Recommended Practice on the Operation of Solution-Mined Underground Storage Facilities

API RECOMMENDED PRACTICE 1115
FIRST EDITION, SEPTEMBER 1994

REAFFIRMED, OCTOBER 2012

AMERICAN PETROLEUM INSTITUTE

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Manufacturing, Distribution and Marketing Department

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FOREWORD

This standard was prepared under the auspices of the API General Committee on Pipelines and provides basic guidance on the operation of solution-mined underground hydrocarbon liquid or liquefied gas storage facilities.

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Suggested revisions are invited and should be submitted to the director of the Manufacturing, Distribution and Marketing Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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Recommended Practice on the Operation of Solution-Mined Underground Storage Facilities

SECTION 1—INTRODUCTION

1.1 Scope

This recommended practice provides basic guidance on the operation of solution-mined underground hydrocarbon liquid or liquefied petroleum gas storage facilities. This document is intended for first-time cavern engineers or supervisors, but would also be valuable to those people experienced in cavern operations. This recommended practice is based on the accumulated knowledge and experience of geologists, engineers, and other personnel in the petroleum industry. All aspects of solution-mined underground storage operation, including cavern hydraulics, brine facilities, wellhead and hanging strings, and cavern testing are covered. Users of this guide are reminded that no publication of this type can be complete, nor can any written document be substituted for effective site-specific operating procedures.

This recommended practice does not apply to caverns used for natural gas storage, waste disposal purposes, caverns which are mechanically mined, depleted petroleum reserve cavities, or other underground storage systems which are not solution-mined.

1.2 Overview

Storage of products in solution-mined salt caverns has been utilized in the United States since the late 1940s. Today, storage of hydrocarbon liquids and liquefied petroleum gases in caverns developed in both domal and bedded salt formations is utilized throughout the world.

Salt caverns can act independently as long term, seasonal storage vessels; or they may serve as short term, operational storage. Caverns can also be inserted into the production plant/pipeline systems to prevent supply interruptions when maintenance or emergency shut downs occur or to “float” on pipelines to optimize operations.

Storage of product in a salt cavern may require careful review to ensure that the product is compatible with the salt. Chemical and physical properties of the salt at the cavern depth and at the pressure anticipated should be reviewed to verify that unwanted chemical or physical reactions will not occur. Incompatibility of product and salt is rarely a problem for most hydrocarbons. Examples of exceptions are storage in bedded salt caverns where sulfides are present and storage of jet fuels with de-icing agents that absorb water.

In summary, storage of products in salt caverns can provide an economical, safe, and environmentally sound method to store large quantities of compatible materials.

1.3 Regulatory Requirements

Federal, state, and local regulations should be consulted for specific permitting and operating requirements. In most cases, regulations will have specific record keeping requirements (i.e., casing pressure, annulus pressure, total injection rate, etc.) and will also have mechanical integrity test requirements (see Section 8).

1.4 Referenced Publications

The latest editions or revisions of the following documents form a part of this recommended practice to the extent specified in the text.

API

RP 5C1	*Recommended Practice for Care and Use of Casing and Tubing*
Spec 5CT	*Specification for Casing and Tubing*
RP 1114	*Recommended Practice for the Design of Solution-Mined Underground Storage Facilities*
RP 2220	*Process Contractor Safety Performance*

DOT[1]

49 *Code of Federal Regulations*, Part 192 “Transportation of Natural and Other Gas by Pipeline” and Part 195 “Transportation of Hazardous Liquids by Pipeline”

NFPA[2]

13	*Standard for the Installation of Sprinkler Systems*
15	*Standard for Water Spray Fixed Systems for Fire Protection*

1.5 Definitions

1.5.1 brine: a saltwater solution, said to be saturated when maximum salt per unit weight has been dissolved (approximately 26 percent by weight at 20˚C).

1.5.2 caprock: a mantle composed chiefly of anhydrite, gypsum, and limestone.

1.5.3 casing shoe (casing seat): a cement base formed at the bottom of the casing which provides both an anchor and pressure containment area.

