

ISMA* Technical Conference

Brussels, Belgium
10-13 September 1968

**In 1982, the name of the International Superphosphate Manufacturers' Associations (ISMA) was changed to International Fertilizer Industry Association (IFA).*

LIQUID FERTILIZERS : TECHNOLOGY AND ECONOMICS

By Travis P. Hignett
Director of Chemical Development
Tennessee Valley Authority
Muscle Shoals, Alabama.

The rapid rise in popularity of liquid fertilizers in the United States has stimulated interest in them throughout the world. The purpose of this paper is to describe the technology and economics of producing and distributing liquid mixed fertilizers. Special emphasis will be placed on phosphatic materials used in the mixtures, as this subject is presumed to be of more direct concern to members of The International Superphosphate Manufacturers' Association.

Liquid mixed fertilizers are those which contain at least two of the three primary nutrients - N, P₂O₅, and K₂O. The term "liquid mixed fertilizers" is commonly used to include true solutions, suspensions and slurries. Some authors prefer the term "fluid fertilizers" which is scientifically preferable but has not been generally accepted by the industry. The terms "suspension" and "slurry" refer to liquids that contain solids. The solids may be soluble salts in a saturated solution, or insoluble compounds such as dicalcium phosphate. Some authors use the terms "suspension" and "slurry" interchangeably; others prefer to reserve the term "suspension" for mixtures that have been treated to minimize settling of the solid ingredients. The usual treatment is inclusion of 1 - 3% of gelling-type clay in the formulation. True solutions are sometimes called "clear liquids" to distinguish them from slurries or suspensions.

An important property of clear liquids is the "salting-out", the temperature at which some of the ingredients crystallize from solution. A salting-out temperature of 32° F. (0° C.) is often used as a standard, although obviously the requirements depend on climate, season, and length of storage.

STRUCTURE OF THE INDUSTRY

The liquid mixed fertilizer industry in the United States consists of over 1200 plants that compound the mixtures, using materials supplied by larger manufacturers. The annual production of these plants ranges from less than 500 tons to over 25,000 tons and may average between 2000 and 3000 tons. The plants are classified according to type of operation as "hot mix" or "cold mix". A hot mix plant is one that uses phosphoric acid and ammonia. The heat of reaction gives this type of plant its name "hot mix". A cold mix plant is one that purchases ammonium phosphate solution and mixes it with other ingredients; no heat of reaction is involved. When the liquid mixed fertilizer industry was getting started, most of the plants were of the hot mix type, since ammonium phosphate solution was not generally available. Now, cold mix plants are growing in favour as ammonium phosphate solution is available from several large chemical companies. In a recent survey in which 524 plants replied to the question, 36% of the plants reported only cold mixing facilities, 43% used only hot mixing, and 21% used both methods.

Liquid mixed fertilizer plants may be owned by large chemical companies that supply some of their materials, by farmer co-operatives, or by independent companies or individuals. Probably about half are independently owned. Quite often they are operated in conjunction with other farm services, such as feed compounding or seed grain sales. A growing number of plants offer both solid and liquid fertilizers; farmers often prefer liquids for starter application and solids (usually bulk blended) for a basic broadcast application. Most liquid mixed fertilizer manufacturers also market anhydrous ammonia or nitrogen solutions and pesticides. Most of them offer custom application.

GROWTH OF LIQUID FERTILIZERS

Accurate estimation of the amount of liquid mixed fertilizer produced or used in the United States is difficult, partly because of the large and rapidly increasing number of small plants. According to statistics published by the U.S. Department of Agriculture (1), the consumption of liquid mixed fertilizer increased from 27,000 tons in 1954 to 458,000 tons in 1959 and to 1,032,000 tons in 1965. The number of plants producing liquid mixed fertilizer increased from about 300 in 1959 to 1231 in 1966. Since 1965 the consumption of liquid mixtures has increased much more rapidly. According to some estimates, the 1967 consumption may have been as high as 3 million tons, three times the 1965 figure, and about 14% of all mixed fertilizers. Figure 1 shows the growth in use of liquid mixed

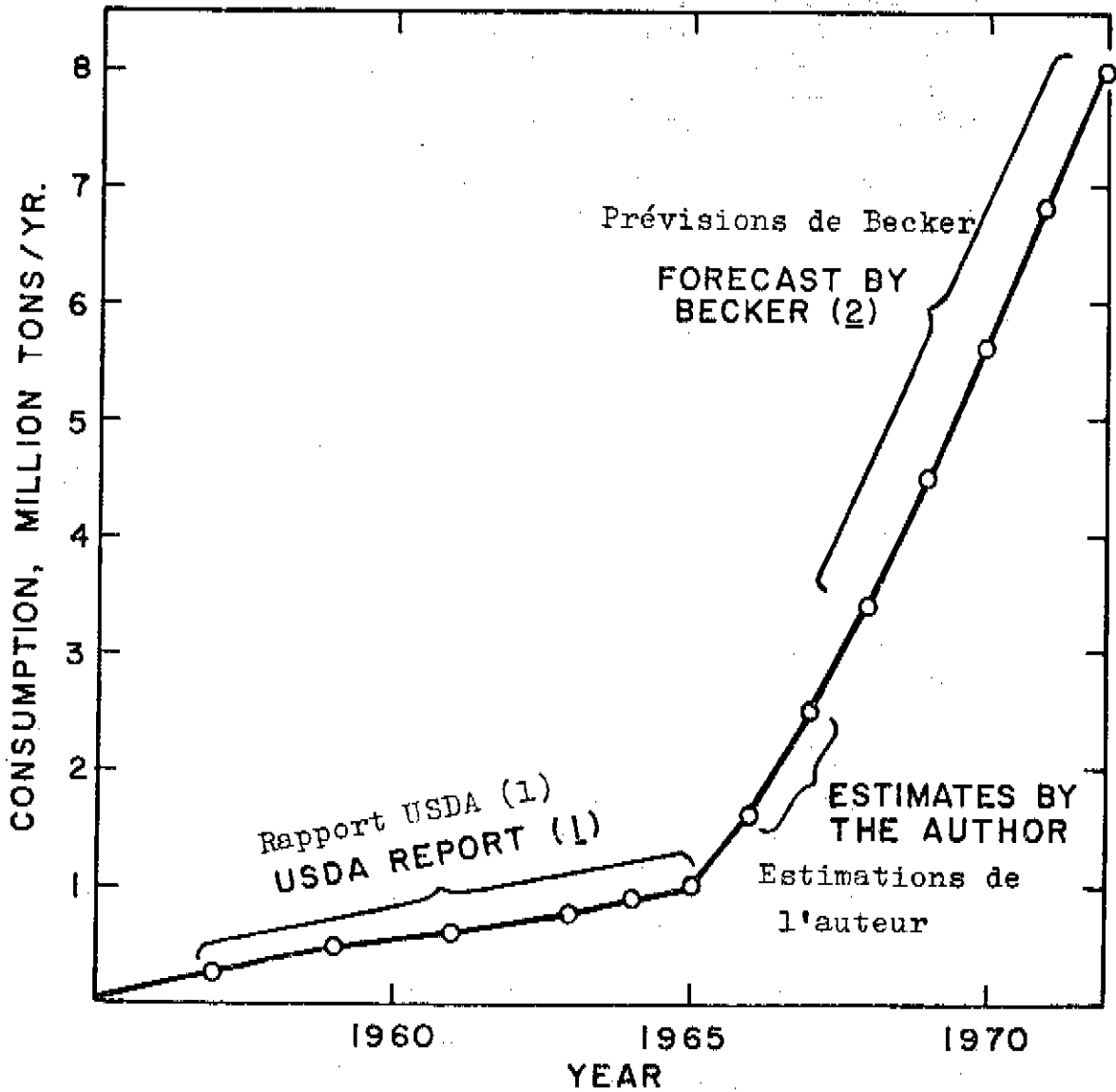


FIGURE I
CONSUMPTION OF LIQUID MIXED FERTILIZER
IN UNITED STATES

CONSOMMATION D'ENGRAIS COMPOSES LIQUIDES AUX ETATS-UNIS

fertiliser from 1957 and the forecast growth to 1972. The forecast is taken from a paper by Army (2) who attributed it to Becker.

The spectacular growth in the last 2 years probably was due in a large part to increased supplies of superphosphoric acid and base solutions made from it. Lack of a sufficient supply of suitable phosphatic materials had limited growth for several years. Contributing factors were increased supplies of nitrogen solutions, urea, ammonia and liquid-grade potash. Also, the competitive position of liquids with respect to bulk blends has improved because of an increased price differential between granular potash required for blends and fine potash used for liquids.

Use of liquid nitrogen materials for direct application has also grown rapidly as shown in the following tabulation.

	Consumption of liquid fertilisers in the U.S., millions of tons		
	1965	1966	1967
Anhydrous ammonia	1.5	2.0	2.4
Aqua ammonia	0.7	0.9	0.8
Nitrogen solutions	1.9	2.3	2.5
Liquid mixed fertilisers	1.0	1.6	2.5
Total liquid fertilisers	5.1	6.8	8.2

The total liquid fertiliser use in 1967 was about 22% of the total of all forms of fertiliser.

The principal reason for the growing popularity of liquid mixed fertiliser is convenience. The most important element of convenience is trouble-free, labour-saving, mechanical handling and application. Farmers often prefer liquid fertilisers for starter application. The liquid is applied at the same time as the seed is being sown or planted. Solid fertilisers can, of course, be applied with the seed, but the operation takes more time and labour. Getting the seed sown or planted at the proper time is a critical operation, and the farmer is understandably impatient of anything that complicates or delays it, for there may be only a few days when the fields are dry enough in early spring. Other labour-saving practices are application of pesticide or herbicide with the liquid fertiliser, simultaneous application of liquid mixed fertiliser and anhydrous ammonia, and injection of liquid fertiliser into irrigation water.

A second reason for popularity of liquid mixed fertiliser is quality. Liquid fertilisers do not cake, they are not dusty, and they remain dependably free flowing. They are homogeneous and more apt to be "on grade" than bulk blends. They are obviously

completely soluble. Many farmers are convinced that they get better response from liquids. The combination of high solubility and accurate placement may give better response than would be obtained with some solid fertilizers.

From the viewpoint of the manufacturer, liquid fertilizers offer several advantages. The manufacturing operations generally are simple and economical. The equipment is inexpensive. Problems of fume, dust, caking hygroscopicity, and inhomogeneity are absent. Losses during manufacture are almost negligible. Control of composition is easier, and any errors can be corrected more readily.

