally give the best ratio. The best guide for determining the proper pH is experience. The pH's of several mixtures made from acids are shown in table 1. These can be used as a guide but the best pH for the kind of acid being used should be determined by experiment. The pH can then be used as a quality control for that acid.

Density of the mixture can also be used as a guide to determine if the mixture has the correct analysis. Each grade has a density which can be easily measured then used to determine whether too much, or too little, water has been added to the mixture. Some typical densities are also shown in table 1. Common laboratory equipment can be used to measure density or a measured volume may be weighed in a bucket or measuring cup.

Heat of Reaction

When phosphoric acid is ammoniated, heat is liberated. The heat liberated when 75 percent phosphoric acid is reacted with liquid ammonia and aqua ammonia is shown in figure 2. If the temperature of fertilizer made this way isn't kept below 212^{o}F, it will boil. This will make control of the reaction difficult and nearly always result in an inferior product. Coolers are often installed to prevent boiling. Reaction products are circulated to the cooler and back to the mix tank as the ammonia is added.

It is especially important to cool the mixture if ammonium polyphosphates are present. Orthophosphates do not break down and it is only necessary to prevent boiling during mixing. Polyphosphates, however, will break down (hydrolyze) and return to orthophosphate if they are stored at too hot a temperature. Fertilizers containing polyphosphates should be cooled to below 100°F. The cooler the better. Some hydrolysis will occur in storage regardless of the temperature.

Other problems occur. Suspensions should be stored at below 100°F to prevent formation of large crystals. Generally, orthophosphate solutions can be pumped to storage at any temperature below boiling because the salts stay in solution as the mixture cools. This is not true of suspensions. As a hot suspension cools, crystals form which can grow large enough to settle to the bottoms of tanks and plug plant lines and applicator nozzles. Scientific data show that the size of the crystals formed in a saturated solution (suspension) are inversely proportional to the crystallization rate and the number of crystals in the suspension (9). To insure that only small crystals which will not settle are produced, there must be a high recrystallization rate. This can be accomplished by cooling the suspensions rapidly while recirculating at a high rate.

Crystal growth can be a problem even with suspensions made from MAP or DAP's because the temperatures reached in the mixer are usually well above 100°F. If stored without cooling, these suspensions can form crystals exactly as suspensions made from orthophosphoric acid. A cooler avoids this problem by providing both quick cooling and rapid movement of the solution.

The packed tower cooler used with solutions such as 10-34-0 made with the TVA pipe reactor process or to cool orthophosphate solutions cannot be used with suspensions because the packing will plug. Therefore, a special spray-tower cooler, such as that shown in figure 3, is recommended. Such coolers ensure that a suspension, such as 10-30-0, can be made from orthophosphoric acid, MAP, or DAP and anhydrous ammonia which will store for an extended period.

Viscosity

Viscosity is usually not a problem with true solutions but as shown in table 1, it can be a problem with suspensions. High viscosity in suspensions can affect the pumping rate of suspensions, but, more importantly, the pattern discharged from nozzles can be affected. Viscosity is usually measured by a Brookfield viscometer. Figure 4 is a photograph of this equipment. It consists of a spinning disc (spindle) which is inserted into the fluid. A meter measures the torsion acting on the disc. The model shown is an RVT. Usually a number 3 spindle turned at 100 rpm's is used. Viscosity is measured by attaching the spindle shaft to an electric motor in the meter, inserting the spindle disc into the suspension, turning on the motor, and allowing the meter to operate for 30 seconds. The meter is then turned off and read. The meter reading is multiplied by a factor of 20 to determine the viscosity in centipoises.

Many factors affect the viscosity of suspensions; one is the amount of clay used. However, the most difficult variable to handle is the impurities in the suspension. Figure 5 shows the effect of impurity content on suspension viscosity. As the total impurity content (Ca, Fe, Al, SiO_2, Mg, and SO_4) increases, there is a decrease in the plant food content of the ammonium phosphate base which can be produced. Most commercial MAP's have R_2O_3:F ($R_2O_3 = Al_2O_3 + Fe_2O_3$) weight ratios between 1.8:1 and 2.8:1. This is the impurity ratio that has the most effect on suspension viscosity.

The average suspension manufacturer using solid ammonium phosphate finds it difficult to determine the amount of impurities in the solids he is using or suspensions he produces. In fact it is impractical to even try. TVA has developed a relationship between the water insoluble materials in the MAP or DAP and the plant food concentration in the base suspension. This relationship is shown in figure 6. If MAP used to produce a base suspension contains 20 percent water insoluble solid, the total plant food concentration should not exceed 40 units of plant food. If this concentration is not exceeded the suspension probably should have a satisfactory viscosity. The water insoluble portion of MAP is determined by the following procedure.

1. Weigh 100 grams of ammonium phosphate on a triple beam balance.
2. Add this material to a household blender.
3. Add one quart of water.
4. Mix for 30 minutes.
5. Filter through a Buchner funnel.
6. Dry the filter cake with a heat lamp.
7. Calculate percent water insolubles which equals the weight of dry filter cake.

Figure 7 shows a photograph of this equipment. It can be bought from a local laboratory supply house and a local department store. All of the equipment can be used in field laboratories.

Although these procedures help eliminate problems with viscosity, they are not foolproof because the total impurities are not the only variables affecting suspension viscosity. TVA bench-scale tests show that the ratio of iron (Fe) plus aluminum (Al) to fluorine (F) content also affects viscosity of fluids. These data show that when the Fe_2O_3 + Al_2O_3 to F grade ratio is less than 3.0 to 1, the base suspension usually has a low viscosity, if the plant nutrient concentration is not too high. Obviously there is no easy way for manufacturers to remove iron or aluminum from suspensions or to add fluorine to adjust the Fe_2O_3 + Al_2O_3 to F weight ratio to an optimum. The best way to keep problems to a minimum due to the ratio of impurities is to request that manufacturers of MAP insure that the Fe_2O_3 + Al_2O_3 to F weight ratio be less than 3:1. Perhaps some company will offer ammonium fluoride at a reasonable cost which can be added to suspensions. Ammonium fluoride can be produced by ammoniating fluosilicic acid, which is a byproduct of the manufacture of both phosphoric acid and ammonium phosphate.

