Operation and Maintenance of Underground Storage

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ABSTRACT

Storage of hydrocarbons in salt caverns is a comparatively new application of the brining technique. Several hundred active salt caverns testify to the successful operation of such underground storage.

In storage operations a petroleum product displaces brine from the bottom of the cavern. The resultant interface between the hydrocarbon and brine affords a method of calculating incremental capacities and corresponding average diameters. In this procedure measured volumes of hydrocarbon are correlated with the interface level, which can be determined by static pressure or direct measurement. Such information can be a valuable supplement to more detailed sonic caliper surveys. The cavern can be enlarged at selected levels by injecting fresh water as the interface is lowered during the normal filling cycle.

Surface pressures required to confine volatile hydrocarbons range upward to 2500 p. s. i., depending on depth. Subsurface remedial work can best and most safely be performed after the petroleum product has been removed. In the event of tubing failure, compressibility of the more volatile hydrocarbons permits evacuation by intermittent injection of water, and removal of the product.

Although operating problems tend to increase with depth, storage caverns are operating satisfactorily as deep as 8400 feet in North Dakota.

INTRODUCTION

In slightly more than a decade, storage of petroleum products in underground salt caverns has grown from a few experimental projects to several hundred proven installations. This activity is essentially an extension of the much older brine extraction technique. Storage is usually effected by injecting the hydrocarbons into the top of the cavern and thus displacing an equal volume of brine from bottom. Recovery of the product is accomplished by reversing the procedure and injecting either brine or fresh water to displace the product. Throughout the storage cycle the hydrocarbon floats on top of brine. The resultant interface between the two liquids moves down as additional product is stored and upward as product is withdrawn. The existence of these two liquids, and the movement of the resultant interface, represent the fundamental difference between salt cavern storage and brine extraction.

The following operating problems, associated with salt cavern storage, are discussed.

1. Tubing failures and plugging.
2. Measurement of cavern dimensions with emphasis on the movement of the hydrocarbon-brine interface.

3. Control of cavern dimensions.

4. Special operating problems associated with storage at a depth of 8400 feet.

TUBING FAILURE AND PLUGGING

Tubing failures occur in storage wells for the same reasons as in brine wells. Impact from falling ledges and fatigue of the mental are the most common causes. The problem is magnified in the case of storage operations, because of the presence of the hydrocarbon. If the tubing failure occurs above the hydrocarbon-brine interface, the high pressure product is transferred to the tubing from the annular space. Warning or shut-off devices are normally provided to protect the brine or water system in the event of such failure. Such devices can be actuated by increased velocity or pressure in the brine return stream.

Tubing failure above the interface prohibits further injection of product. In such a case the tubing must be pulled and repaired before additional storage can be effected. Although tubing can be pulled and re-run under pressure, petroleum products are usually removed prior to pulling because of the attendant fire hazard. Such evacuation can be effected intermittently by utilizing the compression of the stored product to inject a limited amount of water. After this water has descended to the interface, an equivalent volume of stored product can be withdrawn. Experience reveals that, in the case of propane storage, three to four per cent of the total volume can be removed on each such cycle. After the interface has risen to a level above the tubing failure, normal continuous displacement can be resumed.

When a tubing failure is limited to a point below the interface, the seal between the hydrocarbon and brine is undisturbed, and normal injection or recovery is possible. If this type failure is experienced during the withdrawal season, the difficulty, and attendant loss of capacity, may go undetected until the following period, when product is injected to this level. Because of this possibility, it is sometimes considered prudent to run a wire-line to determine if the tubing is intact at the beginning of each storage season.

Tubing may become plugged by insolubles or by crystallization of salt. Here again the problem is complicated by the presence of a volatile hydrocarbon. If tubing is plugged near bottom, it may be cut-off or perforated so that operation can be resumed. Salt plugs at higher levels can often be dissolved, particularly if fresh water is circulated through smaller diameter tubing. When such procedures fail, the tubing must be pulled for repairs.

Obviously, all reasonable precautions should be taken to prevent plugging. A build-up of fine insolubles, such as andydrite, in the bottom of caverns sometimes plugs tubing. Such difficulty can be avoided by raising the tubing. Wire-line depth measurements, through open-end tubing, are helpful in determining when the tubing should be raised.