The cost of the phosphatic component of liquid mixed fertilizers is somewhat higher than for solids. However, the nitrogen is less expensive. Fine potash used in liquids is less expensive than granular potash used in blends.

The main disadvantage of liquid mixed fertilizer is low analysis. The average analysis in 1965 was 8.1:15.2:5.7. For comparison, the average analysis of all mixed fertilizer (solid and liquid) in 1965 was 7.9:15.5:12.7. The main difference is in the K_2O content, which reflects the low solubility of potassium chloride in liquid mixtures.

In order to minimize the disadvantage of low analysis, the final product is transported only short distances from local mixing plants. Probably most liquid mixed fertilizers are transported no more than 25 miles. The materials for compounding liquid mixtures, on the other hand, may be shipped over long distances, but they are quite concentrated. The potash is usually refined potassium chloride (62% K_2O); the nitrogen is shipped as anhydrous ammonia (82% N) or urea/ammonium nitrate solution (28 to 32% N); and the phosphate may be shipped as a base solution (11:37:0), orthophosphoric acid (54% P_2O_5), superphosphoric acid (70 to 80% P_2O_5), elemental phosphorus (229% P_2O_5), or solid ammonium polyphosphate (15:61:0).

THE ROLE OF SUPERPHOSPHORIC ACID

The use of superphosphoric acid caused a major breakthrough in the technology of liquid fertilizers. "Superphosphoric acid" is a term generally applied to phosphoric acid containing a substantial percentage (usually 50 to 80%) of its P_2O_5 in the form of polyphosphoric acids. The use of superphosphoric acid has the following advantages.

1. Higher analysis base solutions can be prepared because of the high solubility of ammonium polyphosphates.

2. Since polyphosphates will sequester the impurities in wet-process acid, this acid can be used in the preparation of clear solutions.
3. Substantial amounts of trace elements can be dissolved in ammonium polyphosphate solution, whereas many of these elements are essentially insoluble in ammonium orthophosphate solution.

Although superphosphoric acid has been known for many years, its first known commercial use in making liquid fertilisers was in 1957 when superphosphoric acid produced by the Tennessee Valley Authority was shipped to the West Kentucky Liquid Fertiliser Company, at Hopkinsville, Kentucky, where it was ammoniated to make a base solution (11:33:0). The superphosphoric acid contained about 76% P_2O_5 , and about 50% of the P_2O_5 was present as polyphosphoric acids, mainly pyro. This concentration was chosen because it was near a eutectic between ortho and pyrophosphoric acid which occurs at 75.4% P_2O_5 and 61° F. (16°C.). TVA had only limited success in promoting the use of superphosphoric acid by liquid fertiliser manufacturers. The main drawbacks were the scarcity and high cost of tank cars for transporting the acid and occasional difficulty with crystallization of the acid. Also, few liquid fertiliser manufacturers had suitable tanks for storing acid.

In 1959, TVA started manufacture of the 11:33:0 base solution from acid of about 76% P_2O_5 content. The grade was changed in 1960 to 10:34:0 which had a lower salting-out temperature. This solution became quite popular with liquid fertiliser manufacturers; it was shipped in mild steel tank cars or trucks and stored in mild steel tanks. Also, it relieved the manufacturers of the need for carrying out any chemical reactions. In 1962 the grade was changed again to 11:37:0, which was made from acid of 79 to 80% P_2O_5 content with a polyphosphate content of about 70%. A typical sample of 11:37:0 contained 27% of P_2O_5 as orthophosphate, 42% as pyrophosphate, 20% as tripolyphosphate, and 11% as higher polyphosphate. The solution has a pH of 5.8 - 6.2. Its viscosity is 80 centipoises, and its specific gravity is 1.4 at 75° F. (24°C.).

Several advantages of the 11:37:0 over earlier solutions soon became evident. Its higher polyphosphate content increased its sequestering ability. Control of the composition in the region of maximum solubility was easier because of the shape of the solubility curve (see Figure 2) (3). The 11:37:0 could be stored for several months at 0° F. (-18°C.) without crystallization. When crystals form, they are small, thin crystals of $(NH_4)_5P_3O_{10} \cdot 2H_2O$ that redissolve readily when the solution warms up; crystallization of solutions of lower polyphosphate content yielded large, thick crystals of $(NH_4)_2HPO_4$ that were difficult to dissolve.

Advantage was taken of the good cold weather storage properties of 11:37:0 to store substantial quantities in the northern Midwest States. Demand for liquid fertiliser is highly seasonal, and a

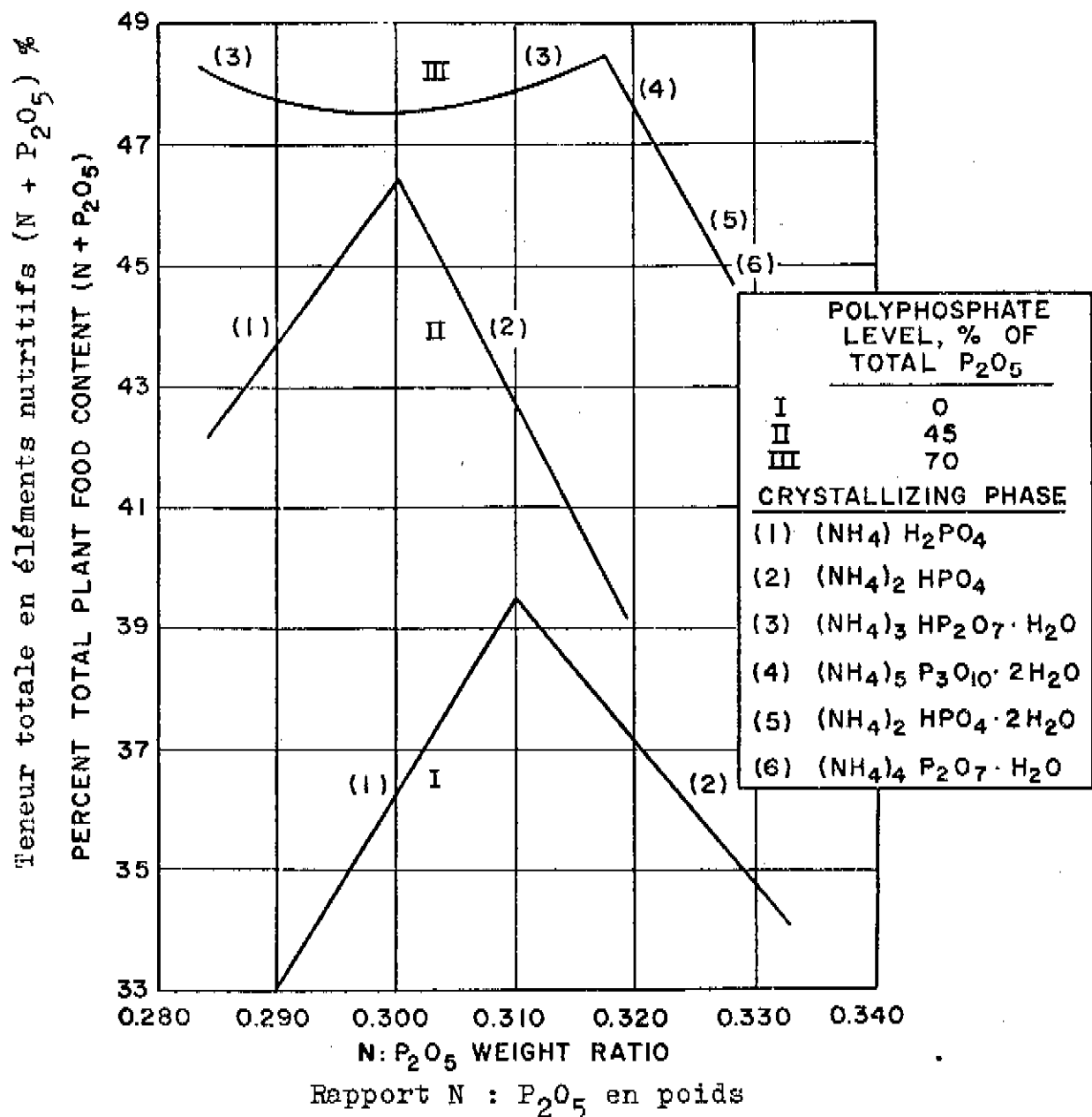


FIGURE 2
EFFECT OF POLYPHOSPHATE LEVEL AND N: P₂O₅ WEIGHT RATIO
ON SOLUBILITY OF AMMONIATED PHOSPHORIC ACIDS, 32°F (0°C.)

INFLUENCE DE LA TENEUR EN POLYPHOSPHATE ET DU RAPPORT
N : P₂O₅ EN POIDS SUR LA SOLUBILITE DES ACIDES PHOSPHORIQUES
AMMONIES A 0°C.

shortage of tank cars often develops in the peak season. To ensure an adequate supply and to take advantage of seasonal discounts, some producers purchased 11:37:0 in the autumn and stored it through the winter. Winter temperatures in the northern states often go as low as -20°F . (-29°C) and may average as low as 0°F . (-18°C) for as long as a month. Winter storage of 11:37:0 under these conditions has proved entirely satisfactory.

In the 1960's, wet-process superphosphoric acid began to become available, and by 1967, facilities were available to produce about 400,000 tons of P_2O_5 in this form; about 10% of the total wet-process acid capacity. Data are not available on actual production or what proportion was used to make liquid fertilisers. Both the wet-process superphosphoric acid and the ammoniated solution made from it are available to liquid fertiliser manufacturers. The usual grade of the solution is 10:34:0.

RAW MATERIALS FOR LIQUID MIXED FERTILISER

Furnace Acid

Phosphoric acid made by the electric-furnace process has only inconsequential amounts of impurities from the fertiliser manufacturer's viewpoint. The concentrations most used in liquid fertiliser are 54, 76, and about 80% P_2O_5 . The production of phosphoric acid from phosphorus in a modern plant has been described by Allgood et al. (4). The plant has sufficient flexibility to produce acids of any of the above concentrations without significant difference in operating cost, which is about \$ 4 per ton of P_2O_5 including depreciation but not including the cost of the phosphorus.

The properties of the acids of the three concentrations are:

Concentration, % P_2O_5	54	76	80
Specific gravity			
At 25°C .	1.573	1.921	1.986
At 75°C .	1.535	1.885	1.952
Viscosity, centipoises			
At 25°C .	19	800	-
At 75°C .	5	80	250
Crystallization temperature, ^a $^{\circ}\text{C}$.	15	21	54
Distribution of species, % of total P_2O_5			
Ortho	100	49	15
Pyro	0	42	39
Tripoly	0	8	24
Tetrapoly	0	1	12
Other	0	0	10

^aApproximate.

