# Problems with Tank Foundation Heaters

Extensive experience over several years with a number of such problems leads to a limited number of conclusions and recommendations for solutions

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One of the problems of storing anhydrous ammonia at atmospheric pressure is the protection of the soil beneath the tank from freezing. If freezing conditions are allowed to occur, an ice lens will form under the tank, potentially resulting in deformation of the tank bottom and buckling of the side walls.

When the soil has such poor bearing capability that piling is required, the bottom of the pile cap is placed above grade and the soil is protected by the free air space between the pile cap and the soil. However, the cost of piling is excessive and piling is used only when it is required because of soil bearing problems.

The typical atmospheric pressure ammonia storage tank is supported directly by the soil, with only a relatively thin layer of sand and insulation between the soil and the bottom of the tank. Even though the bottom of the tank is well insulated, heat will be lost from the soil into the −28°F tank.

Unless artificial heat is supplied to the soil, the soil temperature will be less than 32°F, and any water in the soil will freeze and expand. As this happens, more water will be drawn to the freezing site by capillary action and by diffusion due to the lowering of the water partial pressure. Eventually, an ice lens of considerable thickness will be formed. In most soils, this ice formation will cause excessive deformation of the fill. This phenomenon and some specific incidents were discussed in detail by D. M. Morrison and H. T. Marshall (*1*) of the Chicago Bridge & Iron Co.

As reported by C. C. Hale (*2*), there are currently three types of foundation heating in use: electric, ethylene glycol, and hot air. Probably because of high captial costs, only three cases of ethylene glycol and two cases of hot air heating were reported in Hale's 1973 survey of industrial practice.

All these installations reported good experience, but the number of installations was not statistically significant. Most of the ammonia tanks, including all of Farmland's tanks, have electric heating systems; and the remainder of this article will be devoted to this type of heating.

## Two types of electric heating systems used

Two types of electric foundation heating are currently in use. One uses metal-sheathed electric heating cable, and the second uses ordinary plastic-insulated electric wire. Both types are installed in metal conduits beneath the undertank insulation.

The cable-type element normally has Nichrome wire electrically insulated by mineral powder. The insulation is contained by a sheath of copper or stainless steel. Heat output is in the range of 20 W./ft. This sytem has the advantage of low installation cost, but the cable itself is expensive, especially the stainless steel-sheathed type. The copper-sheathed cable has a much lower cost, but copper is attacked by ammonia.

The wire-type element utilizes ordinary No. 12 or No. 14 electric wire, has a fairly low material cost, but has a higher cost of installation. Heat ouput is in the range of 2 W./ft. of wire, so several wires are usually installed in each conduit. If the wire is heated above 150°F, the plastic insulation can flow around the wire at a pressure point. Therefore, the heat output or number of wires per conduit must be kept rather low, and the conduits should probably be closer together than the cable-type element.

Farmland and its CFCA subsidiary currently have 19 atmospheric pressure ammonia storage tanks in operation and 7 in various stages of construction. These tanks incorporate various electric heater systems and an assortment of insulation systems as shown in Tables 1 and 2. Fifteen of the tanks are at manufacturing plants, and the remaining eleven are remote terminals serviced by pipeline, rail, or truck. The tanks were constructed over a period of 16 years by various contractors.