Adding Ammonium Polyphosphate

Another way to minimize the effect of iron and aluminum is to sequester them with polyphosphate. Adding polyphosphate also helps increase solubility of plant nutrients so that, in some instances, high analysis suspensions such as 12-36-0 can be produced without exceeding viscosity limitations. Bench-scale data show that when enough ammonium polyphosphate solution is added to supply between 7 and 10 percent of the P_2O_5 as polyphosphate, enough of the impurities are sequestered and plant nutrients dissolved so that an excellent 12-36-0 that will store for prolonged periods at reasonable temperatures can be produced from good quality MAP. However, tests also show that it probably will be advisable to use a cooler like that shown in figure 3 for this product.

Until this year TVA was the only producer of solid ammonium phosphate containing polyphosphate. TVA's product contained 20 percent polyphosphate and had a grade of 11-55-0. It was demonstrated in field programs that this product could be used to produce an excellent suspension fertilizer with high analysis and good storage characteristics. TVA has developed a new pipe reactor process for producing granular MAP containing polyphosphate using the TVA ammoniator-granulator. Several companies are interested in producing this product.

Slow Solid Breakdown

When solids are used to produce suspensions, some companies report problems in obtaining satisfactory breakdown of solid raw materials in a reasonable length of time. Often this is caused by not adding enough ammonia for the MAP or enough phosphoric acid for DAP. Plant and small-scale tests show that MAP must be ammoniated to an $N:P_2O_5$ ratio of 0.33:1 resulting in a 10-30-0 or 11-33-0 grade. When the $N:P_2O_5$ ratio 0.30:1 is used, even though this is on the eutectic point, longer mix times are usually required and often solids do not completely disintegrate. This can also occur if aqua ammonia is used rather than anhydrous ammonia.

When producing suspensions from DAP, producing a grade with an $N:P_2O_5$ ratio of 0.33:1 is important. This is accomplished by adding enough phosphoric acid to adjust the N:P_2O_5 ratio of the DAP (18-46-0) from 0.391:1 to 0.274:1 and then adding enough ammonia to bring the final ratio to 0.33:1. The extra acid and ammonia supply enough chemical heat to break down the DAP. The amount of extra acid added sometimes has to be varied to accommodate the impurity content of the DAP used. Usually 30 percent of the P_2O_5 is supplied as phosphoric acid. When this amount of acid is used, about 50 pounds of ammonia per ton of product must be added to adjust the N:P_2O_5 ratio to 0.33:1. The resulting product temperature immediately after mixing is usually between 135 and 145°F and the product should be cooled before it is stored.

Choosing the Right Potash

The properties of several common grades of potash (KCl) are shown in table 2. Only two of these grades, the soluble grade and the fine standard grade, are suitable for suspensions. Of the two, the soluble grade is preferred. These two grades are suitable for suspensions because they do not contain particles too large to suspend without excessive settling. Potash is heavier than water and, therefore, will settle. In fertilizer suspensions, a suspending agent (suspending clay) will interfere with settling. In this mixture, the smaller the potash particle, the slower the settling rate and the better the suspension (10).

TVA's "rule-of-thumb" for suspension potash is that 100 percent pass a 20-mesh screen and 90 percent pass a 35-mesh screen. Table 2 shows that only the soluble and the fine standard grades meet this criteria. The soluble grade is more suitable for suspensions for two reasons. It contains more plant food and, therefore, has a lower impurity content.

The soluble grade has only a trace of water insoluble materials while other grades of potash contain from 0.4 to 0.6 percent water insoluble material.

Experience shows that grades made using potash with a water insoluble portion as high as 0.4 percent can result in suspensions which thicken in storage so that they cannot be pumped. Care must be taken to adjust the formula for the lower plant food analysis when the standard grades are used. A 4-12-24 grade made from potash containing 62.5 percent K_2O contains 768 pounds of potash per ton while the same grade made from potash containing only 60 percent K_2O requires 800 pounds of potash. This means that 32 extra pounds of solid and 32 pounds less water are added, a change of 64 pounds in the solid-liquid balance. The prepared grade must be adjusted for this.

For the best suspension the purest potash available which meets the size specifications should be chosen. But the choice should be dictated by economics; lower grade potash should be considered if the savings are great enough. The operator, however, should know that problems can occur which may reduce any savings. Salvaging settled or thick suspensions is costly.

Preparing a Proper Carrier for Suspensions

A suspension will settle and grow crystals unless a proper carrier is prepared. The usual suspending agent is attapulgite clay, although other suspending agents are sometimes used. If attapulgite clay is used to prepare the carrier, it must be sheared and gelled before it will keep the solids suspended and prevent crystal growth.

Most suspensions contain about 50 percent solids which must be suspended by the clay. About 30 pounds of suspending clay is needed to suspend all solids. The clay cannot do this unless it is properly prepared.

Under a microscope, clay as mined and shipped to the suspension manufacturer, appears as tiny needle-like particles which lie parallel to each other. If dropped into water these particles will either float, form soft balls which are wet on the outside and dry in the middle, or settle to the bottom of the tank. For the clay to work properly these particles must be torn apart (sheared) so that they are randomly oriented like straws in a haystack. In this form, settling of solids in the suspension is prevented. But if the particles aren't properly sheared they will not prevent settling. Seven passes through a centrifugal pump are required to properly shear clay. The time required depends upon the size of the pump. One pound of sheared attapulgite clay has a surface area of about 24 acres (11).

Also, attapulgite clay seems to have a size and chemical makeup with a predominately negative electrical charge. When put into a suspension it attracts dipolar molecules such as water, phosphate, and ammonium nitrate (from UAN) in the suspension. This causes the combination to occupy even more space and do a better job of preventing solids from settling.

Attapulgite clay shears best in water. To properly prepare the clay the following steps should be followed:

1. Add enough clay to make a 90 percent water, 10 percent clay mixture. Circulate through the centrifugal pump for at least 3 minutes. Run the agitator if this can be done without splashing.

2. Add the balance of water.
3. Add the phosphate base.
4. Add nitrogen solution if it is required.
5. Add potash if it is required.
6. Mix until the potash is thoroughly suspended. The time required depends upon the intensity of the agitator and size of the pump being used.

Sampling

Although fluids are generally more uniform than bulk blended or even chemically combined solids, they do not have as good an analysis record as they should. Attention to the chemistry of the mixture and to the mixing procedures will usually keep fluids very close to the formulated grade. However, if a poor sample is obtained for chemical analysis this effort is wasted. Poor samples can be obtained by failure to agitate the mixture as it is being sampled from nurse equipment, applicators, storage tanks or mix tanks. Often samples which lead to expensive penalties or which damage the reputation of a fertilizer company are carelessly taken. Samples have been taken from a hose attached to a nurse tank without recirculating through the hose. This results in a sample of the last batch rather than the fertilizer in the tank.