[1]U.S. Department of Transportation. The *Code of Federal Regulations* is available from the U.S. Government Printing Office, Washington, D.C. 20402.
[2]National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471.

1.5.4 casing, conductor: the pipe placed within the drilled hole intended to protect the shallow water sands against contamination and to protect the drill site from sloughing-in during shallow drilling operations. Note: Line pipe is typically used for this large outside diameter pipe string.

1.5.5 casing, intermediate: any casing set after setting surface casing and before setting production casing, using one or more casing strings. Note: In salt dome storage wells, an intermediate casing is often set at the top of the caprock, and a second intermediate casing is set in the top of competent salt that covers lost circulation zones.

1.5.6 casing, production: the principal casing forming the annulus through which stored products pass. Note: The casing's diameter should be large enough to accommodate hanging of solution-mining and brine strings.

1.5.7 casing, surface: casing set to a depth below potable water strata and cemented to the surface to protect potable water sands against contamination and the borehole against lost circulation.

1.5.8 cavern, storage: an underground cavity developed by solution mining of a salt formation for the purpose of storing liquid or gaseous products.

1.5.9 christmas tree: an assembly of valves, actuators, sensors, chokes, pressure gauges, and spools installed on top of the wellhead to control flow into and out of the tubing and tubing-casing annulus.

1.5.10 circulation, direct: flow during solution mining in which fresh water is introduced into the salt formation through the center string with the brine, then returned through the casing/tubing annulus (opposite of reverse circulation).

1.5.11 circulation, reverse: flow during solution mining in which the fresh water is introduced into the salt formation through the casing/tubing annulus with the brine being returned through the center string (opposite of direct circulation).

1.5.12 collapse pressure: the pressure which when applied to the exterior of a pipe causes the pipe to collapse.

1.5.13 closure: the time-dependent decrease of cavern storage volume due to creep and dependent upon the internal cavity pressure.

1.5.14 creep: the geological process that causes salt and other evaporites to flow into subsurface voids that are operated at a significantly lower pressure than the pressure exerted on the walls of the cavity by the formation.

1.5.15 effluent: the brine formed during the solution mining process which may carry along an amount of insoluble material for surface disposal.

1.5.16 elevation (subsidence) surveys: periodic precision vertical control surveys of strategically placed surface monuments at an underground storage facility to determine if subsidence is occurring.

1.5.17 fracture pressure: the pressure which is required to propagate or fracture the geological formation or lift the overburden formations.

1.5.18 gradient, operating: the pressure gradient [pounds per square inch (psi) at casing seat / feet of overburden] existing during cavern operation and is a function of the mode of operation (brine/product injection/withdrawal), the rate of fluid injection or withdrawal and its relative density, the tubing/casing string sizes, and the product-brine interface depth.

1.5.19 gradient, pressure: a parameter expressed as the ratio of pressure per unit depth (usually psi/foot) and determined to characterize the stress limitations of an underground formation.

1.5.20 interface: a surface forming a common boundary between two separate and immiscible fluids in a cavern (for example, between brine and the liquid or gaseous product in storage).

1.5.21 enticular: lens shaped.

1.5.22 lithology: the study or characterization of rock formations.

1.5.23 log: a graphic representation of a subsurface feature obtained through any of several techniques (for example, gamma ray absorption or sonar). Note: Typical applications are density logs (or interface logs) for locating cavern tops, casing setting depths, and product-brine interface; sonar surveys for determining internal cavern configurations; and casing inspection logs for monitoring condition of the casing.

1.5.24 mechanical integrity test: a procedure that verifies that a cavern is capable of storing fluids within design limitations with no significant loss from the cavern or cavern well.

1.5.25 overburden: the strata lying above the salt formations, generally sedimentary in character and composed of sands, shales, limestones, chalk, and anhydrites and may vary from a few feet to several hundred feet in depth.

1.5.26 piercement: a descriptive term applied to salt domes that have pierced subsurface formations.

1.5.27 pillar (see **web**)**:** a descriptive term applied to the residual structural salt acting as both separating wall and roof support in adjacent cavern spaces.

