peratures and may require special handling such as shipment in heated cars or dissolution of crystals after shipping.

The convenience of nonpressure solutions has led to a rapid increase in usage, notwithstanding the higher production cost. Published consumption figures do not differentiate between pressure and nonpressure solutions; however, observation of industry practice indicates that a major portion of the nitrogen solution consumption shown in Figure 1 is in the form of nonpressure solutions.

The distribution of nitrogen solutions follows much the same pattern as that for anhydrous ammonia except that there is more tendency for established fertilizer mixing plants to take the place of the distribution center or act as an intermediary between producer and dealer. It appears also that there is a growing practice of direct purchase from the producer by a farmer or group of farmers who have storage facilities for at least a tank car load of solution **(1)**. Such purchase can be made during the offseason at a reduced price. Direct purchase of anhydrous ammonia by farmers is practiced also, but probably to a much lesser extent.

Custom application is also a factor in distribution. In introducing liquid fertilizer into a new area, custom application is almost a prerequisite because the farmer does not have the specialized equipment required. As usage grows, more and more farmers find it economical to purchase their own application equipment. However, the custom operator may still find customers among farmers whose farms are too small to justify the purchase of the relatively expensive applicators. A further factor is that farmers tend to hire specialized services as farming technology becomes more advanced and farm labor less available. Custom application of fertilizer provides fast, efficient application of plant nutrient at a time when there are many other farm operations demanding the attention of farm personnel.

The custom operator normally provides local transport and application equipment and any on-the-farm storage required. He may provide local centralized storage or buy from a distribution center. He contracts with the farmer to apply the fertilizer at the desired time and amount per acre. The cost of this service varies, depending mainly on the type of application, i. e., surface, subsurface, or in irrigation water. The cost is often based on acreage covered rather than on amount of fertilizer applied.

When the farmer enters into the application, there are several arrangements used. Field storage may be owned by the farmer or distributor, and local transport may be handled by either. Field storage may be either permanent or temporary. In some instances, a farmer with large acreage may operate a small distribution center and sell to his neighbors. He may also do custom application when his application equipment is not being used on his own farm.

Handling and storage

Practice in handling and storage of nitrogen liquids is governed largely by the vapor pressure of the solution, its corrosivity, and safety precautions required. Anhydrous ammonia has a high vapor pressure (211 p. s. i. g. at 40° C.) and is stored in tanks built to withstand a working pressure of 265 p. s. i. g. or more and equipped with relief valves. Aqua ammonia has much lower pressure (2 p. s. i. g. at 40° C. for 25 % ammonia); however, tanks with a minimum working pressure of 100 p. s. i. g. normally are used for storage. Pressure for the pressure-type solutions varies from 1 to 72 p. s. i. g. (at 40° C.), depending on the proportion of free ammonia. Tank strength requirements for these varies with the pressure. Nonpressure solutions can be stored in nonpressure tanks or open vessels unless they are to be transferred by air pressure; in such case, a 30 to 35 p. s. i. g. working pressure is required, in accordance with the code for unfired pressure vessels **(1)**.

A relatively new practice is storage of anhydrous ammonia at atmospheric pressure to allow use of less expensive, lighter weight tanks. The low pressure is obtained by allowing the ammonia to boil (at about −33° C.), withdrawing the vapor, and compressing and cooling it to the liquid form for return to the tank.

Corrosion of tanks and equipment is not a problem for anhydrous or aqua ammonia. Carbon steel is satisfactory and is the material normally used. Nitrogen solutions, however, present a difficult problem because of corrosivity of ammonium nitrate to carbon steel, especially in conjunction with free ammonia. The preferred construction material is aluminum, which has satisfactory resistance. Ammonium thiocyanate is often added as a corrosion inhibitor and usually gives good protection to carbon steel. However, the uncertainties associated with use of inhibitors has led to the general practice of shipping, storing, and applying solutions containing ammonium nitrate in aluminum equipment. Nonpressure solutions, which avoid the corrosive combination of ammonia and ammonium nitrate, are less corrosive and are often stored in carbon steel. However, limited life of equipment is expected for tanks used in such service. There is a growing use of steel tanks lined with plastic materials — or tanks made entirely of plastics — as discussed later under liquid mixed fertilizers.

Ammonia-urea and urea solutions are much less corrosive than solutions containing ammonium nitrate. They are usually stored in carbon steel.

Safety precautions are important mainly in respect to anhydrous ammonia. Hazards are associated not only with the high pressure but also with toxicity and explosibility of the ammonia. Regulations for safe handling have been set forth by the Interstate Commerce Commission, an agency of the United States Government. Tank cars must carry a «Dangerous» placard and certain restrictions in loading and handling must be observed. Anhydrous ammonia is the only one of the nitrogen liquids so regulated.

Ammonia is a toxic gas and full safety regulations should be observed in handling it. A concentration of less than 1 % in the air breathed is rapidly fatal. Severe burns can be caused by ammonia also, and probably constitute the principal type of accidents because the victim usually can avoid respiratory damage by escaping to clear air. The main problem appears to be associated with unskilled labor in local handling and application.

Application

The volatile nature of ammonia requires that any liquid fertilizer containing free ammonia be injected beneath the surface of the soil. There has been some surface application of aqua ammonia and low-pressure solutions but losses by vaporization have been shown to be excessive by several investigators.

Anhydrous ammonia usually is injected to a depth of 6 inches, but a range of 4 to 8 inches may be used depending on soil conditions. The injection operation consists of opening the soil in a narrow furrow, injecting ammonia from a following tube, and closing the furrow quickly. A considerable amount of research has been done by agricultural engineers on the problem of injecting ammonia without loss, with the result that injection equipment has been refined appreciably since initiation of the injection method. Several types of equipment have been developed to fit different soil and crop conditions.