Salt plugging is a particular hazard during the product injection period, because the returning brine often has several months to become saturated at bottom-hole conditions. The seriousness of the problem is directly related to the difference in solubility at the bottom of the hole and the surface. Dilution of the brine with fresh water is the usual preventative. The desired effect can often be achieved by intermittent displacement of the tubing with fresh water. In some instances the compressibility of fluid within the cavern is of such magnitude that the procedure can be effected without interrupting product injection. Under other conditions it may be desirable to inject fresh water continuously, through a small auxilliary tubing string.

MEASUREMENT OF CAVERN DIMENSIONS

One of the most important long range operating problems in salt cavern storage is the measurement and control of cavern dimensions. If the cavern is leached to the desired maximum capacity prior to storing product, further enlargement can be prevented by using brine for displacement during the recovery cycle. More often, however, storage capacity is needed when only a small part of the potential capacity has been achieved, and additional washing is usually limited to the few months when the cavern is empty. Because of these conditions, caverns are usually enlarged by using fresh water for displacement. As will be shown later, this procedure has an important long range effect on cavern geometry.

Sonic caliper logging has been used advantageously to determine cavern shape, during both development and operating periods. Since the tool provides polar orientation, the survey reveals the extent of eccentricity, as well as the diameter at any level. All hydrocarbons must be removed, and tubing must be pulled in preparation for this survey. Because of these requirements several less exacting surveys have been used to determine cavern dimensions. In general these surveys depend on tracing the movement of the hydrocarbon-brine interface as product is injected or recovered.

A gamma-ray logging device can be used to locate the interface. Incremental capacities, and corresponding average diameters, can be calculated by correlating several of these depths with carefully measured volumes of hydrocarbon injected. While this information provides only limited information regarding the cavern shape, it is particularly valuable in evaluating progressive cavern enlargement after a more detailed sonic survey has been run.

If there is sufficient clearance between the casing and tubing, for example between 4 inch and 10 inch pipe, a weight can be run on a measuring line to determine the interface. The density of the weight must be greater than that of the hydrocarbon, but less than that of brine. Obviously this procedure is applicable only where the space between the casing and tubing is adequate. Where such conditions prevail, the interface can be located frequently at little expense or loss of time.

Equilibrum pressure data can also be used to locate the hydrocarbon-brine interface, and thus calculated average diameters. This is accomplished by suspending injection operations at intervals. Tubing and casing pressure, P_2 and P_1 in Figure 1, are read carefully after equilibrium has been reached. It will be recognized that:

$$(1) \quad h = \frac{P_1 - P_2}{0.434(d_B - d_h)}$$

Where:

h = depth to interface, feet

d_b = specific gravity of brine

d_h = specific gravity of hydrocarbon

P_1 = casing pressure - psi

P_2 = tubing pressure - psi

Or:

$$(2) \quad \Delta h = \frac{\Delta (P_1 - P_2)}{0.434(d_b - d_h)}$$

for the incremental part of the cavern. Then average cavern radius for the vertical increment can be calculated by,

$$(3) \quad R = 1.34 \sqrt{\frac{\Delta Q}{\Delta h}}$$

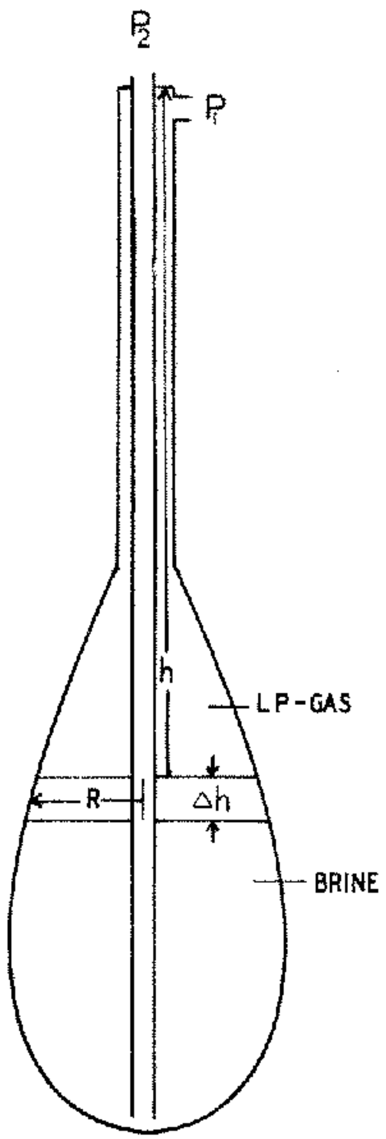
Where:

h = vertical height filled during interval, feet

Q = volume of hydrocarbon injected during interval, measured in 42 gallon barrels