The orthophosphoric acid can be shipped and stored in rubber-lined or stainless steel tanks and handled without particular difficulty. The 76% P_2O_5 superphosphoric acid requires more care; it may crystallize at temperatures below 68° F. (20° C.), although it has a strong tendency to super cool. Its high viscosity at atmospheric temperatures makes it difficult to pump. When shipped, it is loaded into tank cars while hot and used immediately on arrival to make base solution (10:34:0) or liquid mixtures. Acid of about 80% P_2O_5 concentration usually is used to make base solution (11:37:0). It is seldom shipped, and only moderate quantities are stored because it crystallizes at about 129° F. (54° C.).

In the United States there are thirty plants operated by ten companies that produce phosphoric acid from elemental phosphorus. Nine of the plants are equipped to make superphosphoric acid.

Wet-Process Acid

Wet-process acid is used in liquid fertilizers both in the ortho form (54% P_2O_5) and as superphosphoric acid (70 to 73% P_2O_5). The main use of the ortho acid is in combination with sequestrants as explained later.

The ortho acid is clarified by aging and settling to remove a sludge which consists mainly of a complex compound, $(Fe, Al)_3KH_{14}(PO_4)_8 \cdot 4H_2O$ (5). The sludge is disposed of in triple superphosphate manufacture. Precipitation of sludge is never complete; more sludge forms during shipment and subsequent storage, eventually requiring cleaning of tank cars and storage tanks.

Wet-process superphosphoric acid is produced by concentrating the clarified 54% acid to 70 to 72% P_2O_5 . At this concentration it contains about 50% of its P_2O_5 as polyphosphoric acids. It is feasible to concentrate to a higher polyphosphate content, but difficulties with high viscosity may result, depending on the amount and kind of impurities in the acid. The acid contains little or no solids, and sludge does not form in it. Most wet-process superphosphoric acid does not crystallize in cold weather, but it becomes very viscous. To avoid handling problems due to high viscosity, the acid usually is kept warm (150° to 200° F. (66° to 93° C.)) and shipped in insulated tank cars which are said to limit temperature drop to about 2° F. (1° C.) per day in 0° F. (-18° C.) weather.

About forty-four plants in the United States produce wet-process phosphoric acid, of which thirteen are reported to produce superphosphoric acid.

The chemical composition of typical samples of wet-process superphosphoric acid is given in Table I.

TABLE I
Chemical Analyses
of Wet-Process Superphosphoric Acid

Percent by weight							
<u>P₂O₅</u>							W.I.
<u>Total</u>	<u>Ortho</u>	<u>Fe₂O₃</u>	<u>Al₂O₃</u>	<u>F</u>	<u>SO₃</u>	<u>MgO</u>	<u>solids</u>
<u>Acid Made with Uncalcined Florida Phosphate Rock</u>							
72.9	31.8	2.2	1.8	0.3	2.0	0.3	0.4
<u>Acid Made with Calcined Western Phosphate Rock</u>							
72.5	34.0	1.2	3.0	0.3	2.1	0.8	0.3
<u>Acid Made with Uncalcined North African Phosphate Rock</u>							
72.4	25.1	0.6	0.4	0.12	2.7	1.1	0.4

Ammonium Phosphate Base Solutions

The first step in preparing liquid mixed fertilizer is to ammoniate the phosphoric acid with anhydrous or aqua ammonia to make a base solution which may be stored or shipped or it may be converted immediately to an N:P:K mixture. The principal base solutions are 8:24:0 (all orthophosphate), 10:34:0 (about 50% polyphosphate), and 11:37:0 (about 70% polyphosphate). The influence of the polyphosphate content on the solubility is shown in Figures 2 and 3 taken from Slack (3). If the solution is used immediately, the heat of reaction may be utilized to dissolve potassium chloride and urea which have negative heats of solution. If stored, the polyphosphate should be cooled to about 100° F. (38° C.) to prevent rapid hydrolysis in storage.

The rate of hydrolysis is negligible in winter weather, but in summer weather in Alabama when the temperature of the solution in storage ranged from 70° to 100° F. (21° to 38° C.), about one-third of the polyphosphate content of 11:37:0 hydrolyzed to orthophosphate in 6 months. The following tabulation shows the effect of temperature on the rate of hydrolysis of an 11:37:0 solution (pH 6.0) containing 69% of its P₂O₅ in polyphosphate form.

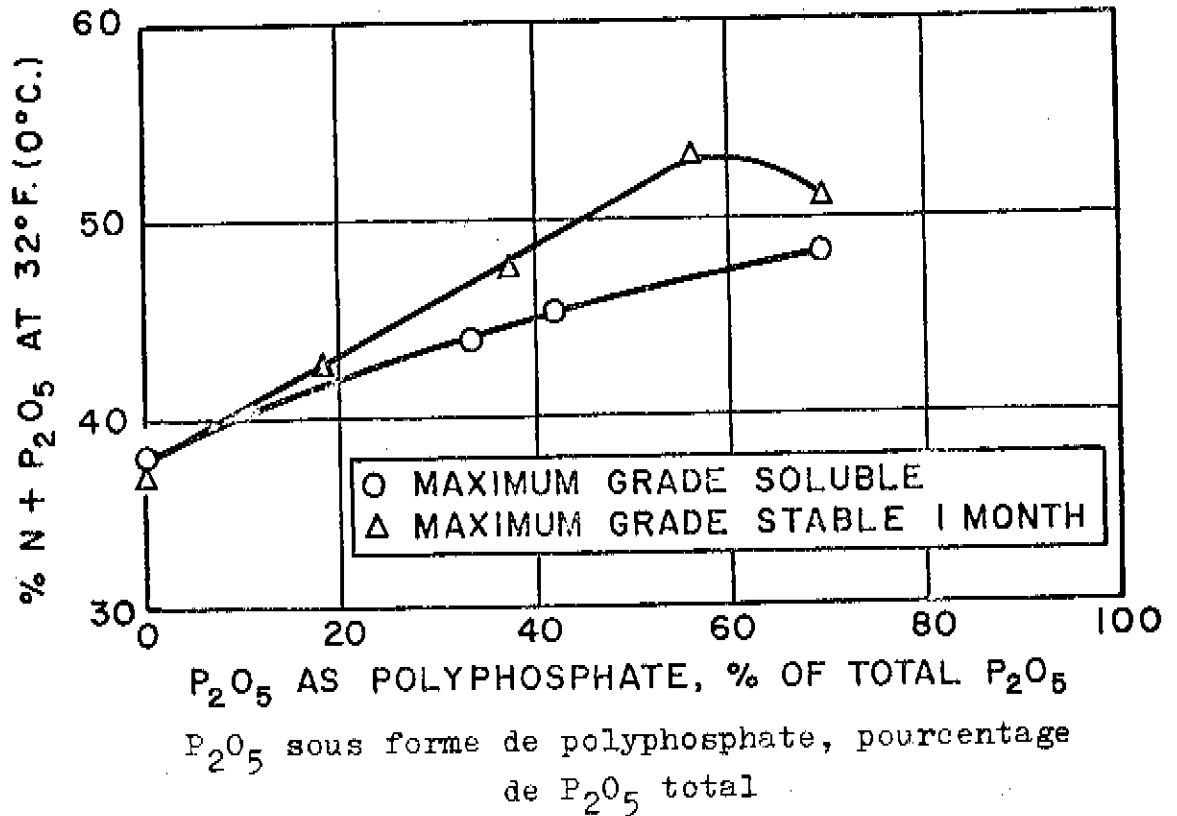


FIGURE 3
EFFECT OF POLYPHOSPHATE CONTENT ON
PLANT FOOD SOLUBILITY AND STABILITY
AT N: P₂O₅ WEIGHT RATIO OF 0.30

INFLUENCE DE LA TENEUR EN POLYPHOSPHATE SUR LA SOLUTION ET
 LA STABILITE DES ELEMENTS NUTRITIFS POUR UN RAPPORT
 N : P₂O₅ EN POIDS DE 0,30

<u>Temperature</u>		<u>Monthly decrease in polyphosphate content, % of polyphosphate initially present</u>
<u>°F</u>	<u>°C.</u>	
80	27	2.2
100	38	9.4
110	43	18.8
120	49	30.4

The ammonium phosphate solutions commonly are stored in mild steel tanks and shipped in steel tank cars or barges.

The base solutions may be prepared by the liquid fertiliser manufacturer as a step in making the final product. More often the base solution is prepared by the manufacturer of the acid or by a regional hot mix plant, and the base solution is then shipped to cold mix plants.

Base solutions made by ammoniation of wet-process superphosphoric acid are opaque black to clear green, depending on the type of rock used to make the acid. The black solution contains a carbonaceous precipitate which may settle on long standing, leaving a clear, green supernatant solution. The solutions may form magnesium ammonium phosphate crystals if the phosphate rock or water used in their preparation is high in magnesium. $Mg(NH_4)_2P_2O_7 \cdot H_2O$ is an example of a crystalline compound often found in base solutions. The crystals form slowly over a period of weeks or months, and often grow to such size that they cause difficulty by plugging nozzles or strainers.

A process has been developed by TVA on a pilot-plant scale whereby 10:34:0 ammonium polyphosphate solution is produced directly from wet-process orthophosphoric acid without the intermediate production of superphosphoric acid (6). The process is not known to be in commercial use.

Nitrogen Materials

The principal nitrogen materials used in liquid mixed fertilisers are ammonia (for neutralizing phosphoric acid) and urea-ammonium nitrate solution. The solution contains approximately equimolar proportions of ammonium nitrate and urea which gives maximum solubility. Such a solution containing 32% total N has a salting-out temperature of 32° F. (0° C.). For winter storage in the northern states a less concentrated solution containing 28% N is preferred. It has a salting-out temperature of 0° F. (-18° C.). Aluminium tanks are preferred for storage of these solutions.

Although combinations of urea and ammonium nitrate give maximum solubility in themselves, they do not provide maximum solubility in N-P-K mixtures; potassium nitrate formed through reaction of ammonium nitrate and potassium chloride limits solubility. For this reason, some producers prefer to use more urea in the mix and less ammonium nitrate or none.

Urea may be supplied as urea-ammonia solution which is used to neutralize phosphoric acid. Or solid urea may be added to the mixture. Recent decreases in the price of urea may make this latter alternative more attractive although it is less convenient than using liquid materials.

Potash Materials

Potassium chloride is used almost entirely to furnish the potash content of liquid mixed fertilisers. White potash made by recrystallization processes is preferred because it has no water-insoluble impurities. The usual grade is 62 to 63% K_2O . A fine particle size is preferred for rapid dissolution.