A sample should be taken from the discharge from a pump as it circulates fertilizer from the bottom of the batch being sampled to the top. Before sampling, the pump should be turned on and the material circulated until uniformly mixed. The circulation time can be determined by experiment. Fertilizer in the tank can be circulated until a uniform density is obtained. A better way to establish the time required, however, is to sample a test batch at 5 minute intervals, send them to a laboratory and determine the time required to obtain three samples which fall within the experimenta [illegible] or of the laboratory. For future samples use this established recirculation time before sampling.

Frequently, control officials will help with this procedure and will sometimes run the analysis either free or for a nominal charge. Also most control officials will supply the experimental error of their laboratory. If this cannot be obtained from the local control officials, it can be obtained for an average laboratory from the American Association of Plant Food Control Officials. Although this procedure requires a lot of time, and sometimes money, establishing the recirculation time necessary to get a uniform sample is well worth the effort.

Summary

If the following procedures are followed, there should be few problems with producing, storing, and using fluid fertilizers.

1. Know the chemical properties of the fluid being prepared and use them to your advantage.
2. Choose proper raw materials. For example, do not use coarse potash for fluids or suspensions.
3. Choose mixing plants and equipment suitable for making the fluids being produced.
4. Prepare a proper carrier to support solids in suspensions by shearing and gelling the clay properly.

5. Strain the mixture properly after it has been prepared and before it goes into storage and into the applicator. It is impossible to strain too much.
6. Store in properly constructed storage tanks equipped with good recirculation and adequate sparging systems.
7. Use applicators and nurse equipment with good sparging or recirculation systems.
8. Use proper sampling procedures.

Most trouble operators have with fluids can be traced to failure to use these techniques. In fact, many manufacturers are using them to produce large quantities of satisfactory fluids.

Use of fluid fertilizers should continue to grow and become even more popular. Use of suspensions, especially, will grow because they provide for high-analysis mixtures equivalent in plant nutrient concentration to granular fertilizers made from competitive raw materials. When carefully mixed and sampled, fluids have the potential for a uniformity not possible in blends and granular fertilizers. Much improvement can be made in making use of this advantage.

References

1. Hoffmeister, George. "Compatibility of Raw Materials in Blended Fertilizers - Segregation of Raw Materials." Proceedings of the 12th Annual Meeting of the Fertilizer Industry Round Table, 1962, pp. 80, 83.

2. Arthur D. Little, Inc. "Summary. A Study of Official Sampling Techniques for Bulk Blended Fertilizer in the State of Florida." Prepared for the Florida Agricultural Research Institute, July 16, 1976.

3. The Fertilizer Institute. "An Evaluation of the AOAC Fertilizer Bag Sampling Procedures," July 1981.

4. Terry, D. L. "Grade Control in Bulk Blend Plants. "Proceedings of the Fertilizer Industry Round Table, 1979, pp. 108-111.

5. Dillard, E. F. and A. W. Fraiser. "Precipitated Impurities in Monoammonium Phosphate and Their Effect on Chemical and Physical Properties of Suspension Fertilizers," TVA Bulletin Y-183, 1983, Muscle Shoals, Alabama.

6. Dillard, E. F., A. W. Fraiser, T. C. Woodis, and F. P. Achorn. "Precipitated Impurities in 18-46-0 Fertilizers Prepared from Wet Process Phosphoric Acid," TVA Bulletin Y-162, 1981, Muscle Shoals, Alabama 35660.

7. Achorn, F. P. "Acid Fertilizers." Proceedings of the 34th Annual Meeting of the Fertilizer Industry Round Table, 1984.

8. Cole, C. A. and M. F. Broder. "Low-Pressure Fertilizers." Presented at the American Chemical Society Meeting, Philadelphia, Pennsylvania, 1984.

9. Badger and McCabe, Elements of Chemical Engineering, Second Edition Fourteenth Impression, McGraw-Hill Book Company, Inc., New York, New York, 1936, pp. 439-462.

10. Balay, H. L. and C. A. Cole, Jr. "Information for Applicators Who Mix Potash in Suspensions," Custom Applicator, 1982, pp. 38-64.

11. Strauss, J. L. "Formulation Principles of Suspension Fertilizers," Proceedings of the National Fertilizer Solutions Round-Up, 1968, p. 1.

Table 1

Properties[a] of Various Suspension and Solution Fertilizers at 75°F

Suspensions

Grade	Specific Gravity	pH	Viscosity[b] (cp)
0-0-31	1.30	8.1	360
0-0-36	1.34	-	900
2-0-30	1.41	7.5	460
2-0-33	1.42	7.5	780
2-0-35	1.42	7.5	1175
3-9-27	1.41	-	650
4-0-30	1.42	7.5	580
4-0-33	1.42	7.5	810
4-12-24	1.40, 1.42	6.8	540
4-13-27	1.45	6.4	690
4-14-28	1.50	6.3	-
5-15-24	1.43	-	680
5.7-20.3-19.8	1.51	6.0[b]	570[c]
6-18-18	1.36	6.5	520
7-21-21	1.55, 1.54	6.5	790
7-22-14	1.42	6.8	490
8-24-8	1.39	6.2	115
8-24-16	1.53	6.5	960
8.5-25.5-8.5	1.42	6.6	440
9-9-27	1.50	6.6	820
10-30-0	1.40, 1.38, 1.33	6.6	520
10.3-20.6-10.3	1.41	6.5	560
11-33-0	1.45	6.7	800
11.6-35.9-0	1.40	6.5	1000

Grade	Specific Gravity	pH	Viscosity (cp)
12-36-0	1.44	6.0	400[d]
13-7-14	1.40	6.0	600
13-11.7-15	1.35	-	710
13-13-13	1.37, 1.32, 1.39, 1.34	6.1	500
13-33-0	1.42	-	-
13-38-0	1.47	6.3	600
13.4-11.7-15	1.35	-	810
14-0-21	1.48	7.8	460
14.3-12.8-12.8	1.35	-	790
14.7-7.3-14.7	1.38	6.4	470
15-5-20	1.57	5.3	900
15-8-15	1.32	-	930
15-8-16	1.32	6.0	930
15-11-11	1.29	-	560
15.1-13.2-11.3	1.32	-	920
15.3-5.1-15.3	1.36	6.5	380
16.8-0-16.8	1.35	7.7	110
18-0-18	1.47	7.8	460
18-6-12	1.31	-	620
18-9.2-9.2	1.34	6.0	610[c]
18-10-10	1.32	-	590
18.7-0-18.9	1.45	8.7	620[c]
21-0-14	1.47	7.6	210
24-12-0	1.15	6.2	350

