Outlook for Underground Storage

Donald L. Katz
Department of Chemical Engineering
The University of Michigan
Ann Arbor

ABSTRACT

The use of the earth to store fluids is reviewed briefly, with emphasis on storage of natural gas in rock layers. The use of salt cavities for storage has many advantages over alternate methods. Monitoring and safety procedures are brought out as necessary for long-term use of all storage facilities. The application of these experiences to storage in salt cavities is advocated; the development of documented safe practices and monitoring procedures are especially appropriate to this type of storage.

OUTLOOK FOR UNDERGROUND STORAGE

People view the earth from different perspectives; some, the surface scenery, mountains, lakes and valleys, others as the source of our minerals near the surface or from underground mines or wells. A limited number view the earth as a place to store fluids usually under pressure. Table I lists the modes most commonly used.

The need for storage of fuels underground is the high demand in winter and low demand in summer, especially in population centers in the northern and central regions of the U.S. for space heating. A secondary use comes from the inventory needs between the continuous supply of high vapor pressure liquids from process plants and their utilization either as raw materials for chemicals or for fuels.

TABLE I

Underground storage modes

Underground Storage Container	Principal Fluids Stored
Underground porous rock layers	Natural gas
Salt cavities	Propane, butane, natural gas, chemicals
Mined cavities	Propane, butane, radioactive wastes
Frozen earth with roof at surface	Propane, LNG

The earth's fluid pressure rise with depth of some 43 lbs/sq. in. per 100 feet increase in depth is one basic quality the earth offers for storage. The impermeability of in situ salt, anhydrite, and some dense limestones provide barriers to underground fluid movement. The high threshold displacement pressure for organic fluids to displace water from low permeability caprock shales, limestones, and dolomites is another quality of the earth utilized in underground storage.

This paper will review the status of the underground storage industry from the viewpoint of the author's experiences and readings. It is intended to orient the sessions of this Fourth Salt Symposium directed, in good part, toward storage in salt cavities.

Need for fuel storage

The variable need for fuel in cooler weather provides the basic impetus for the preponderance of storage projects. Pipeline systems carrying natural gas long distances to market need to operate near full capacity, year around. Processing plants recovering LP gas, propane in particular, make their products year around, with need for storage greatest in summer.

To show the variation in fuel requirements for space heating, Figure 1 is presented for a typical home in the Chicago area. The monthly therm requirements (100,000 BTU/therm) are plotted, with the difference between the total need and the basic cooking, water heating, and dryer representing the space heat load. The space heat load represents the degree-day pattern need for all building heating requirements in the Midwest.

On top of this monthly variation in fuel requirements are great variations in peak day needs—sometimes lasting for near-high levels for as much as 3 or 4 days at a time during December through February. The peak day therm expectancy for a winter season in Chicago is 19.3 therms