Some use of caustic potash solution (neutralized by phosphoric acid) has been reported in mixtures that are used for tobacco fertilisation, but this material is too expensive for general use.

Other Materials

Solid ammonium polyphosphate has been used recently in place of base solutions. This is a high-analysis (15:61:0) granular material made by TVA from electric-furnace superphosphoric acid (7). It is shipped in bulk in covered, hopper-bottom rail cars or in barges. It is particularly attractive when long-distance shipments are involved. Use of this material to make liquid (suspension) fertilisers in Hawaii has been reported (8). Use of solid, crystalline diammonium phosphate also has been reported.

When sulphur is required in liquid mixed fertilisers, it is often supplied as solutions of ammonium bisulphite or ammonium thiosulphate which are marketed for that purpose.

Various micronutrient materials are used, although care must be taken to select those that are soluble. Salts and oxides of iron, copper, manganese, and zinc are nearly insoluble in ammonium orthophosphate solution, but many of these materials are appreciably soluble in ammonium polyphosphate solution.

MANUFACTURING OPERATIONS

Production of Ammonium Polyphosphate Base Solution

A detailed description of the production of 11:37:0 in the TVA plant has been published (9). A diagram of the plant showing recent changes is shown in Figure 4. The operation is a simple one; control of the $N:P_2O_5$ ratio is by pH, and control of the concentration is through specific gravity. The total operating cost in a recent 6-month period was \$1.07 per ton of product. The plant capacity is about 15 tons per hour.

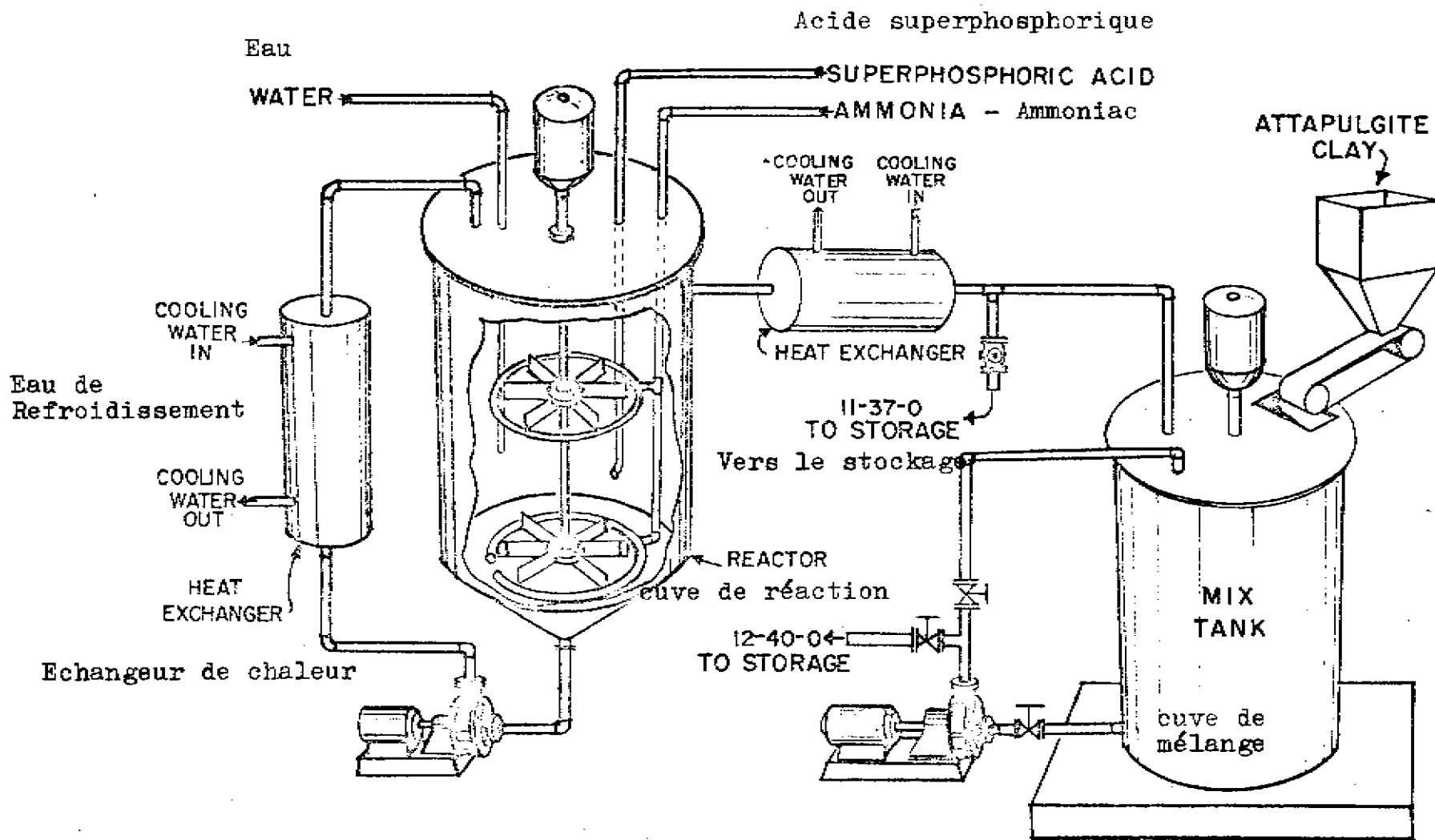


FIGURE 4

TVA PLANT FOR PRODUCTION OF 11-37-0 LIQUID
OR 12-40-0 SUSPENSION FERTILIZER

ATELIER TVA POUR LA PRODUCTION D'ENGRAIS LIQUIDE 11 : 37 : 0 OU EN SUSPENSION 12 : 40 : 0

Hot Mix Plants

Some hot mix plants use a continuous process similar to TVA's, but most of them use a batch method for making N-P-K grades. Many plants receive anhydrous ammonia and convert it to aqua ammonia which is stored and later used to ammoniate phosphoric acid. A heat exchanger is used to remove the heat of solution that is generated during production of aqua ammonia. The same heat exchanger is used to cool the solution during neutralization of the acid by recirculating the solution from the mix tank through the heat exchanger. A plant of this type is shown in Figure 5.

Sequestration

Many liquid mixed fertiliser manufacturers use wet-process orthophosphoric acid together with a sequestrant. One advantage is that wet-process orthophosphoric acid is cheaper than superphosphoric acid. Also, superphosphoric acid and its derivatives have been in short supply, so with a limited amount of these materials, more liquid mixed fertiliser can be made by using them as sequestrants.

Disadvantages of using wet-process orthophosphoric acid with a sequestrant are that most of the products are lower grade, the production method is more complicated, and the products are more likely to form precipitates on standing.

The sequestrants used are superphosphoric acid and its ammoniated products. Probably 11:37:0 is the most popular sequestrant. The proportion of sequestrant required to solubilize the impurities in wet-process acid is such that 20 to 60% of the P_2O_5 in the product is supplied by the sequestrant, depending on the impurity content of the wet-process acid and the sequestrant, the polyphosphate content of the sequestrant, and the grade of the mixed fertiliser. Procedures for sequestration have been described (10).

Cold Mix Plants

Cold mix liquid fertiliser plants are growing in popularity because they are simple and inexpensive. They are essentially a blending and mixing operation, the liquid counterpart of the bulk blend plants.

Owing to the lower cost of equipment for handling and storing liquids, liquid cold mix plants are cheaper than bulk blend plants. Scott (11) gives typical investment costs of \$ 25,000 for a liquid cold mix plant, \$ 45,000 for a bulk blend plant, and \$ 60,000 for a liquid hot mix plant. Abell (12) states that cold mix plants are more economical than hot mix for annual outputs up to 3000 tons.

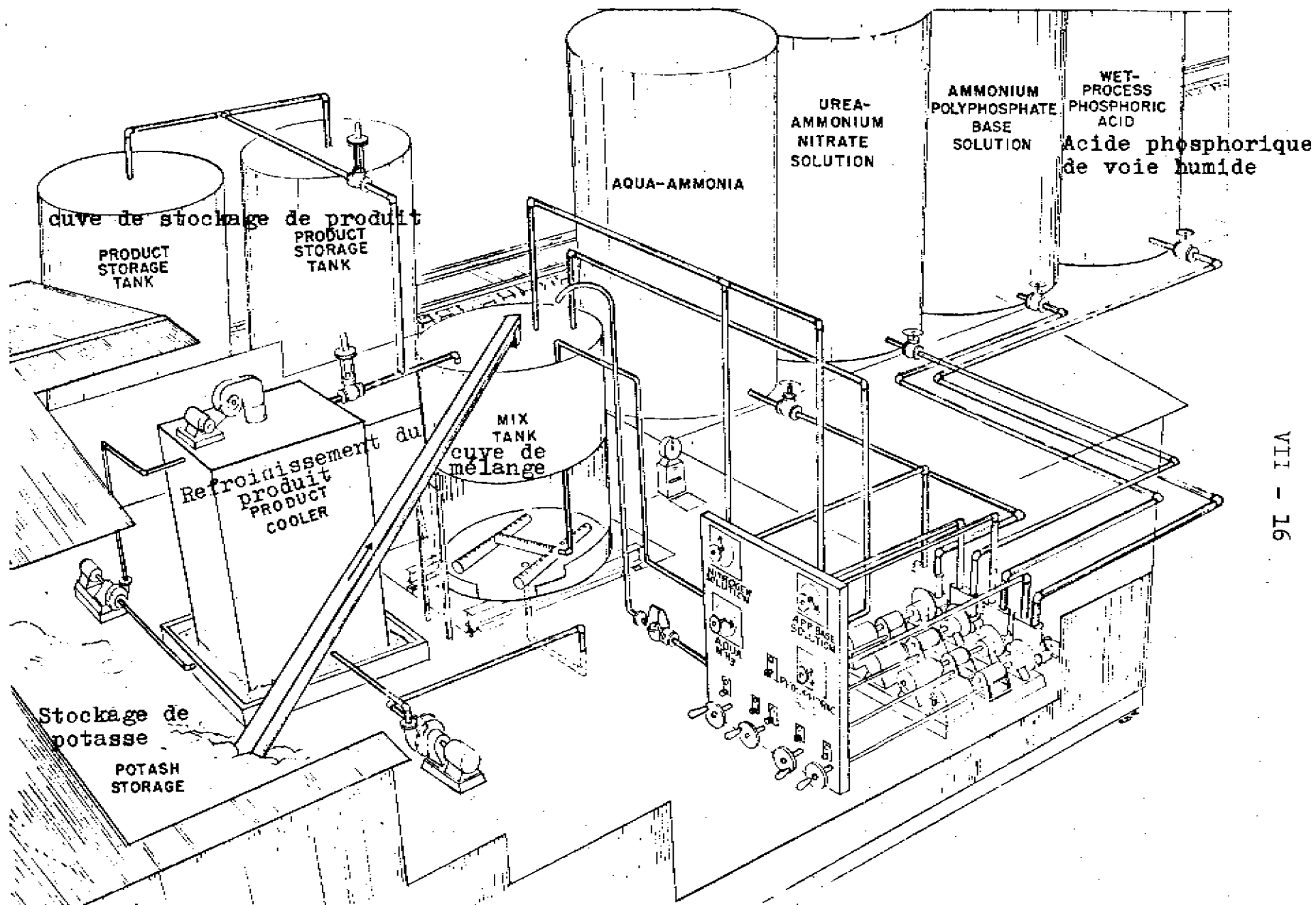


FIGURE 5

TYPICAL HOT-MIX PLANT EQUIPPED TO USE SEQUESTRATION TECHNIQUE
 ATELIER TYPIQUE DE MELANGE A CHAUD EQUIPPE POUR EMPLOYER LA TECHNIQUE DE SEQUESTRATION