Special Suspensions

Fluid Clay	Specific Gravity	pH	Viscosity (cp)
25% Attapulgite Clay, 0.55% Tetrasodium Pyrophosphate, 74.45% Water	1.15	8.6	150

Grade	Specific Gravity	pH	Viscosity (cp)
25% Attapulgite Clay, 9% N (from urea), 0.55% Tetrasodium Pyrophosphate, 55.16% Water	1.24		
Limestone, 1.5% Attapulgite Clay, Water + Other Materials			
60% Limestone	1.48, 1.56, 1.54	9.0	750
50% Limestone	1.45	9.0	640
40% Limestone	1.35		
60% Limestone, 6% K_2O	1.60		
60% Limestone, 2.6% N	1.60		
50% Limestone, 5.3% N	1.58		

Solutions

Solutions from Thermal Orthophosphoric Acid

Grade	Specific Gravity
4-11-11	1.26
4-12-8	1.22
5-10-10	1.25
6-12-6	1.22
6-18-6	1.27
7-14-7	1.26
8-8-8	1.25
8-16-8	1.31
8-24-0	1.26
9-9-9	1.27
10-10-5	1.24
10-20-0	1.26
12-6-6	1.24
12-8-4	1.23
14-7-7	1.28
14-14-0	1.25
15-5-5	1.25

Grade	Specific Gravity
16-4-4	1.22
16-8-0	1.22
18-6-0	1.23
20-5-0	1.24

Solutions from Wet-Process Polyphosphoric Acid

Grade	Specific Gravity
7-21-7	1.31, 1.32, 1.35
10-30-0	1.42
10-34-0	
11.1-35.8-0	1.41
14-8-8	1.25
15-5-10	1.24
18-6-6	1.25

Solutions from Wet-Process Orthophosphoric Acid

Grade	Specific Gravity
3-9-9	1.22
4-10-10	1.23
5-10-10	1.26
5-15-0	1.16
5-20-0	1.24
6-18-6	1.30
7-7-7	1.20
7.4-20.3-2.8	1.27
8-8-8	1.25
8-16-0	1.23
8-22-3	1.29
8-24-0	1.30, 1.28, 1.28, 1.26
8-25-0	1.31
9-30-0	1.35

Grade	Specific Gravity
10-0-0-10Zn (Aqua + $ZnSO_4$)	1.27
10-20-0	1.22
12-0-0-26S (Ammonium Thiosulfate)	1.337
12-6-6	1.24
12-12-0	1.23
14-6-3	1.20
15-7-0	1.16
15.5-15.5-0	1.28

Special Solutions

Urea-Ammonium Nitrate Solution

Grade	Specific Gravity	pH	Viscosity (cp)
28-0-0	1.28	7.5	18
30-0-0	1.30	7.5	22
32-0-0	1.32	7.5	25

---

a. As measured in the FES laboratory. Properties will vary as purity of ingredients vary.

b. Brookfield Model RVT Viscometer, No. 3 spindle at 100 rpm's.

c. At 47°F.

d. Twenty-five percent of P_2O_5 from 10-34-0 ammonium polyphosphate solution.

Table 2

Typical Potash Product Data[a]

Particle Size (Weight Percent-Tyler Mesh)	Soluble	Standard	Fine Standard	Coarse
+6	-	-	-	-
+8	-	-	-	2
+10	-	-	-	15
+14	-	-	5	39
+20	-	-	20	31
+28	-	-	23	8
+35	7	6	22	3
+48	33	34	14	2[b]
+65	37	34	9	
+100	15	16	4	
+150	5	5	2	
-150	3	5	1	
K_2O equivalent (%)	62.50	60.59	60.20	60.50
KCl (%)	98.94	95.91	95.36	95.77
Water insoluble portion (%)	0.02	0.35	0.62	0.59