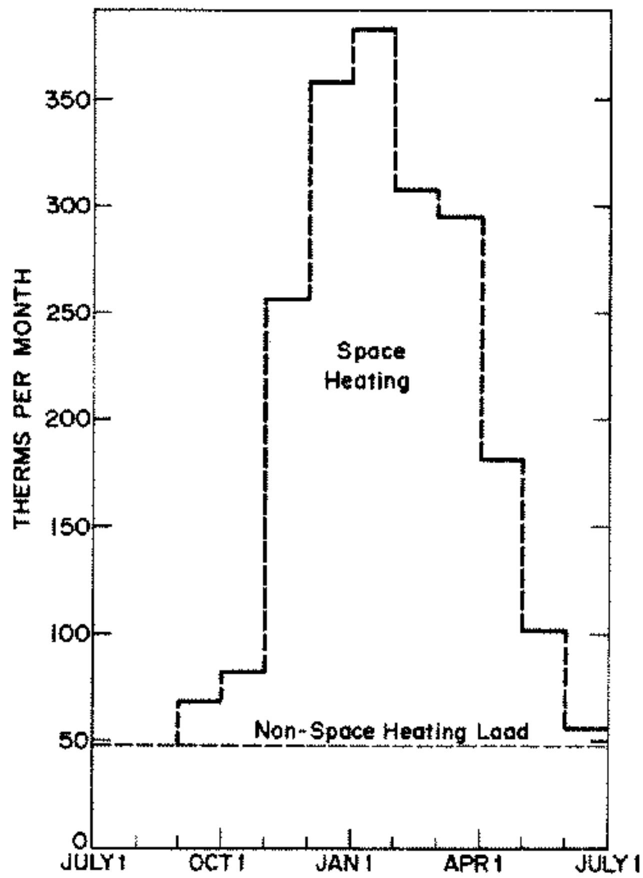

Figure 1. Therms (100,000 Btu) Used per Month—Average Home, Chicago Area.

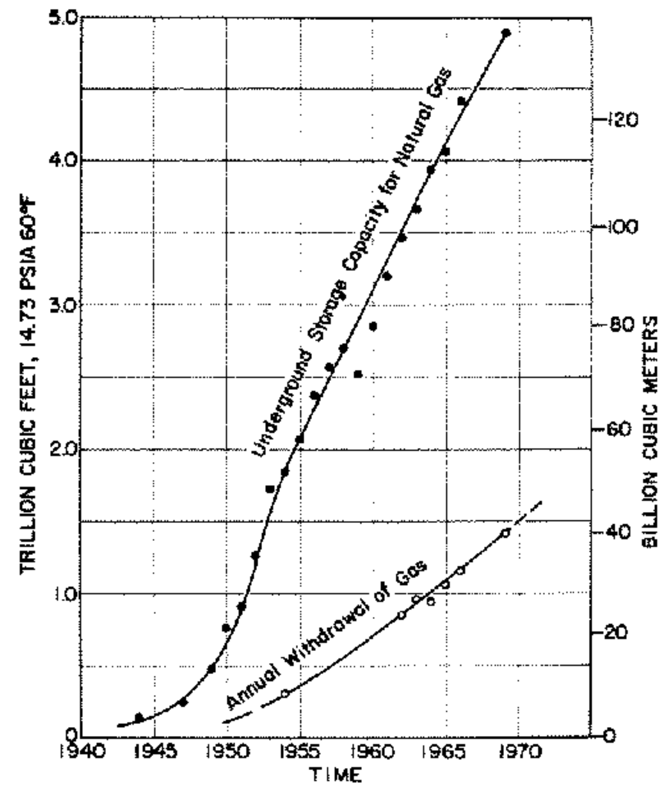

Figure 2. Growth in Underground Storage of Natural Gas in U.S.A.

as compared to a January average consumption of 383/31 = 12.3 or 1.57 times the average day's consumption.

Process plants extracting natural gasoline and LP gases always have had a storage problem for their high vapor pressure products. Since storage in the earth handles the pressure aspect easily, it has fulfilled a great need for conserving these products produced in summer but needed in winter without the burden of expensive above-ground pressure or refrigerated storage tanks.

The need to keep a high load factor on long distance natural gas pipelines seems obvious for lower costs of transportation. From consideration of the higher capital costs in the future for the Alaskan gas line, LNG (liquefied natural gas) ships, or SNG (substitute natural gas) plants, it seems clear that year around full capacity operation of these supply sources will emphasize the need for underground storage.

Growth and use of storage

Natural gas has been stored for winter use for more than 50 years (AGA, 1966; Katz, 1968), but the bulk of the storage growth has taken place in the past 30 years as shown on Figure 2 (Katz and Witherspoon, 1971; Ibrahim, et al., 1970). One would expect some reduction in the rate of growth of the underground storage capacity curve due to the recent gas shortage but the annual withdrawal curve could well continue for some time unchanged because of the growing emphasis on higher use of gas for space heating, permitting this segment of the utilization to grow at the expense of other uses.