A diagram of a typical cold mix plant is shown in Figure 6. It includes storage tanks for base solution or suspension and nitrogen solution, and bulk storage for solid potash. Mixtures are prepared batchwise in the mixing tank which has a capacity of 5 tons. The potash is screened using a screen with 1/8-inch openings to remove trash or occasional large lumps. The mixing time is that required to dissolve the potash which depends on the degree of agitation, the temperature of the materials, and the saturation temperature of the final solution. When the initial temperature of the mix is at least 20° F. (11° C.) above the saturation temperature, dissolution should be completed in 15 to 20 minutes.

In areas where potash is not needed, as in some parts of the western United States, a very simple cold mix plant can be used as shown in Figure 7. It consists merely of storage tanks for phosphate-base solution and nitrogen solution, a pump, and a meter. Mixtures are made by metering these two materials and water successively into the nurse tank. A similar system may be used to supply potash-containing grades by adding a third tank to supply a high-potash solution or suspension. Plants of this type are called "satellite" plants, as they depend on a central plant to supply the high-potash liquids and sometimes the phosphatic base liquid.

The simplicity of these plants reminds one of Cunningham's prophetic words (13) 9 years ago:

It may be that in time the country will be covered with depots like petrol pumps from which farmers can get nitrogen solutions with minor elements added as required..... If N, why not P and K ?

SUSPENSION FERTILISERS

A disadvantage of clear liquids is the low analysis of grades that contain a substantial proportion of K_2O . This disadvantage is minimized by the marketing system; the final mix is seldom transported far. Nevertheless, the increased cost of transportation and application often is significant.

By going to suspensions, the analysis can be increased to a level comparable with granular solid or bulk blended fertilisers. For instance, popular grades of suspension fertilisers are 7:21:21, 3:10:30, 10:20:20 and 15:15:15, about twice that obtainable in clear liquids in these ratios.

The advantages of higher analysis have stimulated much interest in suspensions. Although the estimated production of suspensions in 1967 was only 10% of the total production of liquid mixed fertilisers, a survey indicated the production was likely to double in 1968.

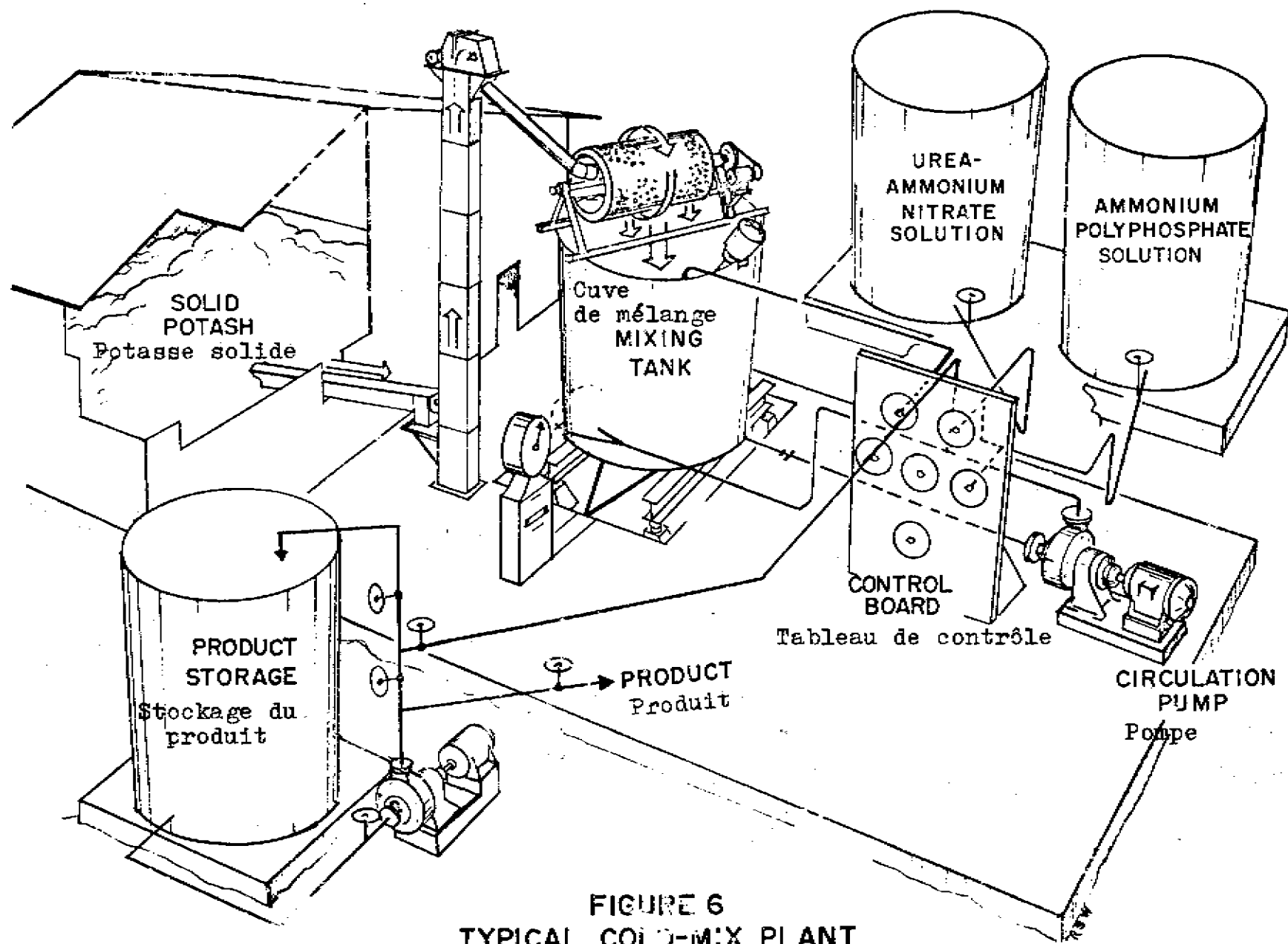
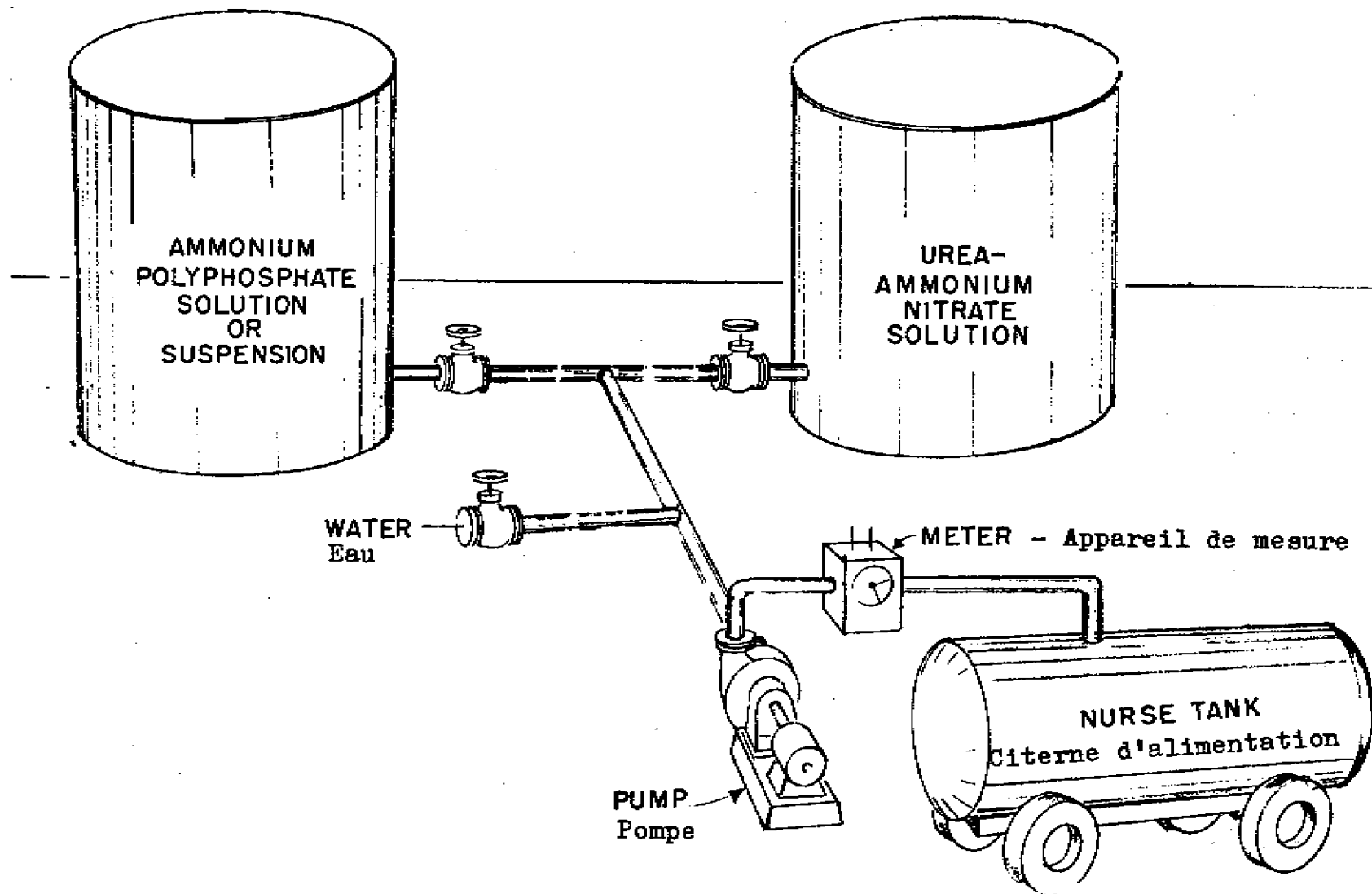


FIGURE 6
TYPICAL COLD-MIX PLANT

US LIER TYPIQUE DE MELANGE EN VRAC



VII - 19

FIGURE 7
 COLD MIX PLANT FOR NON-POTASH GRADES
 ATELIER DE MELANGE A FROID POUR DES FORMULES SANS POTASSE

Handling and application of suspensions, in its present state of development, are not as simple, convenient, and trouble-free as for clear liquids. From the farmer's viewpoint, the main advantage of liquids is convenience, and this advantage is lost in going to suspensions. It is likely, therefore, that liquid fertilisers applied by the average farmer will continue to be mainly clear liquids in the immediate future, although suspensions are already being used by some farmers (14). Farmer-applied liquid fertilisers are mainly starter fertilisers which need not contain much potash and can be fairly high in analysis.