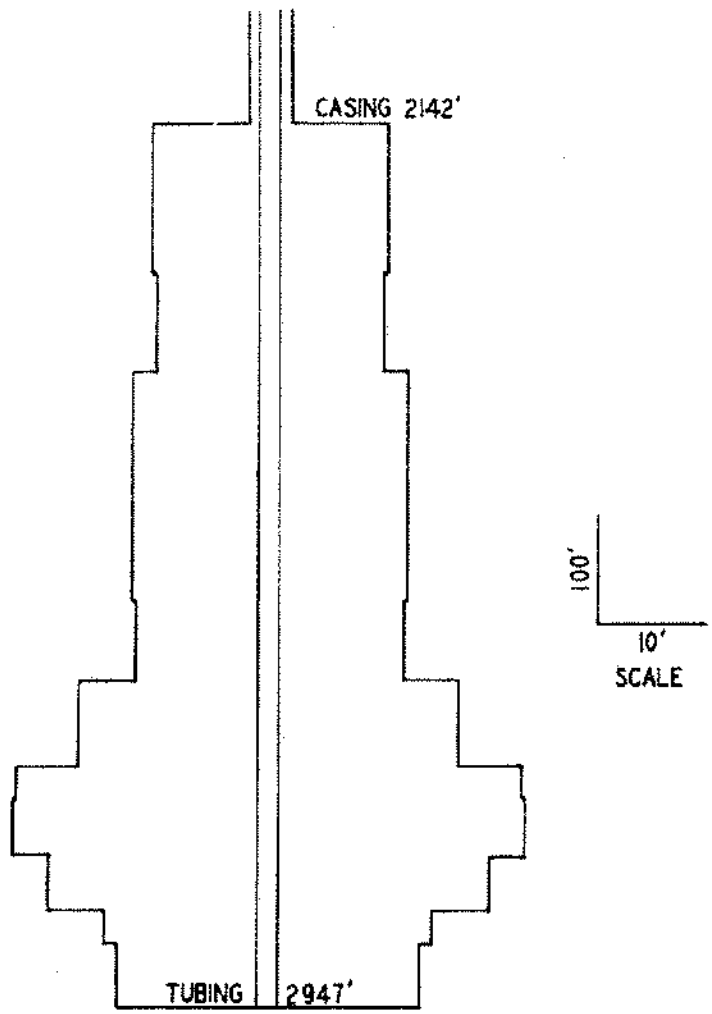
R = average radius for interval, feet

This method is dependent upon precise pressure measurements, and is most dependable where caverns are formed from thick sections of salt. The method can be checked at the beginning and end of the cavern filling cycle since "h" values are determined at these times by casing and tubing measurements. These known depths are helpful in adjusting the specific gravity of the liquids to subsurface conditions. Typical results of this type survey are illustrated in Figure 2.



A SIMPLIFIED VIEW OF A SALT STORAGE CAVERN

FIGURE-1



AVERAGE CAVERN DIAMETERS BY PRESSURE EQUILIBRIUM DATA

FIGURE-2

CONTROL OF CAVERN DIMENSIONS

Because of the usual pressing need for underground storage, most salt caverns have been utilized when only a small part of their potential capacities has been dissolved. The seasonal nature of the storage is such that only a short time is available for subsequent leaching. Additional enlargement, at the approximate rate of 16% per cycle, has commonly been effected by displacement with fresh water. This procedure has an additional advantage, over brine displacement, in that brine retention facilities are unnecessary. Enlargement by fresh water displacement is concentrated near the bottom of the cavern by the hydrocarbon-brine interface. As the volume at this lower level increases, the time of confinement is magnified, and the extent of solution at lower levels is further accelerated.

