Storage of Anhydrous Ammonia in a Mined Cavern

A tight, impermeable, structurally adequate rock formation is the single most important factor in guaranteeing the integrity of amined cavern for storing volatile liquids.

J. L. Sherman
E. I. du Pont de Nemours & Co., Inc.
Wilmington, Del.

A mined cavern for storage of anhydrous ammonia has been completed by Du Pont at Gibbstown on the New Jersey side of the Delaware River, east of Chester, Pennyslvania. This unique ammonia storage facility received its first tanker shipment in November 1968 and has been in continuous service since that time. In all respects, the storage is functioning as predicted by its designers.

The Du Pont storage cavern has a volume of 1 million cu. ft. and a capacity of 20,000 tons of ammonia. The cavern, which was mined out of solid rock, is in the form of intersecting tunnels 20 ft. wide by 30 ft. high in a rectangular grid with its floor 370 ft. below the surface. The interior surface of the cavern is bare rock without lining. The impermeability of the rock and the absence of significant fractures prevent harmful water in-leakage. Leakage of ammonia into the surrounding rock is effectively prevented by both the tightness of the rock formation and a hydrostatic water pressure of 143 psi, which far exceeds the cavern operating pressure. These features, combined with a deep layer of weathered rock between the overburden and bed-rock, eliminate any possibility of contamination of water bearing strata in the overburden.

Although the storage of volatile liquids, such as liquid propane, in large mined caverns is fairly wide spread in the petroleum industry, the storage of ammonia in this manner has little precedent. A 3½ million cu. ft. ammonia storage cavern, completed in 1967 in Norway, is the only other facility of this type in existence.

This unusual type of construction for the Gibbstown storage was chosen because suitable rock formations at reasonable depth made the project feasible at costs competitive with high integrity and the adequately protected surface storages Du Pont has constructed at other sites.

Obviously, the presence of a sound, imprevious, dry rock formation at reasonable depth is all important to this type of construction. Exploratory studies to determine feasibility, preferred location, and elevation were conducted by competent, experienced specialists in this field.

Feasilibity study

Our feasibility study required drilling nine exploratory holes to a depth of about 500 ft. Cores were taken to determine rock type and structure, and the permeability of the rock to water injected into a particular stratum was determined by formation pressure tests. Hole caliper surveys were correlated with the other information to reveal structural faults, and "swabbing" tests were conducted to determine rate of water leakage into the drill hole and to obtain water samples from particular strata. Selected cores were tested for compressive strength, permeability, and chemical stability in ammonia.

The exploratory drillings revealed that the overburden of silt, sands, and clays varied in thickness from 90 ft. to 150 ft. The first area explored (5 holes) was considered unsuitable because the bedrock contained highly micaceous schist strata which was soft and fractured. A second area was selected and, after drilling four holes, was found to be suitable below a depth of 300 ft. The rock here is a Wissachickon formation of the Pre-Cambrian period composed of gneiss and schist, with pegmatites and amphibolite in varying amounts.

The mining of caverns of this type is a highly developed art utilizing very specialized equipment and techniques. Mining began with the drilling of three shafts lined with steel tubing cemented in place. Two shafts of 16 in. and 24 in. inside diameter were used for ventilation during construction and the main shaft, with a 42 in. inside diameter, was used for transporting men and machinery into the operation and for removing rubble from the blasting operations. Power driven machinery, including jumbo drilling rigs and front end loaders, were dismantled and lowered through the main shaft. Rock was removed in a single 20 cu. ft. steel can which made a round trip in less than a minute.