**Table 1. Farmland's ammonia storage tanks**

| Tank location | Year of constr. | Capacity (1,000-tons) | Tank diameter (ft.) | Single or double wall | Design/ Construction |
|---|---|---|---|---|---|
| Lawrence, Kans. | 1959 | 2 @ 7.5 ea. | 100 | Single | Chemico/Nooter |
| Hastings, Nebr. Nos. 1, 2, 3 | 1961 | 3 @ 15 ea. | 140 | Single | Chemico/CB&I |
| Hastings, Nebr. Nos. 4 and 5 | 1963 | 2 @ 15 ea. | 140 | Double | Chemico/CB&I |
| Fort Dodge, Iowa Nos. 1 and 2 | 1966 | 2 @ 30 ea. | 170 | Double | Kellogg/PDM |
| Dodge City, Kans. | 1967 | 2 @ 30 ea. | 170 | Double | Kellogg/DB&I |
| Fort Dodge, Iowa, No. 3 | 1968 | 30 | 170 | Double | CB&I |
| Sgt. Bluff, Iowa | 1968 | 30 | 170 | Double | CB&I |
| Enid, Okla., No. 1 | 1973 | 30 | 135 | Single | CB&I |
| Garner, Iowa | 1974 | 30 | 170 | Single | PDM |
| Vernon Center, Minn. | 1974 | 30 | 170 | Single | PDM |
| Greenwood, Nebr. | 1974 | 30 | 170 | Single | PDM |
| Conway, Kans. | 1975 | 30 | 170 | Single | PDM |
| Aurora, Nebr. | 1976 | 30 | 167 | Single | Graver |
| Pollock, La. | 1976 | 30 | 135 | Single | CB&I |
| Benson, Minn. | 1976 | 30 | 170 | Single | Brown-Minneapolis |
| Barnesville, Minn. | 1976 | 30 | 170 | Single | Brown-Minneapolis |
| Washington, Iowa | 1976 | 30 | 170 | Single | PDM |
| Trilla, Ill. | 1976 | 30 | 170 | Single | PDM |
| Farnsworth, Tex. | 1976 | 30 | 135 | Single | CB&I |
| Enid, Okla., No. 2 | 1976 | 30 | 170 | Single | PDM |

A typical foundation, insulation, and heater system for a single-wall tank is shown in Figure 1. The insulating material is usualy 4 to 6 in. of glass foam, although a mixture of perlite and asphalt is sometimes used. A vapor barrier is provided below the insulation material to prevent moisture from being drawn through the insulation to freeze on the tank bottom. Glass foam is also placed inside the ringwall to protect the ringwall from low temperatures.

The heater conduits are located in a layer of sand about 6 in. below the vapor barrier. This places the heaters close enough to the tank to prevent freezing below the insulation, but also far enough away to allow the heat to spread between conduits and to protect the vapor barrier from high heater temperatures.

The double-wall tank heating system is similar, with the heaters placed about 6 in. below the bottom of the outer tank.

During 1973, 15 heaters failed under one of the three double-wall tanks at the Fort Dodge plant. The cause of these failures is not known. When attempts were made to replace the heaters, most of the old heaters could not be removed from the conduits, even though the conduits were filled with alcohol.

Some of the heaters were removed by brute force, usually breaking the cable and sometimes bringing sand with the portion that did come out. The cause of the sand being in the conduits is subject to speculation. There is a possibility that the sand got in during construction, but it is generally believed that settlement of the tank floor caused the conduits to break near the ringwall.

Because of the ammonia shortage in 1973 and 1974, the tank was not needed so it was emptied of liquid and allowed to heat up. New heater conduits were installed in 1975 by drilling holes in the ringwall and then pushing the conduits into the sand layer along side the old heaters. To minimize the distance of the push, conduits were pushed from each side to the middle, and half-length heaters were installed.

## Lawrence installation had unusual foundation

The two Lawrence tanks were designed by Chemico and were constructed in 1959 by the Nooter Corp. The tanks have a very unusual foundation design. As shown in Figure 2, they rested on compacted sand and gravel, with a concrete ringwall that contained the above-grade fill but did not support the tank wall. The gravel fill extended about 15 ft. down to a layer of shale. Four inches of glass foam were used for insulation, and a polyethylene vapor barrier was placed below the insulation. The copper-sheathed heaters were located in aluminum conduits approximately 86 in. below the tank bottom. The stainless steel capillary-tube temperature detectors were in aluminum conduits 64 in. below the tank bottom.