Figure 3 shows the growth pattern typical of salt dome caverns and illustrates a method of controlling such enlargement. In the example the cavern was initially washed, by tubing injection, to a capacity of 125,000 barrels. Stage A represents the cavern shape normal at such time. After continued use of fresh water displacement, a cavern shape such as illustrated for Stage B is typical. In the illustration a modest part of the capacity increase was achieved by supplemental washing. A maximum radius of the magnitude shown for Stage B is generally within tolerable limits, but a long range plan of control is desirable.

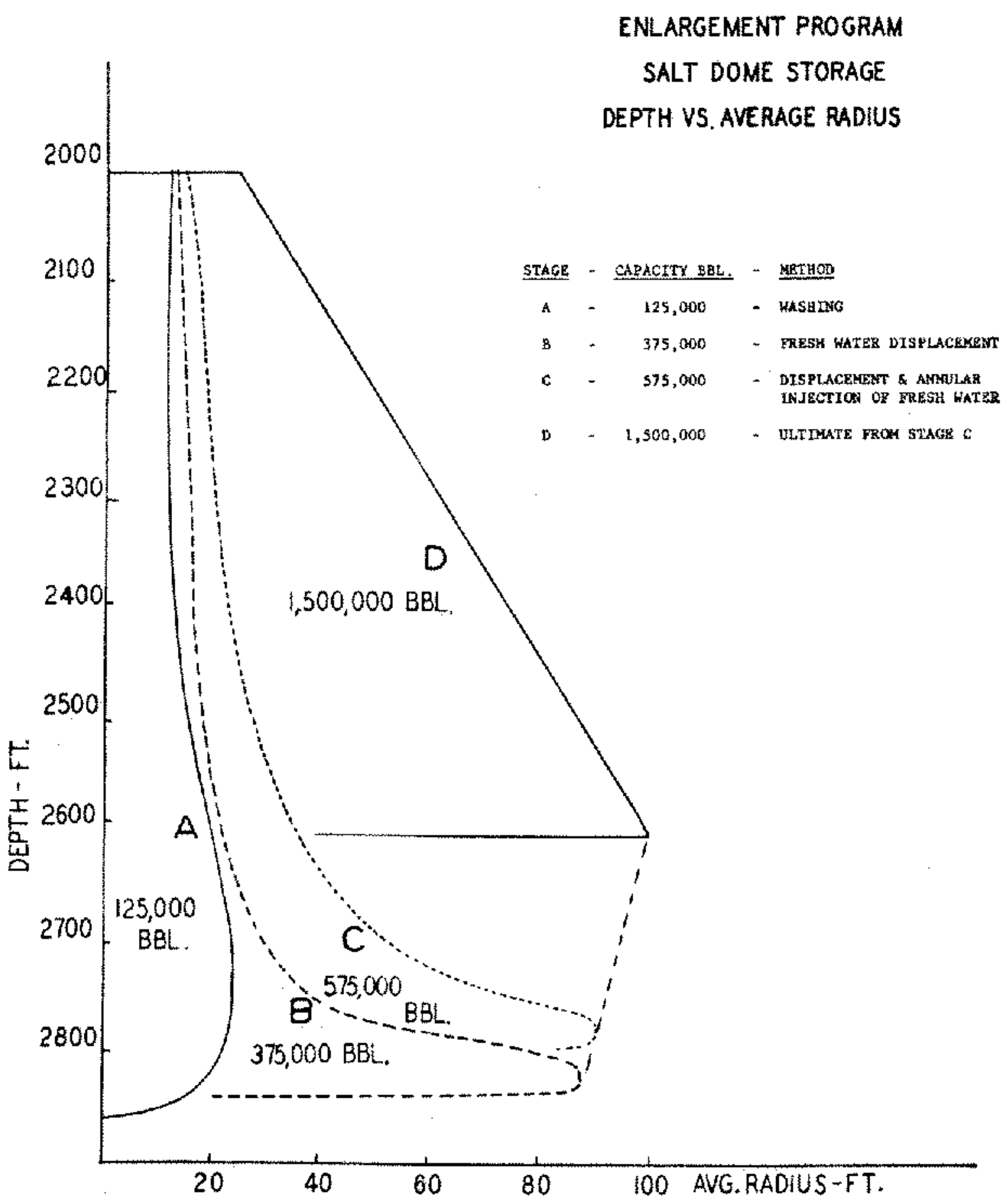
The time to apply such control measures will vary widely with individual caverns. Factors bearing on this timing include:

1. Structural considerations.
2. Cavern eccentricity.
3. Solubility characteristics.
4. Spacing of caverns with respect to each other and with respect to property lines and the edge of the salt dome.
5. Rate of insoluble build-up on bottom.
6. Economic considerations, such as the relative cost increase associated with brine displacement.
7. Need for additional capacity.