Design of the cavern itself was largely dictated by geological features which determined the overall boundaries, the level of floor and roof, and the orientation of the cavern chambers. Figure 1 shows the plan of the cavern including the pillars, the two pump sumps and the main shaft which contains the filling pipe. Section A-A is an idealized view of the chambers, pillars and pump sump. In

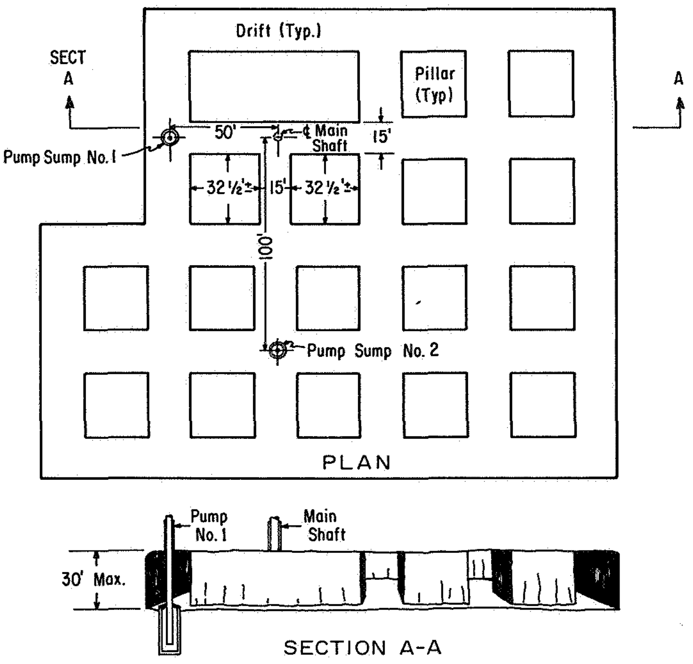

Figure 1. The plan of the ammonia storage cavern.

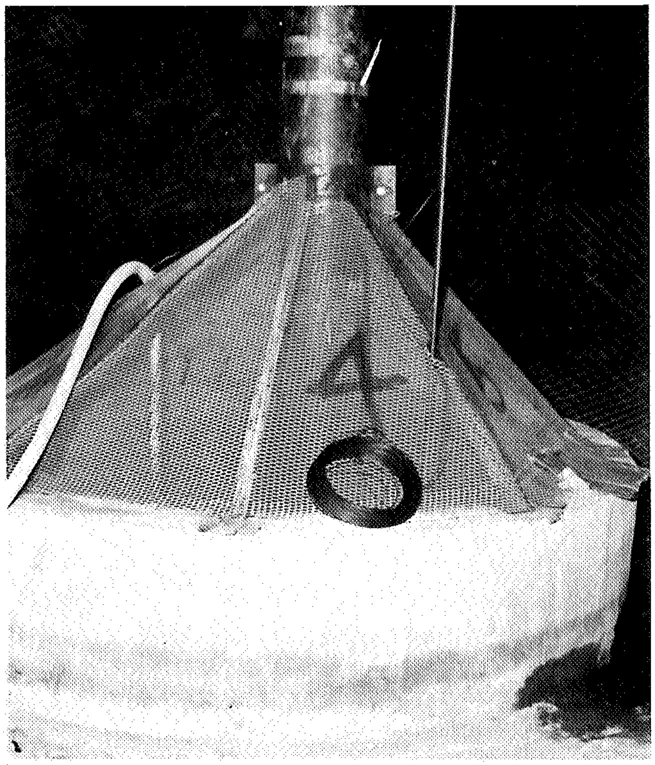

Figure 2. Conical guard screens to prevent debris from falling into the sump.

reality, the rock surfaces are far more irregular than shown.

The cavern is filled through a single 12 in. dia. pipe extending down the main shaft and discharging against an impingement plate anchored into a concrete slab in the cavern floor. Stored product is recovered by two deepwell pumps in separate shafts taking suction from 6 ft. dia x 20 ft. deep concrete sumps. Large rock debris, which might fall into the sump, is excluded by conical guard screens, Figure 2. Both pumps are enclosed in dip tubes which are sealed into the cavern floor and extended into the sumps.

Pump assembly removal

Although we ultimately intend to cool the cavern to atmospheric pressure, several features are provided to permit withdrawal of the pump assembly with the cavern under pressure. These features are:

1. A weight operated valve which closes the opening of the dip tube when the pump is raised about 1 ft.
2. A spring operated valve which closes the pump inlet when the pump is raised about 1 ft.
3. A neoprene device similar to those used to seal oil well drill strings seals the upper end of the pump column during lifting.