The gravel and unusual heater location were apparently used to minimize heat make-up to the tank. An ice lens could be expected to grow in the gravel, but there would be no deformation because the pieces of rock would not contain moisture and therefore would not expand as would soil.

Over a period of several years, most of the heaters failed and could not be removed from the conduit. Investigation

## Table 2. Heating and insulation systems in Farmland's tanks

| Tank location | Type of heater | Heater capacity (kW) | Heater conduit spacing | Method of temperature control | Tank bottom insulation |
|---|---|---|---|---|---|
| Lawrence, Kans. (Orig.) | Silicone Rubber Cable-Copper Braid | 28 | 3ft.-0in. | Auto set on Capillary: All on/All off | 4-in. Glass Foam |
| Lawrence, Kans. (Rev.) | MI Cable—[1] S/S Clad | 45 | 4ft.-0in. | Four Zones—Manual | — |
| Fort Dodge, Iowa, Nos. 1 & 2 | MI Cable— Copper Clad | 72.5 | 3ft.-10in. | Auto set on any T/C: All on/All off | 6-in. Glass Foam |
| Hastings, Nebr. Nos. 1, 2, 3 | Silicone Rubber— Copper Braid | 40.5 | 1ft.-6in. | Auto set on T/C All on/All off | 4-in. Glass Foam |
| Hastings, Nebr. Nos. 4 & 5 | Silicone Rubber— Copper Braid | 40.5 | 1ft.-6in. | Auto set on T/C: All on/All off | 7-in. Asphalt-Perlite |
| Dodge City, Kans. | MI Cable— Copper Clad | 73 | 4ft.-0in. | Auto set on T/C: All on/All off | 4-in. Glass Foam |
| Fort Dodge, Iowa, No. 3 | No. 14 Wire | 98 | 2ft.-0in. | Auto set on T/C: All on/All off | 6-in. Glass Foam |
| Sgt. Bluff, Iowa | No. 12 Wire | 98 | 2ft.-0in. | Two Zones—Manual | 6-in. Glass Foam |
| Enid, Okla. No. 1 | No. 14 Wire | 53.6 | 3ft.-0in. | Auto set on any RTD | 4-in. Glass Foam |
| Garner, Iowa | MI Cable— Copper Clad | 90 | 3ft.-10in. | Auto set on any T/C: | 6¼-in. Asphalt-Perlite |
| Vernon Center, Minn. | MI Cable— Copper Clad | 73 | 3ft.-10in. | Auto set on any T/C: All on/All off | 6¼-in. Asphalt-Perlite |
| Greenwood, Nebr. (Orig.) | MI Cable— Copper Clad | 126 | 3ft.-11in. | Two Zones—Manual | 6¼-in. Asphalt-Perlite |
| Greenwood, Nebr. (Rev.) | No. 12 Wire | 140 | | | |
| Conway, Kans. | MI Cable—S/S Clad | 81.2 | 3ft.-10in. | Four Zones–Each auto on T/C in zone | 6¼-in. Asphalt-Perlite |
| Aurora, Nebr. | MI Cable—S/S Clad | 40 | 3ft.-0in. | Four Zones–Auto on T/C | 5-in. Glass Foam |
| Pollock, La. | No. 14 Wire | 53.6 | 1ft.-6in. | Four Zones–Each auto on RTD in Zone | 4-in. Glass Foam |
| Benson, Minn. | MI Cable—S/S Clad | 79.7 | 4ft.-0in. | Four Zones-Each auto on T/C in Zone | 6-in. Glass Foam |
| Barnesville, Minn. | MI Cable—S/S Clad | 79.7 | 4ft.-0in. | Four Zones–Each auto on T/C in Zone | 6-in. Glass Foam |
| Washington, Iowa | MI Cable— Copper Clad | 81.2 | 3ft.-10in. | Four Zones— Manual | 4-in. Glass Foam |
| Trilla, Ill. | MI Cable—S/S Clad | 81.2 | 3ft.-10in. | Four Zones— Manual | 4-in. Glass Foam |
| Farnsworth, Tex. | No. 14 Wire | 53.6 | 1ft.-6in. | Four Zones–Each auto on RTD in Zone | 4-in. Glass Foam |
| Enid, Okla., No. 2 | MI Cable—S/S Clad | 60 | 6ft.-0in. | Four Zones–Auto on T/C in Zone | 6-in. Glass Foam |