Since the history described above is typical of many salt dome storage caverns, it is only reasonable that several approaches to the problem have been applied. Raising tubing above the zone of enlargement and use of brine for displacement are the most obvious. An additional method which permits continued use of fresh water for displacement and provides a means of developing latent storage potential, is suggested herewith. In this procedure tubing should be raised to a level above the cavern enlargement in preparation for Stage C of the program illustrated in Figure 3. Displacement with fresh water will then leach salt immediately above the existing zone of enlargement.

In addition to moving tubing, it is suggested that fresh water be injected into the annulus as product is injected. This water will rapidly fall through the hydrocarbon to the interface, where maximum solution action will be achieved. Under carefully controlled conditions, this type of solution may also be desirable even when operations have been suspended. Similarly, the cavern may be enlarged during the recovery cycle as the interface rises. The procedure has the advantage of retrieving part of the capacity sacrificed by raising the tubing, and it is a means of developing unused capacity at an upper level. This method can be repeated at higher levels, so that brine displacement can reasonably be deferred for many years after the original washing of the cavern.

It should be noted, however, that the rate of enlargement is dependent upon the volume of fresh water injected, rather than the number of years involved. For the case presented, initial enlargement by displacement was effected in seven years, whereas, with increasing capacity and displacement, the same result could be expected in four years, if all of the increased capacity is utilized each season. For the illustration presented, it is calculated that tubing might be raised in six progressive steps before a cavern such as that of Stage D (Figure 3) is realized. The program can be accelerated if increased capacity is the prime consideration, or it can be retarded if the economy of fresh water displacement is an overriding factor. Reliable information regarding changing cavern dimensions is necessary in order to evaluate the progress of such a program. During an expansion period it seems advisable to start with a detailed sonic caliper survey. As the enlargement progresses, evaluation by tracing the interface can be expected to provide valuable control.



ENLARGEMENT PROGRAM
SALT DOME STORAGE
DEPTH VS. AVERAGE RADIUS
STAGE - CAPACITY BBL. - METHOD
A - 125,000 - WASHING
B - 375,000 - FRESH WATER DISPLACEMENT
C - 575,000 - DISPLACEMENT & ANNULAR INJECTION OF FRESH WATER
D - 1,500,000 - ULTIMATE FROM STAGE C
D
1,500,000 BBL.
A
125,000 BBL.
C
575,000 BBL.
B
375,000 BBL.
DEPTH - FT.
2000
2100
2200
2300
2400
2500
2600
2700
2800
20
40
60
80
100
AVG. RADIUS - FT.

FIGURE-3

DEEP UNDERGROUND STORAGE

In the Williston Basin of North Dakota salt cavern storage, for propane, has been operated successfully at a depth of 8400 feet for the past two years. Experience to date is encouraging, and provides assurance that projects at such a depth are feasible. Additional time and data will be necessary to determine if appreciable salt flow exists under such conditions. Operating experience thus far indicates that, if such a flow exists, it is of no practical significance to storage operations.

Most problems in deep operations are similar to, but more severe, than those experienced at usual storage depths of less than 4000 feet. For example, considerably more effort is required to prevent salt crystallization. Consideration has been given to installing an inner string of tubing to provide continuous dilution of the saturated brine, but intermittent displacement of the main tubing with fresh water has been adequate for the current rate of product movement. Dehydration of propane is more severe than usual, because the propane is saturated with water at a higher than normal temperature as it reaches the surface. Nevertheless, conventional dehydrators are suitable when adequate free-water removal facilities are provided. As would be calculated, pressure required to inject propane to this depth is in the order of 2500 psi.

Both initial investment and operating cost are appreciably higher than for salt cavern storage at a more modest depth. In conclusion, it should be stated that economics seem to favor such deep salt storage as compared to mined storage.