On the other hand, much of the basic fertiliser application is custom-applied by broadcasting before ploughing, often in the form of bulk blends. If the fertiliser is custom-applied, the farmer is not concerned with the ease of application. Custom application of suspensions offers the liquid fertiliser industry a means for competing with bulk blends. The market for broadcast fertiliser for plough down is substantially larger than for starter fertiliser, so any success in this field will greatly increase the sales potential of liquids. Some success is already apparent: in some areas, plans for new bulk blend plants have been cancelled in favour of suspension facilities.

Suspension fertilisers are made in the same types of plants as clear liquid fertilisers. For instance, 12:40:0 base suspension is made by TVA in the same plant as the clear liquid 11:37:0 (see Fig.4). The only change in the operation is to add less water in the reactor and to add 3% clay in the mixing tank. The properties of the clay are shown in Table II. The suitability of clay for making suspensions must be determined by tests as it cannot be predicted from its chemical analysis or physical properties. The desired type is a clay that forms a gel when agitated vigorously with aqueous solutions. Its function is to increase the viscosity of the liquid and thus prevent settling, and to hinder crystal growth in saturated solutions. About 1.0 to 1.5% clay is sufficient, but 3% is added to 12:40:0 base suspension to allow for dilution when the base suspension is used to make other grades. For instance, when 12:40:0 is used to make a 7:21:21 suspension, the clay content of the final product is about 1.5%.

TABLE IIProperties of a Commercial Attapulgite Clay

Analysis (moisture-free basis), % by weight	
SiO ₂	59.2
Al ₂ O ₃	10.5
MgO	10.6
Fe ₂ O ₃	3.6
CaO	1.4
K ₂ O	1.0
TiO ₂	0.5
Ignition loss	11.4
CO ₂	2.0 (maximum)
Free moisture (as produced), %	11-14
Colour	Light grey
pH	7.5 - 8.5
Specific gravity	2.4
Bulk density (packed), lb/cu.ft	35 - 40
Wet screen analysis (+325 mesh), %	5 (maximum)

The specific gravity of the 12:40:0 suspension is 1.44 at 75°F. (24 C.), and its viscosity is about 700 centipoises at the same temperature. Similar suspensions, slightly lower in grade, are made from wet-process superphosphoric acid.

N-P-K suspensions may be made in cold mix plants using either a base suspension or a base solution plus clay. This is merely a blending process, much the same as cold blending of clear liquids. Since it is not necessary that all materials be highly soluble, there is a greater choice of raw materials. Care must be taken to see that the final suspension has the proper consistency and viscosity to avoid rapid settling, but is still fluid enough for pumping and spraying. All solid materials added should have fine particle size. Particular care should be taken to avoid large particles that might clog strainers or spray nozzles. In general, particles larger than 20 mesh should be avoided.

Storage, handling, distribution, and application of suspensions involve some problems which are being solved by cooperative efforts of liquid fertiliser manufacturers and application equipment

manufacturers. Although base suspensions have reasonably good storage properties, the final mix often does not. So the mixtures are made as they are needed to avoid extended storage. Continuous or intermittent agitation is provided to prevent settling or to resuspend settled material. Various improvements in pumps, strainers, and nozzles have helped. Much study is being given to improving the quality of suspensions and devising methods and equipment to handle and apply them. Successful systems for custom application are in sight, but it may be some time before systems simple enough for use by the average farmer are evolved.

ECONOMICS

In comparing liquid fertilisers with solid compound or blended fertilisers, it is evident that both are made from the same basic raw materials; phosphate rock, sulphuric acid, ammonia, and potassium chloride. Both involve the same or similar intermediates; phosphoric acid and nitric acid or urea. Intermediates for solid fertilisers are initially produced as liquids or slurries. The drying, granulating, and sizing steps that are necessary for making solid fertilisers are omitted in the manufacture of liquids, which is an economic advantage. On the other hand, most liquid processes involve production of superphosphoric acid, which is somewhat more expensive than orthophosphoric acid.

A comparison in 1964 (15) indicated that liquid mixed fertilisers would be slightly more expensive than bulk blends. Granular compound fertilisers would be more expensive than either when the higher cost of distribution associated with the larger output of the granulation plant was taken into account. However, it was concluded that no important economic difference was inherent in these various forms.

More recent estimates (11,16) indicated that clear liquids were slightly more expensive and suspensions slightly cheaper than bulk blends. All three estimates indicated that the cold mix process was economically preferable to the hot mix for plants of about 3000 tons per year output.

The estimates mentioned above were based on market prices of intermediate materials. Market prices are influenced by supply and demand, as well as cost of production. For the last few years, intermediate materials for liquid fertilisers, especially the phosphatic materials, have been in greater demand relative to their supply than solids, so the market price has held up rather well, whereas the price of solid materials has weakened owing to the pressure of oversupply. No doubt this situation will encourage manufacturers to increase production of liquid intermediates and thereby bring about a more equitable balance between supply and demand of materials for liquids and solids.

At the present time, prices of fertilizer intermediates are chaotic; some intermediates are being sold at discounts of 20 to 30% from listed market prices. Since present market prices of fertilizer intermediates are unstable, they are not reliable basis for comparison of the relative cost of solid and liquid mixed fertilizers.

In the present comparison, an attempt was made to compare the economics of solid, bulk blended fertilizers with liquid mixed fertilizers on the basis of an estimated selling price which would yield a substantial return on investment. Ammonium phosphate is an important ingredient of both solids and liquids, diammonium phosphate (18:46:0) in bulk blends, an ammonium polyphosphate solution or suspension (10:34:0 or 11:37:0) in liquids. The prices of these materials were estimated, based on estimated production, storage, and transportation costs plus 20% return on investment. The estimates are shown in Tables III and IV. It was assumed that the liquids would be produced in Iowa from wet-process superphosphoric acid made in Florida. Solid diammonium phosphate was assumed to be produced in Florida and shipped in bulk to Iowa. The estimated price in Iowa of the three materials, 18:46:0, 10:34:0, and 11:37:0, is about the same per ton $N + P_2O_5$.

Both bulk blends and liquid mixed fertilizers are made in small, local mixing plants. In the case of the liquids, it was assumed that the base solution or suspension would be shipped from the regional plant in Des Moines to cold mix plants in the area. An average transportation cost of \$ 4 per ton was assumed, which corresponds to rail shipment for a distant of 150 to 200 miles. Solid diammonium phosphate was assumed to be shipped directly from Florida to the local bulk blend plant and hence would not incur any extra transportation costs.

The estimated cost of producing 1:1:1 ratio bulk blends and liquids in local plants in Iowa is shown in Table V. The liquids have the advantage of lower potash cost (granular potash is required for blends) and lower nitrogen material cost. The operating cost per ton is lower for liquids than blends, principally because of the lower investment cost; however, the concentration of the liquid suspension is somewhat lower and the clear liquid is much lower than that of the blend. The net result is that the estimated price of the suspension is slightly less, and that of the clear liquid is slightly more than that of the blend. However, the differences are small and probably not significant in view of the large number of variables that can affect costs.

TABLE IIIEstimated Price of Diammonium Phosphate (18:46:0)Produced in Florida and Shipped to Iowa

	<u>\$/ ton of</u> <u>P₂O₅</u>
<u>Wet-Process Phosphoric Acid</u>	
Production cost ^a (17)	85.70
Clarification	2.00
Return on investment (17) (20% of \$ 16.5 million)	<u>16.20</u>
Total acid cost	103.90
	<u>\$/ ton of</u> <u>18:46:0</u>
<u>Production of 18:46:0 (230,000 Tons/Yr.)</u>	
Phosphoric acid (0.46 ton of P ₂ O ₅ x \$ 103.90)	47.79
Ammonia (0.22 ton x \$ 60)	13.20
Losses and overage (2% of raw materials cost)	<u>1.22</u>
Total raw materials cost	62.21
Production expense	3.58
Storage and loading expense	1.50
Return on investment (20% of \$ 3.0 million)	2.61
Interest on working capital (6% of \$ 1.0 million)	0.26
Sales and administrative expense (5% of price)	<u>3.69</u>
Selling price f.o.b. Florida ^b	73.85
Freight to Des Moines, Iowa	<u>14.10</u>
Delivered price	87.95
Price per ton of N + P ₂ O ₅	<u>137.42</u>

^a Adjusted to sulphur cost of \$ 41.60 per short ton, delivered.

^b No allowance was made for property tax and insurance.

TABLE IV

Estimated Price of 10:34:0 Liquid or 11:37:0 SuspensionProduced in Iowa from Superphosphoric Acid Shipped from Florida

	<u>\$/ton of</u>	
	<u>P₂O₅</u>	
<u>Wet-Process Superphosphoric Acid</u>		
Cost of production (17)	85.70	
Conversion to superphosphoric acid, including clarification	10.00	
Return on investment (17) (20% of \$ 16.5 million)	16.20	
Freight from Florida to Des Moines, Iowa (\$ 16.62/ton)	23.10	
Excess of car rental over mileage allowance	<u>0.56</u>	
Total delivered acid lost	135.56	
	<u>\$/ton of product</u>	
	<u>10:34:0</u>	<u>11:37:0</u>
<u>Cost of 10:34:0 Liquid or 11:37:0 Suspension</u>		
<u>Produced in Iowa (37,000 Tons of P₂O₅/Yr)</u>		
Superphosphoric acid (\$135.56/ton of P ₂ O ₅)	46.09	50.16
Ammonia (\$60/ton)	7.30	8.04
Clay	-	1.20
Losses and overage (1% of raw materials cost)	<u>0.53</u>	<u>0.59</u>
Total raw materials cost	53.92	59.99
Production expense ^a	1.07	1.16
Storage and loading expense ^a	1.00	1.00
Return on investment (20% of \$0.8 million)	1.47	1.60
Interest on working capital (6% of \$0.41 million)	0.23	0.25
Sales and administrative expense (5% of price)	<u>3.04</u>	<u>3.37</u>
Estimated price	60.73	67.37
Price per ton of N + P ₂ O ₅	138.02	140.35

^aBased on experience in TVA plant.