Average

[a] Product data from several potash companies

[b] Percent -35 mesh

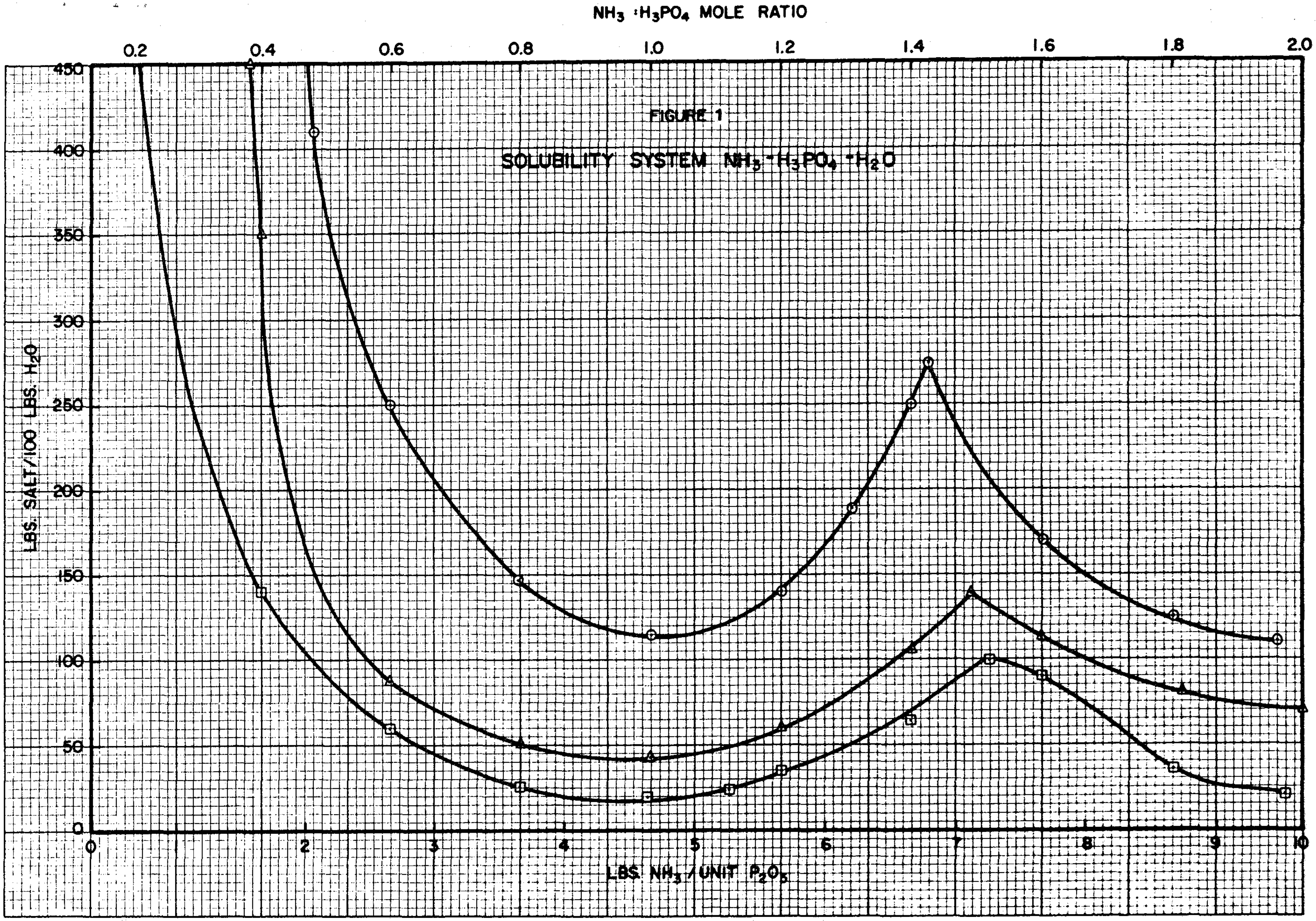


FIGURE 1

SOLUBILITY SYSTEM $NH_3-H_3PO_4-H_2O$

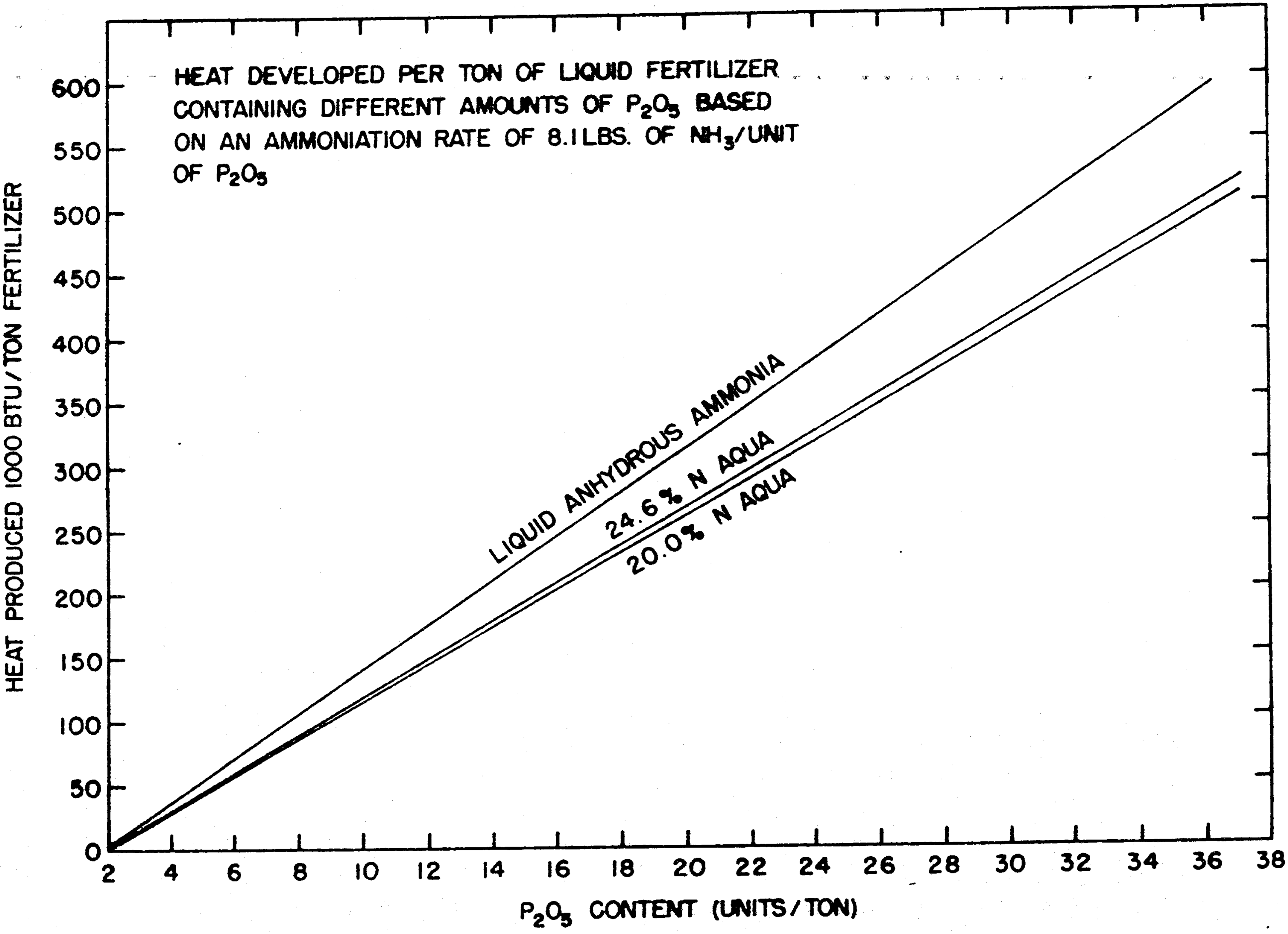

HEAT DEVELOPED PER TON OF LIQUID FERTILIZER CONTAINING DIFFERENT AMOUNTS OF P_2O_5 BASED ON AN AMMONIATION RATE OF 8.1 LBS. OF NH_3/UNIT OF P_2O_5
HEAT PRODUCED 1000 BTU/TON FERTILIZER
0
50
100
150
200
250
300
350
400
450
500
550
600
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
P_2O_5 CONTENT (UNITS/TON)
LIQUID ANHYDROUS AMMONIA
24.6% N AQUA
20.0% N AQUA