1.5.28 product: liquid or liquefied hydrocarbons, including (but not limited to) crude oil and its products, its derivatives, or its byproducts of oil and gas that are as follows:

a. Liquid under standard conditions of temperature and pressure.

b. Liquefied under the temperatures and pressure at which they are stored.

c. Stored under conditions that necessitate the use of displacement fluids to withdraw them from storage.

1.5.29 salt, bedded: a type of salt basin resulting from compressive tectonic forces (**halo-tectonism**).

1.5.30 salt, domal: a type of salt plug resulting from autonomous, isostatic salt movement (**halokinesis**).

1.5.31 solution mining: the process of dissolving a solid material generally for the purpose of forming a void or cavity as in the creation of underground storage in a salt formation through fresh water injection and brine removal.

1.5.32 sonar caliper: a device utilizing acoustical wave reflection technology to ascertain the internal configuration of an underground space.

1.5.33 spool: a general term applied to a wellhead section or a short pipe section flanged at both ends used to couple other functional piping elements.

1.5.34 string: a general term applied to piping or casing suspended from the wellhead. Note: The centermost string extends close to the cavern bottom and is used for brine injection and removal in operational caverns.

1.5.35 tubing (brine) string: tubing is the last string of pipe or casing placed in the well and is run inside the production casing, to near the bottom of the cavity which is designed to be retrieved from the well, and differs from other tubular strings that are normally cemented in place. Note: API tubing (see API Specification 5CT and Recommended Practice 5C1) normally ranges up to 4½ inches; however, for high-rate application, substantially larger pipe sizes may be required. In these instances, API casing is used as tubing. Note: Nomenclature *tubing string*, *brine string*, and *displacement string* are used synonymously in this document.

1.5.36 web (see pillar): the in-situ mass separating adjacent underground caverns and subject to pressure differentials resulting from varying modes of cavern operation.

1.5.37 well: The cased hole created to provide access to an underground cavern.

1.5.38 wellhead: the ground-level surface equipment used to maintain control of the well, including the connecting casing head, tubing head, and Christmas tree.

SECTION 2—CAVERN HYDRAULICS

2.1 General

Operators of solution-mined storage cavern facilities need to be aware of various hydraulic factors that can affect safe, efficient operations. This section addresses certain aspects of these factors in relation to recommended safe operating pressures and flowing velocities. If the storage cavern was designed in accordance with API Recommended Practice 1114, the safe hydraulic operating limits would have been established during the design process. Operators should consult with the facility design group to obtain the operating parameters. If the cavern is converted from another service not specifically designed for product storage, such as brine production, safe hydraulic operating parameters will need to be re-established prior to using the cavern for product storage. Additionally, if and when operators are changing storage from one fluid to another fluid of different specific gravity, operating parameters will change. Again, the facility design parameters should be re-evaluated.

2.2 Pressure

2.2.1 CASING SEAT PRESSURE

Experimental evidence and operating history have shown that the pressure which may initiate or sustain a fracture at the cemented casing seat of the cavern is contingent upon the geological conditions including but not limited to the function of the weight of the overburden, and such pressure is site specific.

The operator should be aware of the various factors such as product injection and withdrawal flow rates, product and brine densities, casing and tubing configuration, cavern roof depth, and system back pressure that can affect the pressure at the casing seat. Care should be exercised during cavern development and operation to prevent conditions that would cause the pressure at the cemented casing seat to exceed the fracture pressure.

2.2.2 MAXIMUM ALLOWABLE OPERATING PRESSURE

Maximum allowable operating pressure is the pressure at the wellhead of a storage cavern that has been calculated to be safe with respect to the (a) fracture pressure, (b) wellhead equipment design, (c) adjacent cavern spacing, and (d) applicable government regulations. An alarm or safety shut-down device should be installed to prevent overpressuring the storage cavern.