Features 2 and 3 will maintain a seal during pump removal independent of feature 1 and vice versa. In the event the above devices become inoperative, the dip tube can be filled with oil to produce a hydrostatic seal.

To increase the cool down rate and to permit cooling to -28°F for atmospheric pressure operation, refrigeration machinery is provided. Vapor is removed from the top of the cavern, compressed and then cooled against liquid ammonia being pumped to consumers. The condensed liquid is returned to the cavern. Without refrigeration it was predicted that cooling the cavern with ammonia at -28°F would require 12 months to reach -10°F, but with refrigeration this temperature was reached in 19 weeks.

Of major concern during feasibility studies, design and construction was the problem of contamination of the ammonia by water soluble salts carried by water leaks. Among the many alternate schemes contemplated in advance in case excessive water leakage was encountered were:

1. Pressure grouting to seal faults.
2. Above ground purification to reject water and salts concentrated in vaporizers.
3. Freezing of water in very narrow passages by operating the cavern at temperatures below -10 F.

During the mining operation, much attention was given to estimating the rate of water in-leakage which, at completion of mining and after selective pressure grouting, was measured to be 0.5 gpm.

Upon completion of mining, considerable time and effort were expended in cleaning the cavern floor to remove the 5,000 tons of rock dust. This was done to avoid contamination of pumped ammonia and to prevent wear or obstruction of the pumps despite assurances by the contractor and our own engineers that the rock dust would not be transported along the cavern floor into the sumps.

Inert purging was considered and rejected because cavern design pressure exceeded the maximum pressure which could be developed in the unlikely event the ammonia vapor ignited. Activation of the cavern began, therefore, with a purge of ammonia vapor to remove air. Over an 8 day period about 70 tons of ammonia were added as vapor; about 50 tons of vapor were purged. The purged vapor was recovered by water scrubbing for use as aqua ammonia. After completion of purging, about 2,000 tons of liquid ammonia at ambient temperature were introduced over a 7 day period. At the end of this time pressure was 60 psi. The refrigeration system was operated

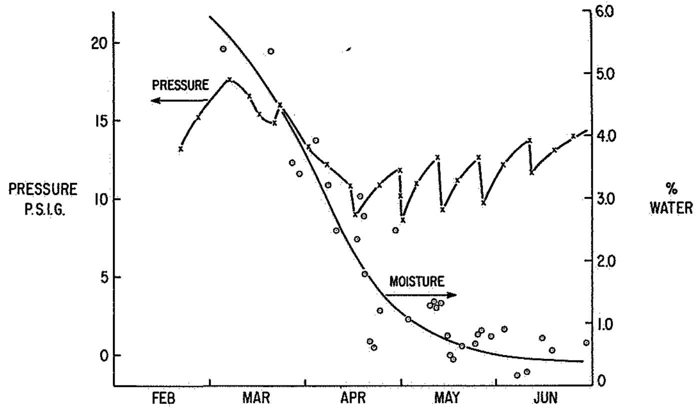

Figure 3. Time chart of cavern pressure and moisture content.

during this period rejecting heat to an evaporative condenser.

Figure 3 is a time chart of cavern pressure and moisture content. Initially, moisture content was high due to the presence of water in rock crevices and irregularities in the cavern floor. Most of this water was drainage from drilling operations. The gradual reduction in moisture content is the result of dillution by the periodic addition of fresh ammonia. Neither the initial high moisture content or contamination by dissolved salts has resulted in serious problems at the consuming operations. It is expected that freezing eventually will result in negligible entry of water into the cavern.

In conclusion

The Gibbstown ammonia storage cavern has demonstrated the feasibility and safety of this unique form of construction. It must be recognized, however, that feasibility is totally dependent on the presence of a tight, impermeable, structurally adequate rock formation which must be explored and proved adequate before construction is begun. Because of the unavoidable uncertainty in the magnitude of water leakage into the cavern, the owner must be prepared to deal with small rates of water contamination if encountered.