The use of solution mined salt cavities was demonstrated and documented for storing propane in the period of 1948–1950. According to Howard (1973) the first salt cavity created for and used to store propane was done by D. C. Stewart, et al., in Hutchinson County, Kansas in the fall of 1948. The papers by Howard (1951) and Matheny (1951) describe the subsequent project by Richardson and Bass in Winkler County, Texas; they made the first disclosures of the storage in salt cavities. Growth in the volume of storage was rapid as shown by Figure 3 (Katz and Coats, 1968). The limitations placed on geographical location by the absence of salt beds is widespread; the subject is treated in earlier Salt Symposia of the Northern Ohio Geological Society. The numerous salt domes of the Gulf Coast, the bed lying from Carlsbad area of New Mexico into Kansas, the Michigan Basin, Ohio, New York, Pennsylvania beds and the western Dakota-Montana beds which extend into Saskatchewan and Alberta are the primary U.S. areas permitting the use of salt cavities.

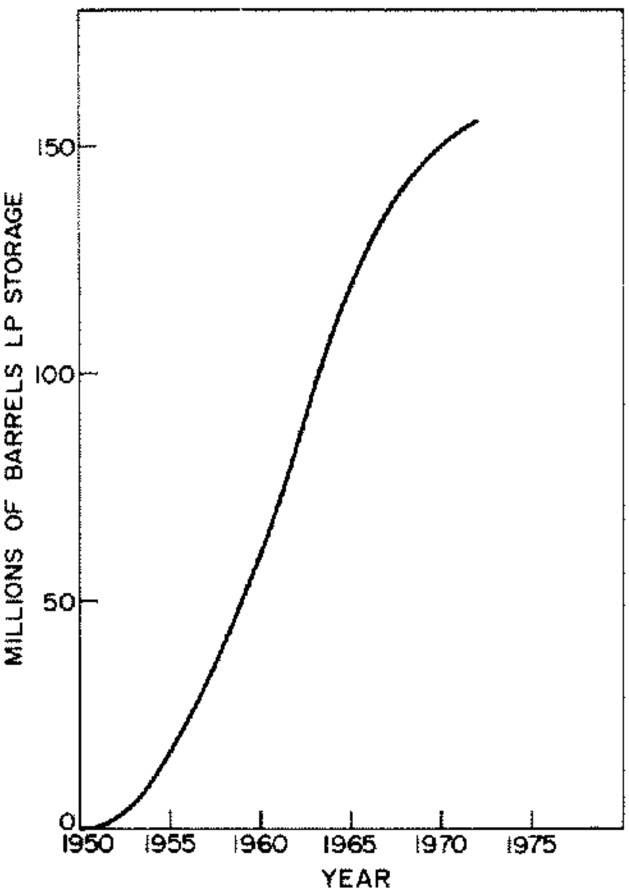

Figure 3. Growth of Underground Storage of LP Gas in U.S.A.

Although salt had been mined as brine for nearly a century from some of the above areas for the early U.S. chemical industry, such operations had no need to be careful with regard to maintaining a seal on the fluids in the salt cavities. The Southeastern Michigan Gas Company uses such a well for gas storage, but it is a unique example of a tight system; many others were not. Petrochemical companies on the Gulf Coast, Sarnia, Downriver Detroit, Midland, etc. have used salt cavities for ethylene ammonia, partially concentrated brines and other fluids (Katz and Coats, 1968). A recent paper (Allen, 1972) updates the use of salt cavities for natural gas.

Salt cavities are particularly advantageous for LP gases and other volatile liquids as compared to porous media. The cavity is a tank while the interstices of porous sandstones or carbonate rocks present problems when gas-liquid interfaces are involved. If a gas is used to displace propane from porous media, a meniscus develops at the interface and two phase flow in porous media ensues. The gas can bypass liquid propane and a certain fraction of the pore space remains liquid filled. The use of water to displace propane from porous media also involves only fractional recovery because of two phase phenomena (Matheny, 1951).