2.2.3 MINIMUM ALLOWABLE OPERATING PRESSURE

Minimum allowable operating pressure is the pressure at the wellhead of a storage cavern that has been calculated to prevent cavern closure due to (a) plastic flow, (b) the prevention of formation subsidence, or (c) the prevention of overstressing of the vertical walls due to adjacent cavern pressure. A minimum pressure normally is not of concern when operating a storage cavern using brine or fresh water for product withdrawal. Minimum pressure can, however, be a problem when a gas phase product is being stored without brine or water displacement (i.e., when the cavern is operated as a gas bottle.) Operators of a gas storage facility should consult with an appropriate expert to determine the minimum allowable pressure that will prevent damage to the storage facility. Approximate correlations exist in the literature giving the induced stresses as a function of geometry, rock properties, and other variables.

2.2.4 RATE OF PRESSURE CHANGE

It has been theorized that rapid depressurization may cause roof collapse or side-wall “slabbing.” It is recommended that a maximum pressure release rate be determined for each salt formation being used and that the pressure release rate be very closely controlled (see API Recommended Practice 1114).

2.3 Maximum Product Injection Rate

Maximum product injection flow rate is a function of the casing and tubing design, cavern roof depth, product being injected, and maximum allowable casing seat pressure for the storage cavern.

2.4 Maximum Allowable Brine Injection Rate

The maximum brine injection flow rate is a function of the (a) casing and tubing design, (b) cavern roof depth, (c) the type of product stored, (d) product system back pressure, and (e) maximum allowable casing seat pressure. A properly designed casing/tubing combination will aid in preventing excessive velocities in the brine tubing and exceeding the maximum safe brine injection flow rate. Excessive flow rates contribute to equipment erosion and possible erosion corrosion.

2.5 Pressure Surges (“Water Hammer”)

The operator of a storage cavern is cautioned to be aware of the possibility of excessive pressure surges caused by the sudden stoppage of a flowing stream of a relatively noncompressible fluid. This stoppage can happen in storage cavern operations when a product is injected or withdrawn at very high flow rates. Brine, fresh water, and some relatively noncompressible products can cause pressure shock waves severe enough to damage the system piping, wellheads, or the cavern formation if flow is stopped abruptly. If the cavern facility is routinely operated with flow rates that can cause unacceptable pressure surges, provisions should be made to regulate valve closure times to eliminate potential surge problems.

2.6 Specific Gravity

Specific gravity for liquids is typically the unit weight of the product in relation to the unit weight of an equal unit of water; specific gravity for gases is typically the unit weight of the gas being handled in relation to the unit weight of an equal unit of air. Operators need to know the specific gravity of each product that is stored in their facility. The specific gravity of products is used in the calculation of cemented casing seat pressure and in pressure loss calculations of flowing streams.

2.7 Brine Saturation

Operators of cavern storage facilities using brine for product displacement should establish a procedure for determining the saturation of the brine. The use of a diluted brine will result in an increase in storage cavern size after each product displacement operation. Determining saturation is more important in older storage fields where additional cavern volume might affect the integrity of the facility. The amount of salt saturation has a direct relationship to the specific gravity of the brine. Brine-specific gravity or product-specific gravity must be known to calculate pressures during cavern operations.

SECTION 3—STORED PRODUCT FACILITIES

3.1 Pumps and Compressors

The product handled and the pressures and flow rates required will dictate the type of pump or compressor needed. The product’s storage underground in a cavern presents no unique design or operating criteria relative to pumps or compressors.

3.2 Product Control

Product pressure regulation and/or flow rate control may need to be installed and maintained to prevent cavern over/under pressure as well as to prevent rapid cavern pressure changes.

Emergency shutdown equipment should be of a failsafe design and is normally installed to prevent a product release or to minimize the quantity of product released. This result can be accomplished with typical surface safety alarms and shutdowns.

3.3 Product Measurement

Product measurement is recommended for custody transfer, for internal record keeping, or as an operational tool to provide early warning to prevent the unintentional emptying or overfilling of the cavern.

The product stored and the pressures and flow rates required will dictate the type of meter used. The product’s storage in an underground cavern presents no unique metering design or operating criteria. However, widely variable flow rates at some installations may require more complex metering systems.