FIGURE 2

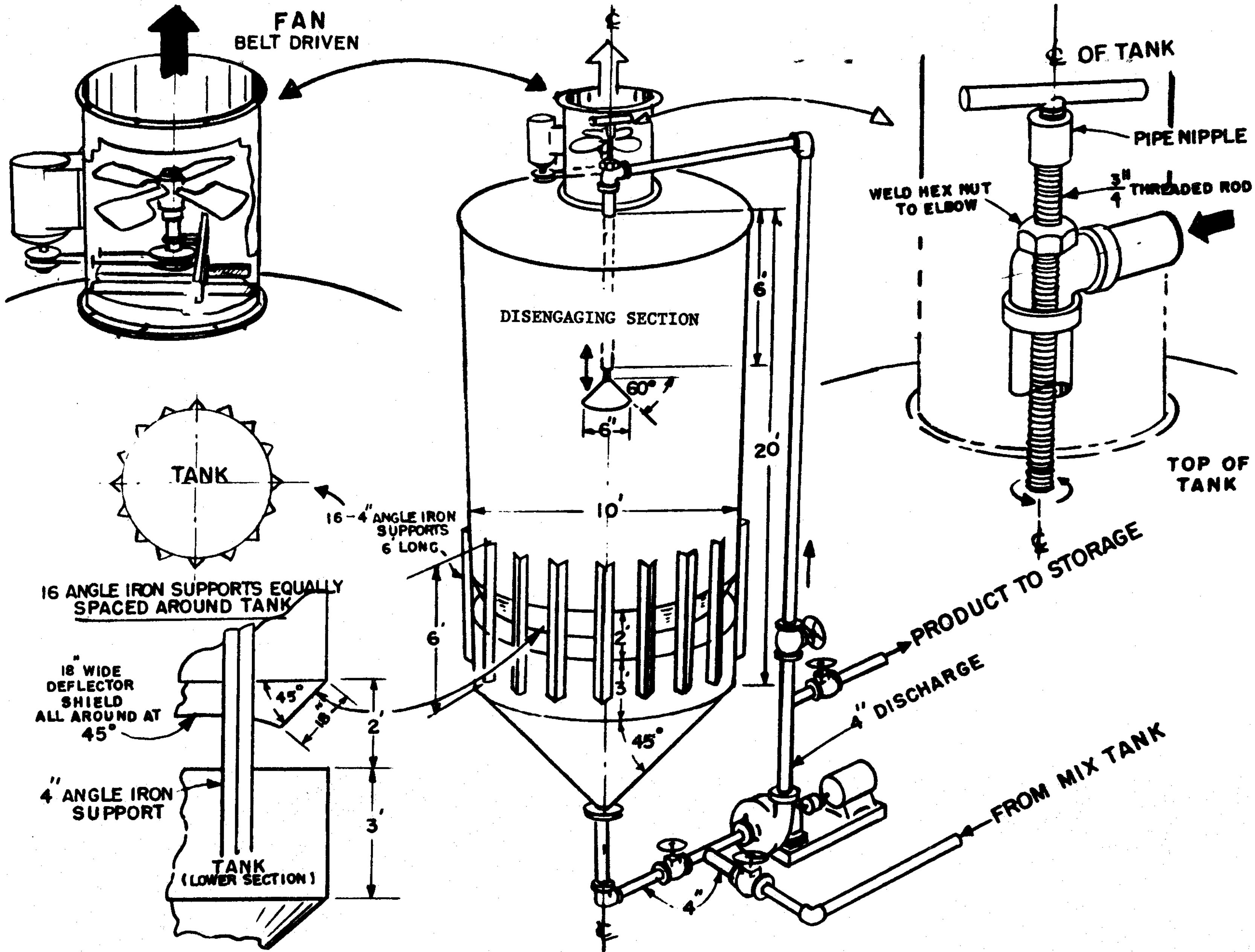


FIGURE 3
SUSPENSION COOLER
(NO PACKING)