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[1] MI = mineral insulated

showed that the ringwall on the north tank was severely cracked and the reinforcing bar broken in several locations. These failures appeared to be fairly recent, and it was speculated that they were caused by expansion of the fill due to freezing. However, this cause of failure is not conclusive because the wall was designed for very little stress and it could have failed from fairly normal soil stresses. Nevertheless, it was decided to install new heater conduits.

The first method tried was to drill through the ringwall and push the conduits in, as was done at Fort Dodge. Because the Lawrence tanks contained cold ammonia and because they were single-wall tanks, it was attempted to push the conduits into the gravel, well below the vapor barrier. This was not successful and it was decided to drill holes for the conduit.

The drill, powered by a "Ditch Witch," was aligned using surveying equipment and supported by a special jig to keep it properly aligned with the tank bottom. In addition, a battery-powered alarm system was installed to ring a bell if the drill touched the bottom of the tank. A 50% ethylene glycol mixture was pumped through the hollow drill to remove the gravel. Drilling rates of up to 23 ft./hr. were obtained in this manner.

The holes were drilled about 16 in. below the tank bottom, and on parallel 4-ft. centers. One-inch, Schedule 80 carbon steel pipes were installed after each hole was drilled. The holes were drilled to the center line from each side, and half-length pipe conduits were installed. New stainless steel-sheathed heaters were installed and secured in the pipes. In a similar manner, thermocouples were installed in pipes placed 30 in. below the tank bottom. After the new conduits were installed, a new, stronger ringwall was poured outside of the existing ringwall. Figure 3 shows the new system. Both tanks were revised in this manner.

During the excavation for the new ringwalls, several of the old aluminum heater conduits were uncovered. They were so severely corroded that very little of the conduit was left. It is speculated that the aluminum conduits failed because of galvanic corrosion and that failure of the conduits caused failure of the heaters.

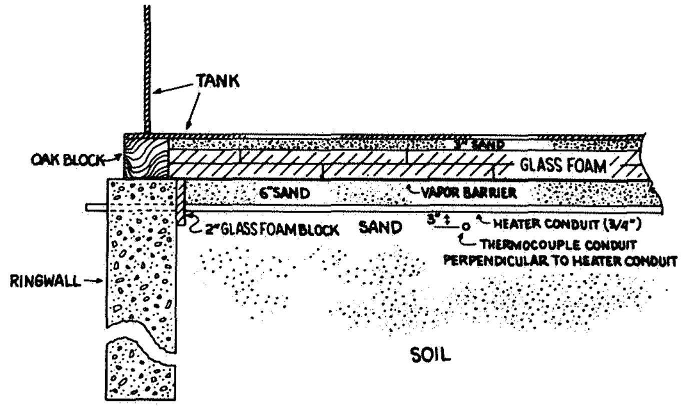

Figure 1. Typical foundation, insulation, and heater system for a single-wall ammonia storage tank, atmospheric pressure.