Sonar interface detectors are measurement devices used in liquid underground storage caverns developed in domal salt (although these detectors can also be used when debrining gas caverns). These detectors are clamped to the bottom of the longest hanging string. The interface detector reads the distance from the bottom of the longest hanging string to the brine/product interface. Knowing this distance and the geometry of the cavern allows the operator to determine the approximate inventory of the product in the cavern. However, in some caverns, interface detectors cannot be used due to cavern geometry or other factors. See 11.1.2.2 for more information on the use of sonar interface detectors.

Wireline interface/density logs may also be used to locate the position of the product/brine interface.

3.4 Product Conditioning

When product is withdrawn from an underground storage cavern, one should consider that the product may have been in contact with salt or brine or fresh water. Quite often some type of dehydration facility (either free-water knockout or desiccant) is required to condition the product before the product leaves the storage facility.

3.5 Surface Product Piping

All product piping and related equipment should be designed, installed, and operated in accordance with the latest industry codes and/or governmental regulations.

3.6 Tubular Strings

The common tubular configuration involves one or two tubulars hung concentrically within a casing which has been cemented into the salt. Selection of tubing size, grade, and weight per foot are dependent on flow rate, cavern pressure limitations, and surface equipment.

Maximum collapse pressure and axial stress should be considered before selecting the pipe size, grade, and weight. Before changing tubing configuration, the effect of the new tubing on design pressure limits should be evaluated.

Sufficient torque to make-up the connection should be in accordance with the manufacturer's recommended make-up torque table.

3.7 Changing the Product Stored

3.7.1 GENERAL

Different products may be stored in a given cavern at different times. Changing products can be accomplished safely and with very little product contamination if proper practices are followed. All operating limits should be re-evaluated to determine that changing products does not exceed any of the operating limits of the underground cavern facility.

3.7.2 POTENTIAL PROBLEM AREAS AND SOLUTIONS

3.7.2.1 Reactivity

This concern can be resolved by a chemical literature search and/or by a specific chemical test such as an accelerated calorimeter test.

3.7.2.2 Product Specifications

High product purity specifications on the new product to be stored will mean that a greater time and expense may be required to "clear" or decontaminate the cavern of the previous product. This factor should be taken into account in overall planning prior to the change.

3.7.2.3 Cavern Decontamination

3.7.2.3.1 *Cavern nitrogen injection/depressurization*, a suggested method for roof trap displacement, is to inject nitrogen down the annulus to a level below the casing seat. Nitrogen will flow upward and should displace any trapped product. As in all displacement operations, care should be taken to prevent the accidental release of any product. This method is only applicable when the product specifications allow some level of nitrogen contamination.

3.7.2.3.2 When time allows, *solution mining* of the cavern can be restarted and salt dissolved from the side wall. Solution mining is a good way to eliminate traps and release the trapped product. However, this process will not relieve roof traps. Very large traps will not be corrected without extensive washing.

3.7.2.4 Brine Decontamination

One method of brine decontamination is to discharge the brine while injecting clean brine into the cavern. The injected brine may be slightly under-saturated and cause some washing. The roof should be protected by a blanket of material insoluble to both brine and salt.

3.7.2.5 New Product Integrity

Before storing the new product, consideration must be given to the specification sensitivity of the new product to the previous product's contamination. If the specification of the new product is stringent, consideration should be given to conducting a series of small displacements (injecting minor amounts of the new product to just below the cavern roof and then withdrawing). Products with wide latitude in specifications can be directly injected into the cavern without the same concern.

3.7.2.6 Product Density

Always calculate the maximum allowable surface wellhead operating pressure for a new product to ensure that the maximum allowable casing shoe pressure will not be exceeded. Take into consideration product density, injection/operating pressure, and brine pressure.