A difference between gas and liquid storage in salt cavities is likely to be the method of filling and removal. With liquid storage, brine displacement is common for production purposes. With gas storage, the gas pressure may be varied without any displacement phenomenon.

BASIC CONCEPTS OF STORAGE CONTAINMENT

Fluids are maintained in storage within the earth by hydraulic pressure and capillary forces in tight caprocks, by gravity separation of phases and water seals below the stored fluid, or by salt beds or other impervious rocks. The kind of seal depends upon the type of storage reservoir. Since rocks may not be continuously perfect in their caprock quality, cement placement and tubular steel piping are subject to imperfections on occasion, maintenance of a goal of complete containment requires diligence, care, and Continuous monitoring. Even then, the unexpected can happen and plans should be made to handle problems which arise with the minimum damage to life, property, and the environment.

Spurred on by the desire for complete containment of stored fluids, occasional incidents or near accidents, much work has been done to accumulate the knowledge required for assurance of containment of various types of reservoirs. For depleted or converted gas or oil reservoirs, the structures and spill areas are normally located by drilling to the storage zone. To rehabilitate oil wells, well casing is inspected with scanning devices, cement bonds are logged, the presence of gas behind the pipe may be checked by neutron logs. Monitoring water-bearing zones above the storage zone is accomplished by water level indicators in observation wells (Katz and Coats, 1968).

In developing aquifers, i.e. water-bearing sands for gas storage, the caprocks are subjected to core tests for permeability and threshold displacement pressure (Katz and Coats, 1968; Ibrahim, et al., 1970), while pump tests are used to evaluate the permeability of caprock in situ (Witherspoon, et al., 1967). With sound caprock and monitoring procedures, the use of delta pressures above discovery, provides the means for growing aquifers and more fully utilizing the resources of converted oil and gas fields (Ibrahim, et al., 1970).

Initial investigations for new storage projects and monitoring of operations have had much attention of the writer over the years (Katz, 1971). Figure 4 shows the delta pressures used in gas storage in porous rocks with an insert illustrating the threshold pressure test (Katz and Witherspoon, 1971). Figure 5 shows a section of a storage system, including a gas storage field, for which monitoring is carried out. Figure 6 is the "symbol" for a test to find

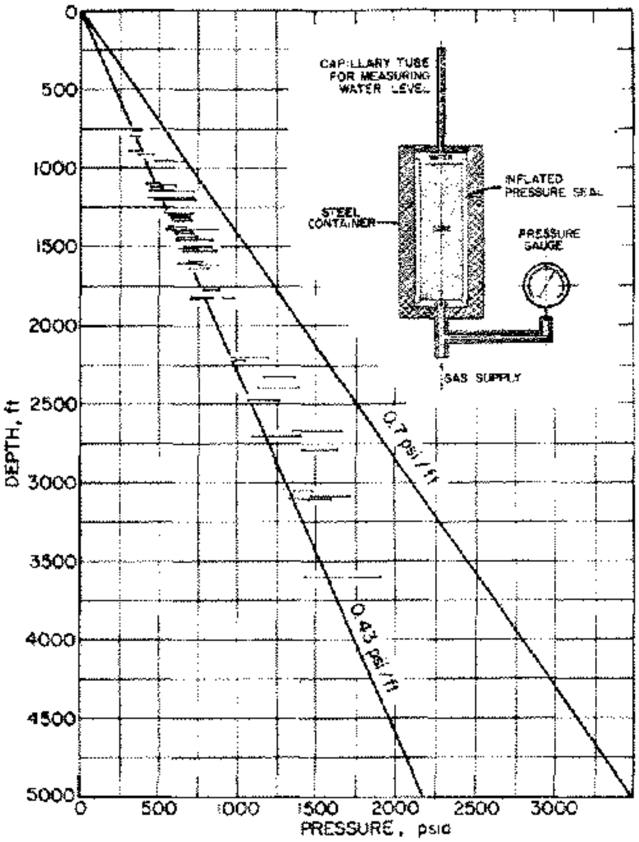

Figure 4. Pressure-Depth Relationship Illustrating Delta Pressures; Threshold Displacement Measurement.