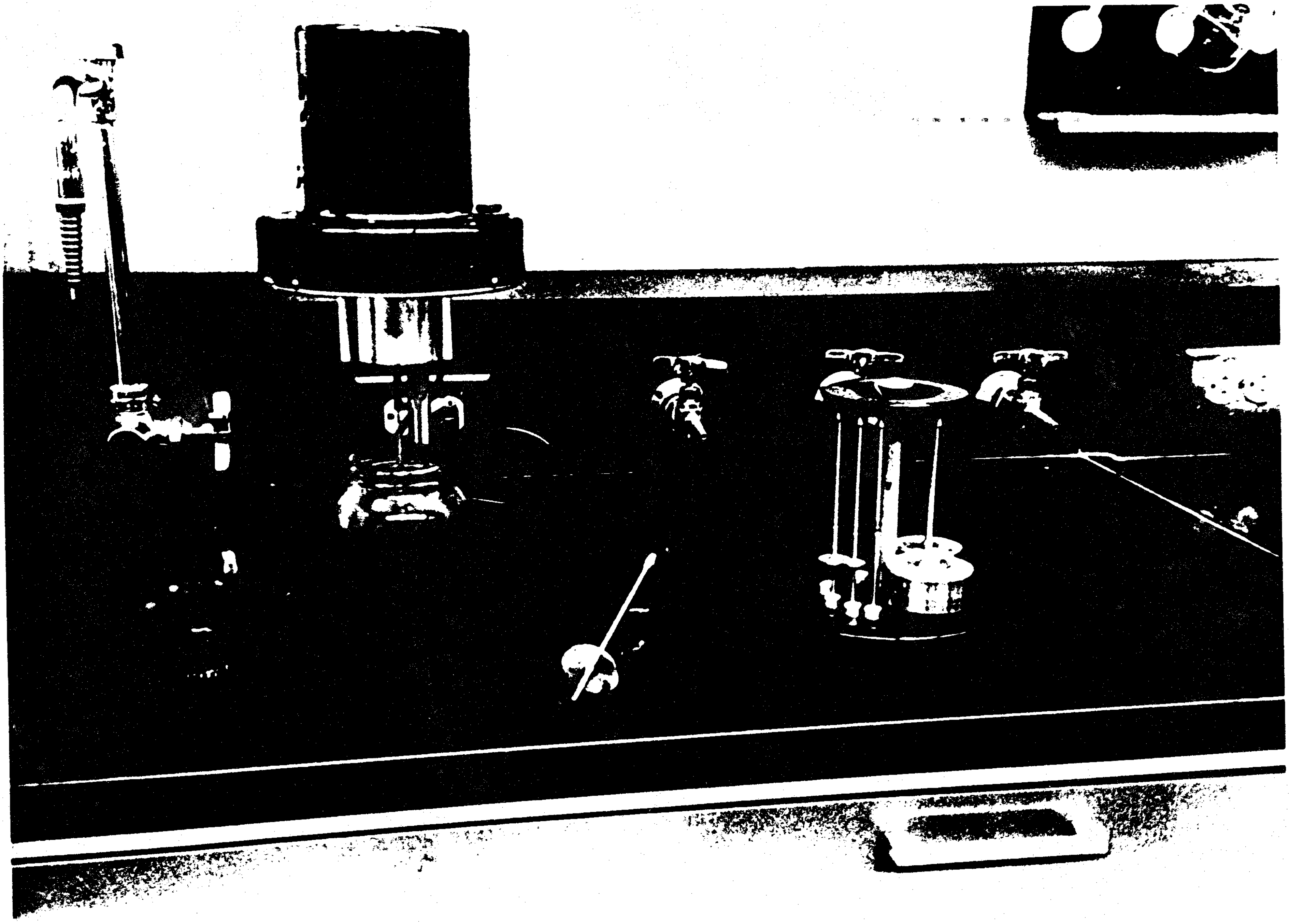
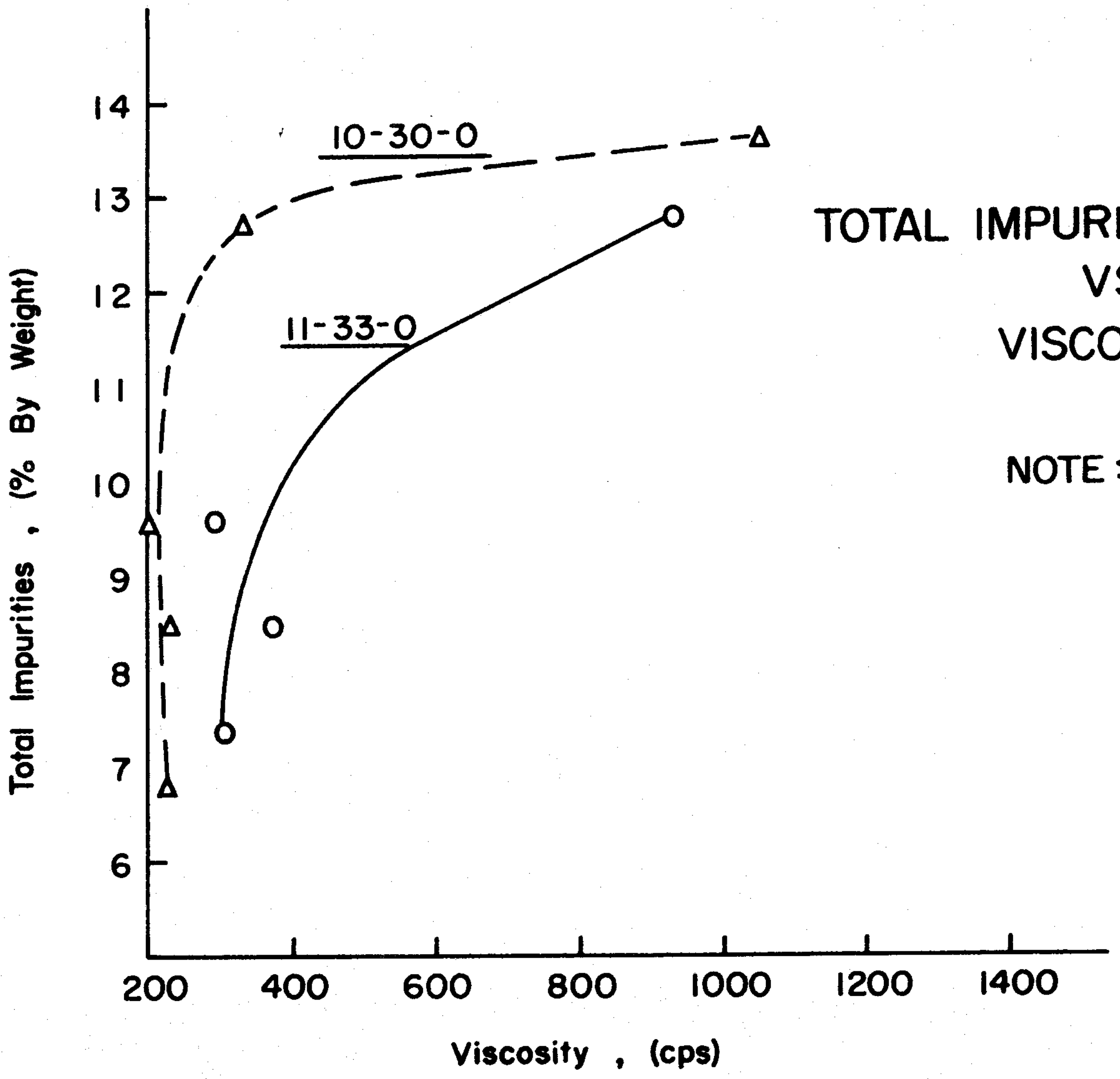