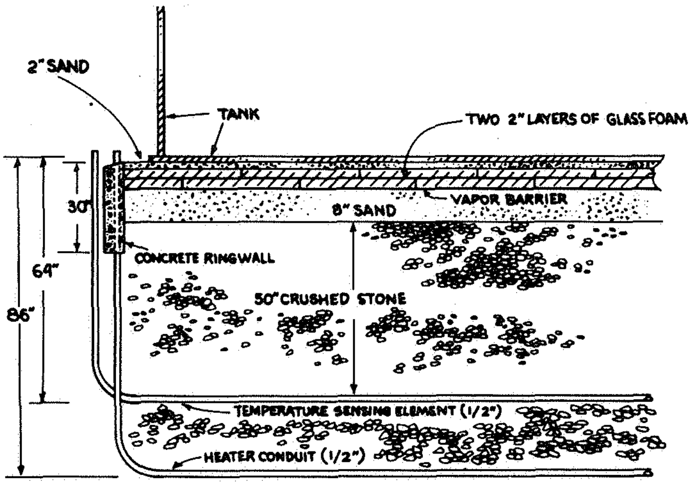

Figure 2. Foundation, insulation, and heater system at Lawrence, Kans.

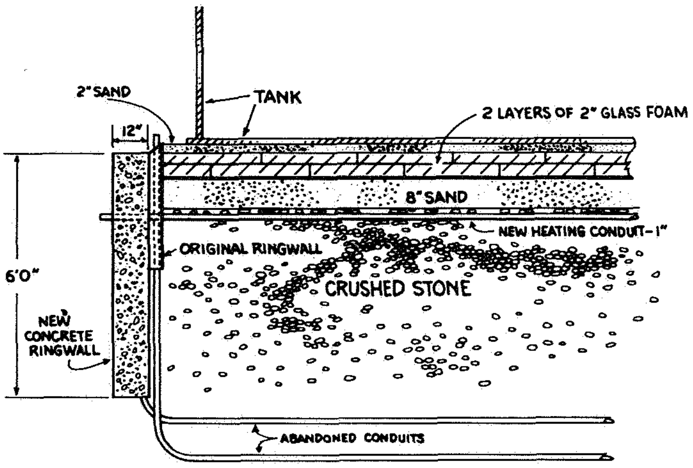

Figure 3. The Lawrence system after revisions had been made.

In conjunction with the repair work, deflection measurements of the tank floor were obtained by welding gate valves onto the roof in five locations and drilling through the valves into the tank. The elevation of these valves relative to the tank base plate was determined with a level and tape measure, and the distance from the valves to the tank floor was determined by lowering a weighted ruler through the valves. These measurements showed normal deflection of the tank bottom.

Because the tank bottom deflection was normal and because of the possibility that melting the ice might cause a large settlement to occur, the heaters have not been energized at this writing. Periodic measurements of the tank bottom deflection are being taken to monitor any changes. It is felt that the tank is safe unless conditions change substantially.

The Hastings plant has five tanks with a foundation and heater design that is similar to Lawrence. However, the Hastings tanks are supported on soil instead of shale and the gravel fill is all above grade. Furthermore, the Hastings tanks do not have a ringwall. This system is shown in Figure 4. It is interesting to note that the Hastings tanks have experienced no known foundation problems.

### Greenwood experience still being worked on

In the winter of 1974-75, a leak in the bottom of the Greenwood tank resulted in the failure of about 50% of the heaters. The original heaters, being copper-sheathed, failed when ammonia leaked into the conduits and reacted with the copper. Since ammonia would still have been in the sand after the tank bottom was repaired, replacement with similar heaters was not advisable. Stainless steel-sheathed cables could not be delivered in time, so the entire heating system was replaced with No. 12 wire. We have just now heard about a failure in this new system. Because of the high wattage with wide conduit spacing, we believe the failure was caused by overheating the wire insulation.