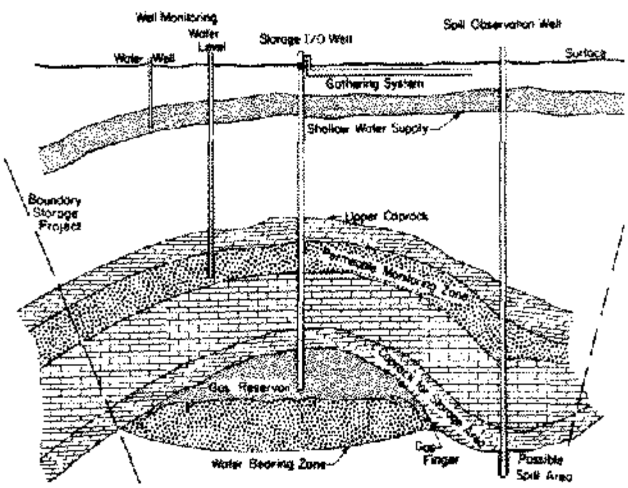

Figure 5. Delineation of Storage System.

a leaking aquifer (Katz and Coats, 1968). When a leak of size occurs, the reservoir pressure may drop so fast due to the leak that the pressure goes below the original aquifer pressure. When this happens, the leak path becomes blocked by water intrusion and the reservoir pressure rises to the original aquifer value.

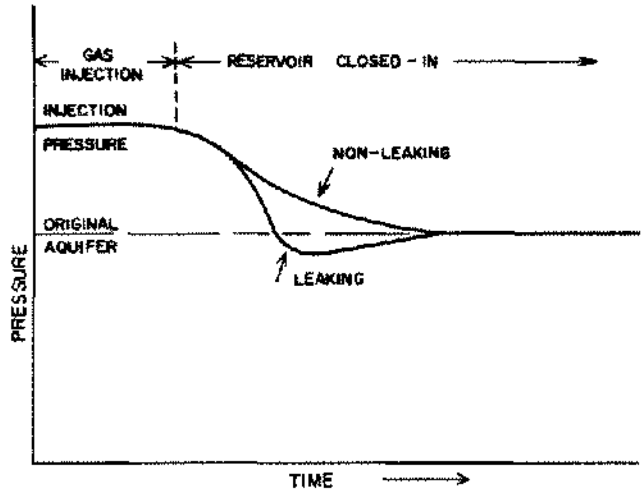

Figure 6. Reservoir Pressure Behavior of Leaking and Non-Leaking Reservoirs when Closed-In.

Figure 7 gives the permeability of caprock versus the measured threshold pressure. This graph is helpful when only permeability data are available for caprocks.

Monitoring salt cavity storage

Just as gas storage fields in porous media have developed monitoring methods, so it behooves salt cavity operations to find ways suitable for monitoring any losses or sudden leaks in either the reservoir media or the conduit systems involved. Any system can stand redundancy in checking to make sure that the operator is the first to know when some problem arises so that early corrective measures may be taken. Recent news reports of surface rock rupture near Elk City, Oklahoma from a salt cavern installation is the kind of event to be avoided (Elk City, 1973).