Much of the anhydrous ammonia used is applied as a side-dressing to growing crops. Some application before planting is practiced also. This may be done by injecting the ammonia in the furrow made by the turning plow or by standard injection blades when soil conditions allow.

Retention of injected ammonia by the soil has been the subject of considerable study. The ammonia must be sorbed rapidly by soil particles if loss to the atmosphere is to be prevented. SOHN and PEECH **(24)** determined that sorption results from neutralization of exchangeable hydronium and aluminum ions on the clay fraction and from reaction with or-

Production and use of fluid fertilizers

by A. V. SLACK, Tennessee Valley Authority, Wilson Dam, Alabama / USA

The large-scale use of fluid fertilizers is a relatively new development in the fertilizer industry. Prior to about 1945, practically all fertilizers were produced and handled in the solid form. In the past 15 years, however, the use of liquids has grown rapidly, especially in the United States.

The principal reason for the growing use of liquids is the economy gained in production and handling. The production cost is reduced by omitting the operations of drying and granulating, and transfer of material by pumping normally is less expensive than use of solids handling equipment. Caking, poor drillability, and segregation of nutrients, problems that are often associated with solid fertilizers, are eliminated also. However, fluid fertilizers have their own peculiar disadvantages, and these have been the subject of a considerable amount of research. Among the drawbacks are high storage cost, corrosion, and relatively low plant nutrient content.

Use of fertilizers in the liquid form is to be expected as a development in keeping with modern technology. In other industries, bulk handling of materials as liquids has grown rapidly as a means of reducing handling costs. The method is especially applicable to fertilizers because of the low unit cost of the material, the several handling steps involved, and the large tonnages used. The fast increasing degree of mechanization on farms is an added factor, since liquids normally are more amenable to bulk handling than solids.

In this paper, principal emphasis will be placed on liquid fertilizer practice in the United States. To the best of the author's knowledge, there is little use of liquid fertilizer in other parts of the world except for a limited amount in the neighboring countries of Canada and Mexico. It is understood, however, that there is growing interest in liquid fertilizer production in France, India, and the United Kingdom and that some production has been started.

There are two main types of liquid fertilizers in the United States. One consists of liquids containing only nitrogen and the other of solutions containing two or more plant nutrients, usually nitrogen and phosphate or nitrogen, phosphate, and potash. There is very little usage of products containing phosphate alone or potash alone.

The nitrogen liquids and liquid mixed fertilizers constitute two independent segments of the United States liquid fertilizer industry. They differ in several respects, including structure of the industry, geographical distribution, and application practice. For this reason, they are discussed separately in this paper.

Nitrogen fertilizers in liquid form

Nitrogen liquid fertilizers include anhydrous ammonia and water solutions of ammonia, ammonium nitrate, and urea. For the latter group, there is some usage of the single materials dissolved in water; however, the usual practice is to use a combination of two or more of the three compounds. Major classifications in this group are aqua ammonia (solution of ammonia in water); nitrogen solution, pressure type (solution of ammonia plus ammonium nitrate and/or urea); and nitrogen solution, nonpressure type (solution of ammonium nitrate and/or urea).

Nitrogen liquids may be classified generally under the headings «pressure» and «nonpressure». The former includes anhydrous ammonia and any solution that contains free ammonia. The nonpressure type contains only ammonium nitrate or urea or both. The main advantage of the pressure-type liquids is the low cost that results from use of ammonia, which is the least expensive of the nitrogen materials in use. However, the resulting pressure introduces problems in storage and application and makes necessary the use of more expensive equipment than that used for nonpressure solutions. Both types of nitrogen liquids are lower in cost than solid nitrogen fertilizers. A rough comparison of the cost of the contained nitrogen, at the producing plant, is as follows (based on wholesale current prices, solids bagged).

Material	Index
Ammonia	
Anhydrous	1.0
Aqua	1.03
Nitrogen solution	
Pressure type	1.18
Nonpressure type	1.48
Solid fertilizers	1.87—2.46

Thus the nitrogen liquids have an initial cost advantage over solids in addition to any saving in handling and application costs resulting from the liquid form. This has led to very rapid growth in the use of nitrogen solutions in the past 15 years or so. The trend in usage and current status of nitrogen liquids is shown in Figure 1. All show a rapid rate of growth, especially in the past 5 years. Anhydrous ammonia continues to be the leading nitrogen liquid, with the nitrogen solutions in second place and gaining rapidly in importance.

The use of fertilizer nitrogen in liquid form has gained over the solid form for several years and has now overtaken it. The following tabulation shows the relative status of the two types over the past 15 years.

Year	Per cent of total nitrogen in direct application: Solid	Liquid
1947	92	8
1952	82	18
1957	59	41
1961	47	53

Manufacture and distribution

A full account of the manufacture of nitrogen liquids is beyond the scope of this paper; however, some discussion is desirable as background for examination of the problems in distribution and application. Anhydrous ammonia (82 % N) is the base material for practically all nitrogen liquids and for most of the solids. It is made in large plants by a high-pressure catalytic process, mainly from natural gas as a raw material with minor usage of coke oven gas and of byproduct hydrogen from petroleum processing plants. There are presently about 70 plants in the United States, either operating or under construction.

Anhydrous ammonia normally is shipped away from the producing plant (usually in tank cars) when it is to be used directly or for making aqua ammonia. When it is to be used