SECTION 4—BRINE FACILITIES

4.1 Salinity

The storage field operator should be aware of the salinity of the brine being used in storage operations. The operator will want to establish procedures to monitor salinity based on the specific well configuration and operating conditions at the storage site. Brine can be either supersaturated or undersaturated. Supersaturation can occur because of evaporation from the brine storage pond during extended periods of hot, dry weather or when a sudden temperature drop occurs reducing the solubility of salt in water. Supersaturation can result in operating problems usually manifested by precipitation and growth of salt crystals in pump cases, valve bodies, well tubing, etc., causing increased wear and eventual blockage. Consideration should be given to installation of fresh water flushing systems to facilitate the dilution of salt crystals in critical equipment. The operator should also provide fresh water make-up to stored brine during hot, dry weather to maintain salinity at a point slightly less than saturated.

Undersaturation can occur naturally due to dilution by rain water or by an increase in temperature thereby increasing the solubility of salt in water, or intentional dilution with fresh water. Undersaturated brine has the ability to dissolve salt, which will result in additional cavern growth. This effect should be considered in the operation of mature storage fields or in individual wells where further growth is not desired.

Undersaturation will also result in a fluid which is less dense than saturated brine and may affect cavern hydraulics.

4.2 Brine Sources

Brine needed for the normal operation of storage fields can be obtained from any combination of the following sources:

a. Brine production wells.
b. Brine storage ponds.
c. Purchase from other brine producers.
d. Local sharing agreements in multi-company storage areas.

4.3 Brine Storage Pond

Normally brine is stored above ground in open ponds awaiting use for displacement of product from wells. To conserve brine and to prevent environmental pollution of land, surface water, and ground water, the pond should be equipped with an impermeable lining. In selecting a lining material, consideration must be given to compatibility with brine, hydrocarbon resistance, and ultraviolet deterioration. In some instances a compacted clay lining may be acceptable. Federal, state, and local regulations must be reviewed before lining a pond or making repairs to an existing lining.

Consideration should be given to installing a brine leak detection system. Acceptable systems include monitoring wells, french drains, double pit lining, or combinations of the preceding. Periodic visual inspection of the liner at various brine pond levels should be conducted. Federal, state, and local regulations may dictate the need for and method of leak detection.

Small quantities of hydrocarbon gases may be released when brine from a product well is returned to a pond. Depending on the proximity of the brine storage pond to other facilities (and also upon federal, state, and local regulations) consideration should be given to the installation of a brine/product separation system or a gas detection system which could be used to provide an alarm or to shut down equipment.

The amount of brine storage to be provided relative to the total product storage is dependent on various factors such as the total active storage capacities, diversity of demand for individual products stored, the availability of replacement brine (i.e., brine sharing arrangement at multi-company storage areas), and brine disposal capacity. It is common for the volume of brine storage to be less than 50 percent of the total product storage capacity.

Erosion of external dike walls must be controlled or prevented. Acceptable methods include reducing the slope of the dike walls (for example, a 3 to 1 ratio is recommended for the slope of the dike), planting vegetation suitable to the climate, installing rip rap or environmentally safe stabilized topping, and providing periodic maintenance of the dikes.

Wave action in brine storage ponds can cause underliner dike damage or spillage of brine. Maximum fill levels should be established which allow an adequate freeboard to prevent spillage. In cases of severe wave action, consideration should be given to the installation of mechanical wave control. Federal, state, and local regulations should be consulted for specific requirements.

Because brine ponds are exposed to climatic conditions, unique operating problems occur and must be addressed. These include evaporation, dilution, precipitation, and collection of blowing dirt and sand. In the installation of a brine pond, the operator should consider and allow for contraction and expansion of the liner materials under climate extremes with low brine inventories in the pond. Most pond liners are black and collect significant amounts of solar energy resulting in higher brine temperature at the bottom of the pond. Most brine ponds have pump suction at the bottom of the pond. The brine delivered to the well may be supersaturated and at a higher temperature than the brine in the well. The potential effects on product flashing or hydraulic pressure gradient of operating wells should be considered. Piping should be designed to allow fresh water connection to the brine pumps for flushing the suction piping to clear salt from the pump casing and piping.