FIGURE 4

VISCOSITY MEASURING DEVICE



TOTAL IMPURITIES IN MAP
VS
VISCOSITY

NOTE : $1.8 < \frac{R_2O_3}{F} < 2.8$

FIGURE 5

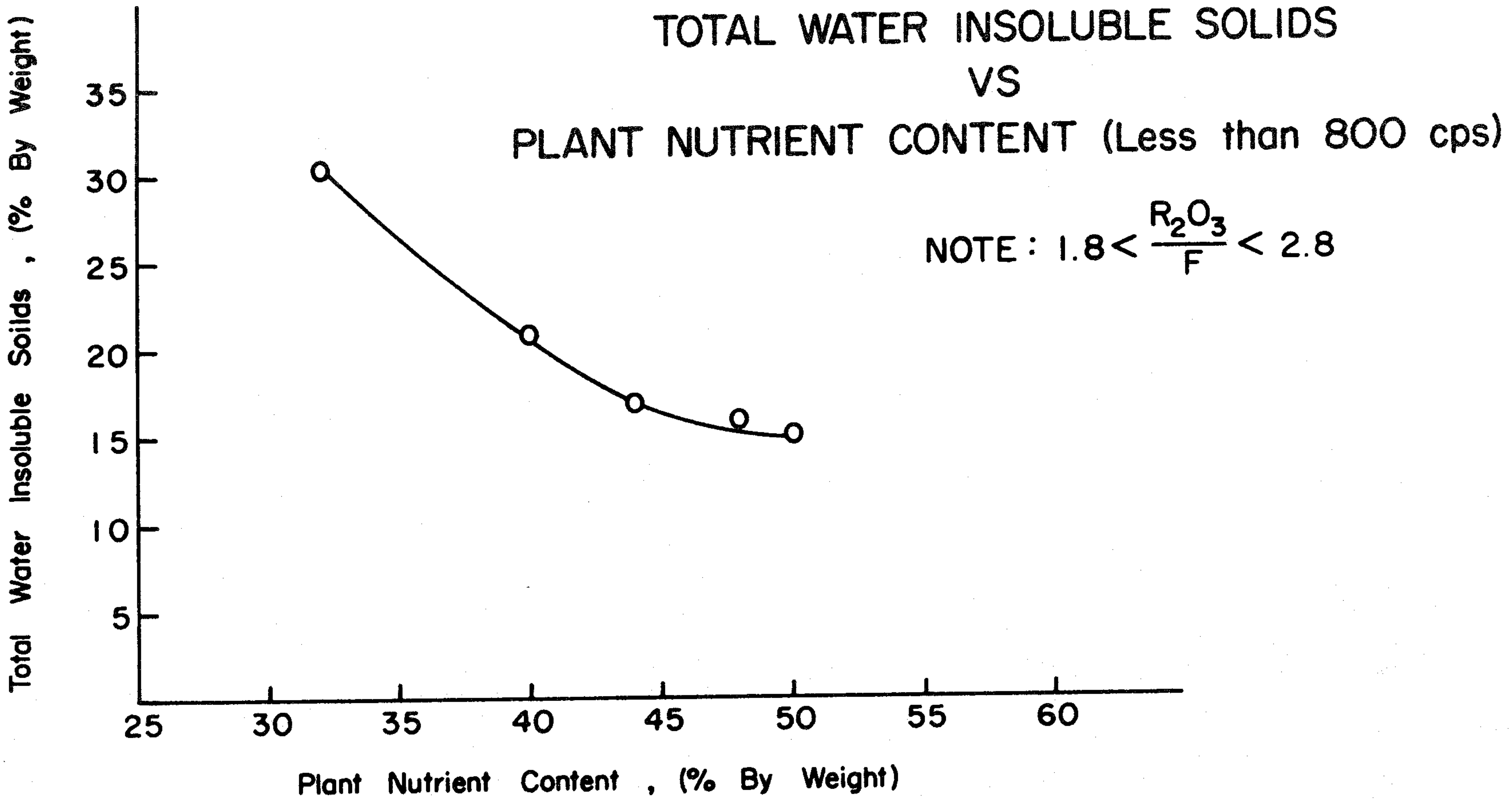

TOTAL WATER INSOLUBLE SOLIDS
VS
PLANT NUTRIENT CONTENT (Less than 800 cps)
NOTE: $1.8 < \frac{R_2O_3}{F} < 2.8$
Total Water Insoluble Solids, (% By Weight)
35
30
25
20
15
10
5
25
30
35
40
45
50
55
60
Plant Nutrient Content, (% By Weight)

FIGURE 6

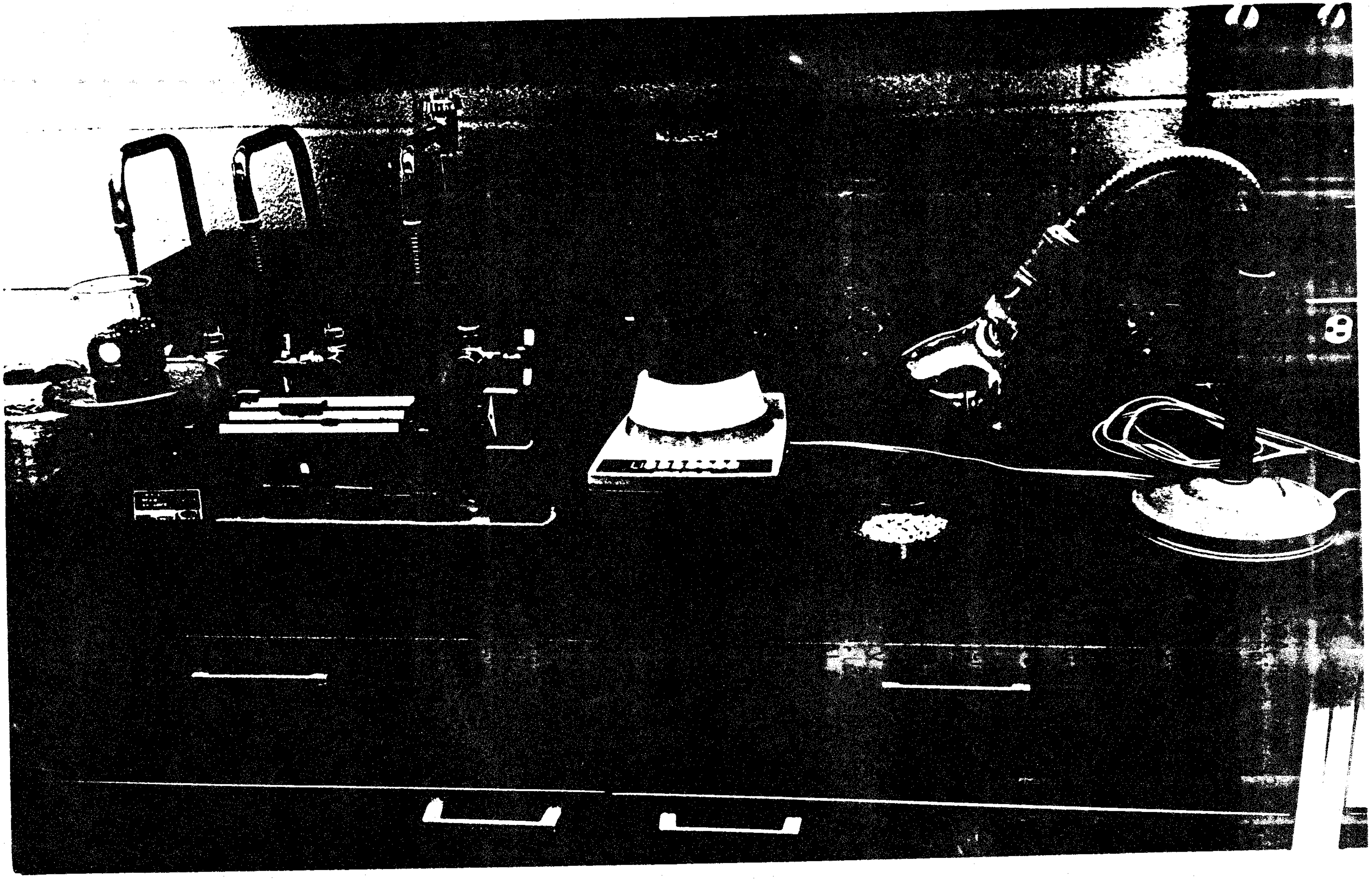


FIGURE 7

TEST EQUIPMENT FOR DETERMINATION OF WATER INSOLUBLE SOLIDS