TABLE V

Estimated Prices of Clear Liquid, Suspension, and Bulk Blend in Iowa

(1:1:1 Ratio)

<u>Material</u>	<u>\$/ton</u>	<u>Lb./ton of product</u>	<u>\$/ton of product</u>
<u>Bulk Blend, 17:17:17</u>			
18:46:0	87.95	740	32.54
NH ₄ NO ₃ (33.5% N)	64.00 ^a	618	19.78
KCl (60% K ₂ O)	35.67	567	10.11
Filler	2.00	75	<u>0.08</u>
Total materials cost			62.51
Operating cost and return on investment (18)			<u>8.96</u>
Estimated selling price			71.47
Price per ton of N + P ₂ O ₅ + K ₂ O			140.14
<u>Suspension, 15:15:15</u>			
11:37:0	71.37 ^b	812	28.98
N solution (32% N)	45.44 ^a	658	14.95
KCl (62% K ₂ O)	32.37	485	7.85
Water	-	45	<u>-</u>
Total materials cost			51.78
Operating cost and return on investment (18)			<u>6.26</u>
Estimated selling price			58.04
Price per ton of N + P ₂ O ₅ + K ₂ O			128.98
<u>Clear Liquid, 8:8:8</u>			
10:34:0	64.73 ^b	471	15.24
N solution (32% N)	45.44 ^a	353	8.02
KCl (62% K ₂ O)	32.37	258	4.18
Water	-	918	<u>-</u>
Total materials cost			27.44
Operating cost and return on investment (18)			<u>6.26</u>
Estimated selling price			33.70
Price per ton of N + P ₂ O ₅ + K ₂ O			140.42

^aList price; substantial discounts are available.^bIncludes \$4 per ton allowance for freight from regional plant to cold mix plant.

CONCLUSIONS

The use of liquid mixed fertilisers is increasing rapidly in the United States. Many farmers prefer liquids because of convenience, ease of application, and adaptability to precise, uniform placement. Both farmers and manufacturers benefit from the absence of caking, dustiness, hygroscopicity, and inhomogeneity. Manufacturing processes are simple and inexpensive; problems of fume and dust are absent. Storage and handling costs are lower for liquids than solids.

Although liquid mixed fertilisers are less concentrated than solids, transportation costs are minimized by shipping highly concentrated intermediates to small, local plants which make the final products.

Ammonium polyphosphate solutions prepared by ammoniation of superphosphoric acid are key phosphatic materials in liquid fertiliser manufacture. Solid ammonium polyphosphate may become an important material for liquids in the future. The ammonium polyphosphate materials are made from either electric-furnace or wet-process superphosphoric acid. A new process now under development produces ammonium polyphosphate (solution or solid) directly from orthophosphoric acid.

Suspension fertilisers, saturated solutions containing suspending solids, are the newest form of liquids and are likely to grow rapidly because of advantages of higher analysis and greater versatility of formulation.

REFERENCES

1. U.S. Dept. of Agr., Statistical Reporting Service, "Consumption of Liquid Commercial Fertilisers in the United States, Selected Years 1954 through 1965," No. SpCr 7-1, Washington, D.C. February 1967.
2. Army, T.J. Proc. Liquid Fertiliser Round-Up (St. Louis), 17-19 (July 1967). The National Fertiliser Solutions Association, Peoria, Illinois.
3. Slack, A.V., Potts, J.M., Schaffer, H.B., Jr. J. Agr. Food Chem. 13, 165-71 (March-April 1965).
4. Allgood, H. Y., Lancaster, F.E., Jr., Mc Collum, J.A., and Simpson, J.P. Ind. Eng. Chem. 59, No. 6, 18-28 (June 1967)
5. Lehr, J.R., Frazier, A.W., and Smith, J.P. J. Agr. Food Chem. 14, 27-33 (January-February 1966)

6. Davis, C.H., and Lee, R.G. "Pilot-Plant Studies of the Direct Production of Ammonium Polyphosphate from Wet-Process Phosphoric Acid." Presented at Regional Meeting of American Chemical Society, Atlanta, Georgia, November 1967.
7. Kelso, T.M., Stumpe, J.J., and Williamson, P.C. Com. Fertiliser and Plant Food Ind. 116, No.3, 10-16 (March 1968)
8. Purdy, W.G., III, Com Fertiliser and Plant Food Ind. 115, No 1, 34-6 (July 1967).
9. Scott, W.C., Wilbanks, J.A., and Burns, M.R. Fertiliser Solutions 2, 6-7, 10-11, 14-15 (November-December 1965).
10. Wilbanks, J.A., Nason, M.C., and Scott, W.C. J.Agr. Food Chem. 9, 174-8 (May-June 1961).
11. Scott, W.C. Proc. Liquid Fertiliser Round-Up (St. Louis), 2-5 (July 1967). The National Fertiliser Solutions Association, Peoria, Illinois.
12. Abell, N.D. Proc. Fertiliser Production and Marketing Conf. (Knoxville), 106-9 (October 1967). Tennessee Valley Authority, Muscle Shoals, Alabama.
13. Cunningham, H.U. Fertiliser Soc. (Engl.), Proc. No 56 (1959).
14. Fertiliser Solutions 12, No.2, 36-8 (March-April 1968)
15. Hignett, T.P. Aggr. Chem. 19, 58-60, 127 (April 1964)
16. Wilbanks, J.A. Proc. Liquid Fertiliser Round-Up (St. Louis), 2.5 (July 1967). The National Fertiliser Solutions Association, Peoria, Illinois.
17. Hignett, T.P., and Striplin, M.M., Jr, Chem. Eng. Progr. 63, No 5, 85-92 (May 1967).
18. Hignett, T.P., and Scott, W.C. "Economic Comparison of Suspension and Bulk-Blend Fertilisers." Paper presented at NPSA Suspensions Round-Up 1968, July 25-26, 1968, Atlanta, Georgia. The National Fertiliser Solutions Association, Peoria, Illinois.

DISCUSSION

MR. HIGNETT (T.V.A., U.S.A.): The earliest known method of producing chemical mixed fertilizers goes back to the 1830's, when Sir James Murray, of Ireland, compounded liquid mixed fertilizers and sold them in 30 gallon casks. Some of the ingredients mentioned were soluble superphosphate of lime, nitrate of soda, and silicates of soda and potash. In 1842, Murray announced that he had made a very large improvement in manufacturing fertilizers: he was able to make them in solid form!

Some of the first liquid fertilizers manufactured were in California where liquids were applied by metering them into the irrigation waters. Then it spread rapidly through the Midwest in the period 1954 - 57, and now in at least 9 States 20% or more of all mixed fertilizers is in liquid form, including some of the largest fertilizer-consuming States. The maximum concentration of plants is in Indiana where there are 129 plants in a State of 36,000 sq. miles. If these plants were evenly spaced out it would mean that no farmer in the State would be further than about 10 miles from a liquid mixed fertilizer manufacturer. This indicates that the typical liquid mixed fertilizer manufacturer is a small local merchant who sells retail to the farmer. He offers custom mixing, custom application and a great many other services that the farmers demand. This reminds me of Howard Cunningham's remark at the first Francis New Memorial Lecture at the Fertilizer Society in London in 1959. He said that the country may eventually be covered by depots, like petrol stations, from which farmers can get nitrogen solutions with minor elements added as required. While liquid fertilizer depots are not quite as numerous as petrol pumps the comparison is very right. Mr. Cunningham evidently did not know how prophetic these words were, for he also said: "This flight of fancy about nitrogen solutions and the repercussions on phosphate and potash application must not be taken too seriously". From a farmer's viewpoint, the primary advantage of liquid fertilizers is convenience. Liquids are dependably free flowing. They can be handled and applied in labour saving, trouble free equipment. There are no bags to lift open and dispose of. There is little delay in filling applicators. There is no dust or caking. Accurate placement is possible and even distribution is easier with liquids than with solids. Liquid fertilization may be combined with irrigation or with the application of herbicides or pesticides and many farmers feel that liquid fertilizers are superior in quality and give better response than solids.

From the viewpoint of manufacture, a primary advantage is the simplicity and low cost of the equipment for production, storage, handling and transportation. Economical manufacture does not require large plants. Dust and cleaning problems are practically non-existent. Losses are very small. Control of composition is simple. Problems of hygroscopicity, dustiness and caking are absent. Storage, loading and handling are not expensive because pumps and piping are cheaper than conveyors, elevators, tractors, shovels and cranes, both in capital cost and in operating cost.

Of course there are some disadvantages with liquids. The main one is low analysis. This drawback is minimized by shipping highly concentrated intermediates to local plants. The final products need not be shipped very far, and by going to suspensions you can make higher analysis materials, although some of the advantages are lost. Phosphatic materials have so far been rather more expensive for liquids than for solids, whilst nitrogen and potassic materials have been somewhat cheaper.

MR. HIGNETT then presented a few slides showing methods of application.

PROF. J.R. ANSTALUX (U.C.B., Belgium): The opinions I shall express in opening the discussion of this paper are those of an agronomist rather than a technician. I do not think an agronomic view is misplaced within these technical meetings, for, the products manufactured by our factories are after all, used by the farmers and, need we say it, their interests are not always in accord with those of the industry. I remember the commercial director of an important Belgium firm telling me jokingly one day that his dream was to produce and sell only one compound*formulation to be applied uniformly over the whole agricultural land area and, of course, preferably in a thick layer! In contrast, certain farmers would wish for special formulations for each of their plots. Nowadays, this kind of farmer is fortunately fairly rare. But the gap separating the two extreme positions is clear. Thus I think it is worth examining what are the real advantages for farmers in liquid fertilizers, compared with solid forms.

Firstly, and to establish a valid comparison, liquid fertilizers must be at least equivalent as far as agronomic efficiency is concerned. In general, I think this equivalence exists, and that if liquid fertilizers sometimes give better results because of their total solubility, in other cases the classical granulated fertilizers prove to be preferable.