For liquids in cavities, sudden or even gradual changes in fluid pressure should assist in noting pin-hole leaks in pipe. Adjustments for temperature changes after changes

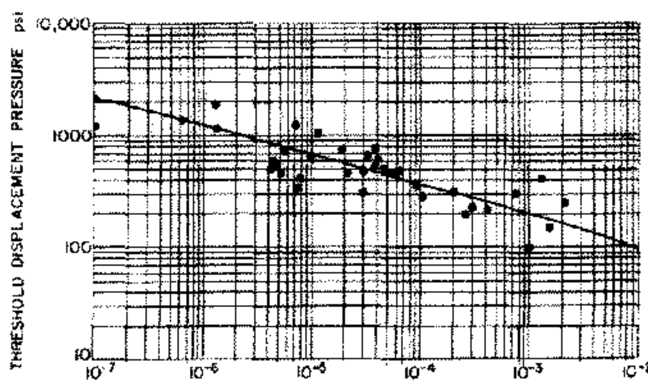

Figure 7. Threshold Pressure versus Permeability Project-Thomas Data.

in cavity content would need to be accounted for in such procedures. Physical monitoring of the surface atmosphere should prevent small leaks from surface piping from generating combustible clouds downwind.

The writer knows very little of the in situ permeability of salt layers, but believes it to be very low, except for anomalies in the beds. Like anhydrite, the salt is a nearly homogeneous crystalling solid of the class christened "super caprocks" (Ibrahim, et al., 1970). The ability of salt to flow, especially when wet, is an advantageous factor. Developers of salt cavities could afford to conduct tracer diffusion tests for component transfer from one cavity to a neighboring cavity at a known distance, as a way of understanding the containment quality of salt beds.

Salt cavities seldom are expected to have a quality exhibited by most (but not all) gas storage fields, i.e. an overlying layer of porous media to be used as a monitoring zone which confines to the same area by virtue of the physical structure any gas percolating upwards. A substitute for this quality should be developed.

Subsidence incidents surely cannot be overlooked in using salt cavities. However, the writer sees no reason why a cavity completed with good completion practice, including blanketing of the top of the cavity during solution, should have unusual subsidence problems. Accumulation of historical successful use of cavities with the degree of subsidence reported as case histories is recommended. Such evidence along with explanations of the more significant subsidences reported in earlier salt mining operations should be convincing to inquirers into safety practices. For long periods of use, individual wells per cavern adequately spaced should be relatively stable. The effect of water on the surface of salt as compared to a relatively anhydrous condition could well be considered in subsidence problems because of increased salt plasticity when wet. The structure of the overlying rock and effect of overburden load on dry and wet salt surfaces might be given consideration much as is followed in mining practices. The internal measurements in caverns should reveal the physical nature of the cavern, especially ledges of insoluble substances.

With greater attention to any interference with the environment, each cavern operator should recognize that his performance record becomes the mark of the industry. Ill-fated incidents at one site reflects on the industry as a whole. It therefore behooves all to share experiences which go to safe practices. Near misses called to the attention of the industry can help everyone.

Recapitulation of advantages of salt cavities

1. Salt cavities are tanks as compared to porous beds. Meniscus problems in the pores are not present as in porous rocks and so the cavities have an advantage for liquids not possessed by rock layers.
2. With adequate salt thicknesses at sufficient depth, salt cavities are the ideal storage for LP gases and other volatile light hydrocarbons. They also have advantages for natural gas for moderate quantities.
3. Acceptance and delivery rates can be very high for both liquids and gases.
4. Salt cavities can store large quantities of fluid in a relatively small area. Ownership problems are much simpler than with extensive land areas.
5. The time schedule for developing salt cavities, though not short, is predictable and much less than for aquifer storage in rock layers.
6. With careful development, salt cavities have a high rate of success.
7. Considerable economic advantage accrues to the natural underground tanks where pressure containment is needed as compared to refrigerated or pressurized surface installations.

Admonitions

Long periods of operation become routine. Careful attention to safety of surface equipment and methods of monitoring underground containment should be sought. The use of individually controlled size and shape cavities has merit; uncontrolled solution at the top of the cavity or between wells can lead to unforeseen problems. Studies and documentation of the degree of subsidence with various operational practices is needed to delineate the better storage practices. Industry's reputation with regard to safe storage practices is dependent on the number of incidents of all operators and the explanations given to the public when incidents occur. Therefore team efforts to minimize any uncontrolled losses of stored fluids is a worthy cause.

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