Since the original writing of this article, the Greenwood tank has experienced a series of heater failures in addition to

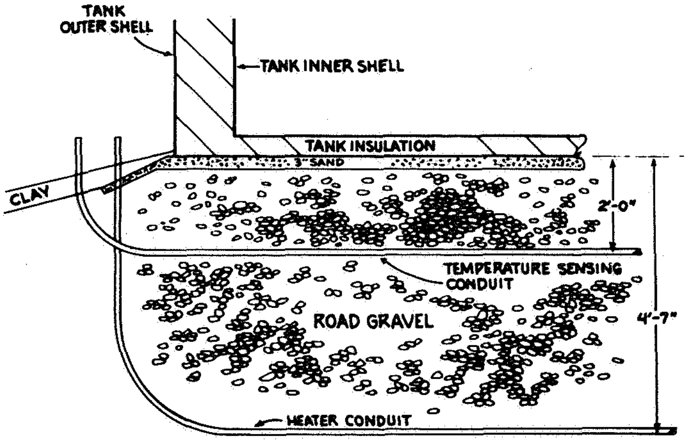

Figure 4. The design at Hastings, similar to that at Lawrence, but tanks are supported on soil instead of shale, and the gravel fill is all above grade level.

the one mentioned above. When the wires were replaced, the insulation was found very brittle, particularly in that portion passing through the ringwall and junction boxes.

Many of the failures were due to the insulation cracking, creating shorts between two wires, or a wire and the conduit; but other failures were apparently due to the ammonia beneath the tank reacting with the copper wire exposed by the cracks.

Subsequent investigation showed the wire actually installed to be shorter than that specified in the design, allowing higher current flow, and thereby overheating the wire, especially at the ends where it was exposed to ambient temperature instead of the much cooler undertank temperature.

Actual temperatures measured at the ringwall were in the 250°F range, with about 160°F being the maximum temperature which the insulation on this type wire can endure without damage. Because all wires must be replaced and more wires added to make the system work properly, the heating system will be returned to MI cable, but with a stainless steel sheath.

One of the problems associated with the metal-sheathed cable installation is the thermal expansion and contraction of the cable as power to it is cycled. If the cable is secured at both ends, there is no place for it to expand in the conduit. Therefore, most installations have two-conductor cables, with both connections at one end. The cable is made several feet shorter than the conduit, and it is clamped at the connected end so that it has room to move at the end that is not connected. Unfortunately, on several Farmland tanks, the contractor failed to secure the cables. As a result, some of the cables moved at the connected end and this movement eventually caused failure.

In all cases, new heater cables were installed and the cables were clamped near the connected end. No problems have been experienced since the repairs were made.

### Conclusions and recommendations

In spite of our extensive experience, only a limited number of conclusions can be reached:

1. Aluminum conduits should not be used because of the potential for galvanic corrosion.
2. When using copper-sheathed cables, the conduit should be properly sealed to prevent the entry of ammonia.
3. The cable-type heaters should call for a clamp at the connected end and the owner should be sure that these clamps are properly installed.
4. An antifreeze solution may be required to remove defective heaters, especially if the conduit was not well sealed against the entry of moisture.
5. The temperature indicators will probably not indicate a single defective heater, so heater condition should be checked periodically by amperage or conductivity measurements.

Even though the Lawrence tanks have apparently been all right without heaters for several years, it cannot be recommended that the heaters can be eliminated. The Lawrence tanks have two unusual conditions which may contribute to the apparent success without heaters: First, they are supported on shale rather than soil below the gravel. And, secondly, a large underground water flow just above the shale apparently restricted freezing temperatures to only the gravel fill. In a large tank without heaters, freezing temperatures would normally be expected to a depth equal to the tank diameter.

The authors recommend that heaters continue to be installed and that the owner pay careful attention to proper design, installation, operation, and maintenance. #

### Literature cited

1. Morrison, D.M., and H.T. Marshall, "Frost Heaves and Storage Vessel Foundations," AIChE Ammonia and Related Facilities Safety Symposium, 1967.
2. Hale, C.C., "Ammonia Storage Design Practice," AIChE Ammonia and Related Facilities Safety Symposium, 1973.