Secondly, one of the advantages of liquid fertilizers rightly emphasized by Mr. Hignett is their greater convenience of use, particularly in the sense that their handling and spreading are entirely mechanised. This can lead to a considerable saving in labour.

We should ask ourselves if this advantage is real and substantial in every case. We should note, firstly, that the spreading of solid fertilizers has been mechanized for a long time and that a range of fertilizer spreaders is available, giving very satisfactory results. We were able to examine a series of these machines at the Joint Meeting of I.S.M.A. in Stresa, last year. I should add that the bulk handling of solid fertilizers is also mechanised. Thus the handling advantages of liquid fertilizers are only truly brought out in relation to fertilizers sold in bags. Undoubtedly, the repeated handling of large quantities of fertilizers in bags is arduous work involving a considerable labour cost. The ability to pump liquid fertilizers must therefore constitute an important economy, but one which only really concerns the large farm, employing wage-earning workers. In practice, this economy no longer operates in small or very small farms using only family labour. And, after all, the majority of agricultural holdings are of this latter type, particularly in Europe. In these small holdings, the available labour is generally plentiful and only exceptionally used at 100% of its capacity. Consequently, the elimination of manual handling of bags and, in addition, the use of contract spreading in the case of suspension fertilizers (the more so in this case because special equipment is necessary) would only lead to less use of the existing irreducible labour force in the small family holding. Nevertheless, we should add that from a human point of view the replacement of the handling of bags by mechanical pumping undoubtedly constitutes an advantage for liquid fertilizers, from which one can certainly derive a most effective psychological sales argument in favour of the adoption of liquid fertilizers.

Thirdly, as we all know, all advantages have their price, and Mr. Hignett has made a most objective price comparison between liquid fertilizers, suspension fertilizers and fertilizers resulting from bulk blending. He tells us that the variations are slight and relatively insignificant in view of the present instability of the prices of the basic constituents. I presume the prices to which Mr. Hignett refers are ex-wholesale. But what interests the farmer is the comparative price per unit of plant nutrient spread on the field, or rather what is termed the price delivered to the roots, but I am well aware of the difficulty in establishing such a price comparison and, equally, of the temporary nature of such a comparison.

We can provisionally conclude, I think, that the more or less considerable advantages of liquid fertilizers, in relation to the classical solid forms, are related to the structure of the agriculture in question. What is apparently perfectly valid for the agriculture of the U.S.A is not necessarily so, or would only be so after adaptation, in the case of European agriculture, not to mention agricultures in the developing countries.

Thus Mr. Hignett's paper, so rich in technological and economic content, gives us the opportunity to reflect on all these problems foreign to technology but which, in my view, should guide and direct it.

I should like to ask Mr. Hignett whether a hot or cold mixing plant does not require operating staff of a higher calibre than that required by a bulk blending plant or, naturally, that of the wholesaler selling fertilizers in bags. I wonder whether this has any effect on the price of the fertilizers.

Could Mr. Hignett also tell us why the control of composition is easier with liquids than with bulk blends?

Finally, why do liquid fertilizers more easily satisfy conditions of application than bulk blends? Does this mean that application is more accurate or more flexible, consequently permitting a more varied range of NPK mixtures?

MR. HIGNETT: I should like to thank Prof. Ansiaux for his kind remarks and I think he has made some excellent points. I find that there are not many of his points that I can disagree with. I might mention that with regard to special formulas I sometimes wonder whether there is more of a psychological advantage to the salesman or to the farmer. However there are cases where minor elements are required - a growing number of cases - and they are required in only small areas. So these special formulas have some advantages.

He mentioned that in some cases granular fertilizers were preferable. Liquids can be applied in such types of application that they give parallel results to granular fertilizers. They are applied in drops, by dribbled application or in bands.

As to the question of whether the operator of a liquid mixed fertilizer plant must be more highly qualified than a bulk blend plant operator, I think

that the operator of a hot mix plant needs be somewhat more highly qualified because he must carry out chemical reactions. He must understand enough about that chemical reaction to do it properly. A cold mix plant on the other hand is merely a job of mixing, as is bulk blending. So it seems to me that there is no difference there.

With regard to control of composition, I think it is easier to control the composition of liquids and easier to correct any mistakes by adding more of something to a liquid in a tank after it has been manufactured. If you find it is deficient in anything, you need only add something more and stir it up. You cannot very well do that with granular fertilizers. We find in our own operation that the composition of liquid fertilizers is controlled more exactly than the composition of solid materials and with less instruments. For instance, we need to measure only the pH and the specific gravity. No chemical analysis is necessary. This is when we are making the ammoniated superphosphoric acid 11-37-0. Of course with a more complex formulation you have more analysis to make.

Concerning the question as to why I think liquids are easier to apply more evenly than solids, we have made quite a few tests broadcasting liquids from spray nozzles or from booms, and we have compared the results with broadcasting of bulk blends from spinning disc application equipment. There is much more evenness of application with the liquid than the solid material.

DR. BANTHIEN (Hoechst Uhde International): We should not forget that your paper is based on a big success of liquid and suspension fertilizers in the United States. I think the question of the use of liquid fertilizers in our European countries is quite different from that in the United States. It would therefore be of great interest to many of us to learn your opinion as to the real cause of this success in the United States and of the continued reluctance of European industry and farmers to use liquids to the same extent.

MR. HIGNETT: It is hardly right to say that farmers were educated to use liquid fertilizers. The big drive towards liquid fertilizers really originated with farmers rather than with industry or the Government.

I am not at all qualified to say how the advantages of liquids could be best applied in other countries. I might mention an experiment I saw in India on the foliar application of liquids. They had information from these tests that showed that, to increase the yield of rice to a given level, it took only half as much nutrient in the form of liquids applied to the leaves as it did with solid fertilizers placed in the ground. So I asked how often they had to apply them: the answer was three times per season for foliar application, and there was a man there with a spray-gun, spraying the leaves. I said: "Is it not very expensive?" "Oh, no, this man has only one or two hectares. He has nothing else to do, so he might as well spray liquid fertilizers."

DR. BANTHIEN: The problem of any European firm would be what to do with the liquid fertilizer manufacture out of season?

MR. HIGNETT: That is a problem in the United States, too. But the usual solution to the problem is that the same man has another business in which he works out of season. It may be gathering seed corn for sale, custom app-

lication of pesticides, compounding feeds for cattle. It is very frequent that you find that the same man who makes liquid fertilizers has also several other businesses.

MR. N. ROBINSON (Fisons Ltd. U.K.): It is said in the paper that the presence of ammonium nitrate and of potassium causes complications with liquids due to crystal growth of potassium nitrate. Has T.V.A. any experience in producing suspensions formulated from ammonium nitrate and urea mixtures? Has T.V.A. investigated any way of inhibiting the crystal growth of potassium nitrate? Finally, does the source of the type of attapulgite clay affect the stability of the suspensions?

MR. HIGNETT: No, we have not studied any way of altering the crystallisation. The only way of coping with the potassium nitrate crystal formation is to cool suddenly so that it crystallises in small crystals, so that they can be suspended better. This applies only to suspensions, of course, not to pure liquids. As regards pure liquids you can do nothing about the crystallisation other than to adjust your formulation so that the crystals do not form. The character of the attapulgite clay is important and we have not any specifications that will tell us in advance of actual test which form will give us a good suspension and which one will give us a poor one. We know some things that we must have, for instance excessive magnesia has caused reaction with liquids and formed excessive solids. There are other types of clay besides attapulgite which also have worked, for instance certain bentonite clays will work. They require a pregelling before adding to the main batch of the liquid, but they are very effective, and very likely you would find that there are clays in most countries that would be useful.

MR. P. MORAILLON (Pechiney-St. Gobain, France): With regard to suspensions, Mr. Hignett mentions two processes - the hot mix and the cold mix. Does one process give suspensions of better stability than the other?

MR. HIGNETT: No, I don't feel that we can say that we have found that one material is more stable or a better suspension than the other, but when you do deal with the hot mix, then you must be rather careful how you cool it, because when you cool it the crystals form and if cooled too slowly large crystals may form, unless you have plenty of clay there widely dispersed. But it is quite possible to make it for good suspensions by either method.

DR. BROWNLIE (Scottish Agricultural Industries, U.K.): I would like to return to the question of the season for liquid fertilizer manufacture. Could Mr. Hignett tell me if he has included in the cost, the cost of storing phosphoric acid for example, because this has normally got to be made all the year round, and presumably has to be stored either by the manufacturer or the dealer. Can you tell me if you include the cost of this in the costing of liquids versus solids?

MR. HIGNETT: The costs do include the cost of the storage facilities where they are required to store about 3 months supply. It is not all storage of phosphoric acid. It is usual to store a liquid mixed fertilizer, 11-37-0, 12-40-0. It is easier to store

because it requires only plain steel equipment. In our plant for example we do not store any substantial amount of phosphoric acid, but we do store a rather large amount of 11-37-0 liquid. Also quite a few of the customers buy it in the fall, when there is a discount, and store it in their own tanks.

MR. CARLSEN (A/S Dansk Svovlsyre-og Superphosphat Fabrik, Denmark):

In your conclusion you state that ammonium polyphosphate solutions prepared by ammoniation of superphosphoric acid are key phosphate materials in liquid phosphate manufacture, and you also state that ammonium polyphosphate may become an important material for liquids in the future. A little later you say a new process now under development produces ammonium polyphosphate solution or solid directly from orthophosphoric acid. Can it be disclosed now? Is it from wet acid or from furnace acid, or is it made by evaporation?

MR. HIGNETT: The process for making ammonium polyphosphate solutions from wet process acid consists of first concentrating the wet process acid to the usual level of about 50-54%, then ammoniating in two stages countercurrently so as to use the heat of reaction to concentrate the ammonium phosphate melt to the point where polyphosphate forms. The ammonium polyphosphate melt is discharged into dissolving water and more ammonia added, if necessary, to adjust the composition to that which is the more soluble. We have concluded pilot plant work and we shall show this at our next demonstration. I think it will shortly be used on a commercial scale.

MR. VAN DE VEEN (Continental Oil): One of the figures that Mr. Hignett has mentioned referred to the 9 States in the United States. I wonder what's wrong with the other 39 with respect to the application of liquid fertilizer?

MR. HIGNETT: There are 9 States in which liquid mixed fertilizer comprises at least 20% of the total mixed fertilizer consumption. That does not mean that liquids are not going well in the other States. It only means that they are going somewhat less well. But to answer your question more directly, the 9 States in which they are going the best are the States in which the farmers are the most progressive, the most open to new improvements. In general I think they are probably the States where farms are largest, although I don't have actual data on that. One of the States is California, and the reason in California is because of the influence of applying them in irrigation water.