**COMEAU, E. T.**

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# DISCUSSION

**HANS ARUP,** Danish Corrosion Centre: You mentioned you had a corrosion problem with the aluminum pipe. If the aluminum pipe could have been in contact with the reinforcement in the concrete, it would form a very powerful galvanic couple, not only could that explain the corrosion of the aluminum but if your reinforcement is high strength steel it could create a hydrogen embrittlement problem on your reinforcement.

**COMEAU:** Yes, the aluminum conduits did go down through the foundation and I agree that the aluminum would be corroded if it touched the steel reinforcement. I do not know whether the reinforcing steel was high strength. Normally, it is not.

**BILL SALOT,** Allied Chemical: In these many tanks of yours, Gene, have any of them been inspected for ammonia stress corrosion cracking; and if so, has any been found?

**COMEAU:** None of our ammonia tanks has been inspected for stress corrosion cracking. Bill, would you care to say why you would bother inspecting? Do you anticipate it as a problem with the type of steel used in these tanks?

**SALOT:** I base it on the many papers that are coming up about cracking.

**COMEAU:** I'm not a metallurgist, but I do not believe the steel in these tanks is particularly susceptible to stress corrosion.

**KEES VAN GREIKEN,** UKF: We did magnetic particle testing on two low temperature storage tanks and did not find any cracking.

We did it especially on the lower situated higher strength steel part of the wall.

**M. BADREL DIN,** Petrochemical Industries Co., Kuwait: Is this foundation design still adopted in building ammonia tanks? Why don't we build these tanks on pillars to be above ground, one meter above the ground for instance, and this way you can insure better safety and can eliminate such problems of foundation failures.

**COMEAU:** Generally, the heated foundation is standard practice. The pile type of foundation is not used except where required because of soil conditions. There's a lot of argument about how a tank foundation should be built, and I don't know who can answer it. I know that Hays Mayo has serious questions about the problems caused by a ringwall under the tank. Hays was co-author of a paper given in 1974 regarding the differential settlement between the ringwall and the bottom of the tank. The work that was done on three of our tanks shows a sharp deflection of the tank bottom right at the edge of the ringwall. The soil will settle but the ringwall doesn't. This is a matter of concern.

The Hastings and Lawrence tanks do not sit on a ringwall. They have been in for quite a while and look to be in good condition. So, how important is the ringwall? I don't know. Certainly, the standard foundation design can cause problems and it should be the subject of continued study.

**HAYS MAYO,** Farmland Industries: The question of the need for a foundation ringwall under an atmospheric ammonia tank has been raised by Mr. Comeau in his discussion of the CFCA atmospheric ammonia storage tanks at Lawrence, Kans. The Lawrence tanks are designed for a maximum of one-half pound per square inch internal pressure. The uplift force resulting from this pressure applied to the area of the roof is less than the weight of the tank roof and sidewalls. The tanks were built in 1953 and are placed on a bed of granular fill. The granular fill is retained by a shallow concrete wall which is somewhat larger in diameter than the tank. The design used does not have a ringwall, directly under the tank. The design uplift forces on tanks presently being built are greater than the weight of the roof and sidewalls and a ringwall with hold-down straps is required and provided. Our policy on all new tanks including fertilizer solution tanks is to provide an adequate ringwall under the tank sidewall.

A paper presented at the 78th National Meeting of AICHE by Melvin I. Esrig, Salim Ahmad, and Hays C. Mayo presents data on tank differential settlements on three Farmland Industries tanks. This data shows that the maximum settlement on these tanks occurred between the ringwall and the tank center. To minimize this effect we are doing additional compaction and inspection of fill under the tank and near the ringwall.

To minimize freezing problems, we are using 6 inches of foam glass for undertank insulation. This reduces heat leakage and minimizes possible freezing problems.

Many ammonia tanks have been in service for 15 to 20 years without an internal inspection. I suggest that AICHE Ammonia and Related Facilities Safety Committee initiate action with responsible authorities requiring an internal inspection at some agreed interval and suggest that 10 years is the maximum time interval.