4.4 Disposal

Methods of brine disposal must be carefully considered. Where allowed by regulations, excess brine may be disposed of in permeable sand formations or oil production zones.

Operators near coastal areas may consider pipelining brine a suitable and permitted distance offshore. Alternatives to brine disposal include delivery to chemical plants as feedstock or brine sharing arrangements at multi-company storage areas.

Operators of brine disposal wells should maintain pertinent disposal records as required by regulatory bodies. These records may be analyzed by the operator to determine the condition of the well.

4.5 Pumping

Pumping brine at a storage facility is necessary to transfer brine to a disposal well, other ponds, or a storage well for product displacement. Brine movement can be accomplished with the same types of equipment readily available for other products, but consideration must be given to the corrosive and erosive properties of brine. When specifying the pump case, impeller shaft, bowl, bushing, packing sleeve, etc., the operator should consider material selection.

It is recommended that fresh water be provided for seal flush and for rinsing and dissolving salt deposits. Design and safety shutdown considerations are similar to product pumps.

Even small brine leaks create corrosive conditions on external cases and piping, which is not only unsightly, but also detrimental to system integrity. Surface preparation and the careful selection of external coating systems are important. Prompt attention to leak repair, cleanup, and spot coating repair is recommended.

4.6 Measurement

Measurement of brine can be accomplished by using the same types of equipment used for product measurement; however, the problem of salt precipitation and crystal growth necessitates more frequent maintenance and cleaning. Because of the stable properties of brine, properly designed and maintained equipment will provide accurate measurement data. Brine streams which should be considered for measurement include the following:

a. Custody transfer.
b. Disposal.
c. Storage wells where product measurement is difficult or impractical.

Federal, state, or local regulations may dictate instances where brine should be measured.

4.7 Control

Brine-pressure regulating and relieving equipment need to be installed and maintained to provide a reliable source of brine at the proper pressure to prevent overpressure of piping and cavern wells. Control valves or stand pipes on brine return-lines to the ponds are common in the industry. Consideration should be given to installation of emergency shutdown equipment to prevent equipment damage or brine releases.

4.8 Product/Brine Separation Systems

Some product/brine separation systems include separator vessels or stand pipes, with the hydrocarbons piped to vents or flares. Dedicated product/brine separation caverns can also be piped into the brine return system.

SECTION 5—FRESH WATER FACILITIES

5.1 Source

A source of fresh water must be available to the storage field operator after the initial development of the field. Examples of applications for the use of fresh water include:

a. Fire protection.
b. Flushing and desalting of wellheads, tubing strings, pumps, valves, etc.
c. Replacement brine production.
d. Stored brine dilution.
e. Bearing cooling, seal flush, etc.
f. Solution mining of existing or new storage caverns.

Consideration should be given to the quality of water as some contaminants can be detrimental to equipment and piping. In climates where freezing is likely, precautions such as heat tracing, extra depth pipe burial, heated pump houses, etc. are recommended. Sources of fresh water include wells, canals, rivers, and local utilities. In many areas the removal of water from waterways and underground formations is regulated by federal, state, or local authorities and may require a permit.

5.2 Pumping

Pumping of fresh water can be accomplished using the same types of equipment readily available for other products, but consideration must be given to the corrosive and erosive properties of fresh water when specifying case and trim materials. Design and safety shutdown considerations are similar to product pumps. However, due to the high pressures associated with washing caverns, particular attention must be paid to ensuring protection against overpressurization of the caverns in the event of inadvertent brine discharge shut-in. Surface preparation and the careful selection of external coating systems are important. Prompt attention to leak repair, cleanup, and spot coating-repair is recommended.

5.3 Measurement

Measurement of fresh water can be accomplished using readily available positive displacement, orifice, or turbine meters. Measurement may be needed to satisfy permit requirements or to provide normally required operating data.

SECTION 6—WELLHEAD/HANGING STRING

6.1 General

Periodic inspection and testing of the wellhead and downhole tubulars should be performed. These inspections and tests are recommended to help limit or prevent the involuntary release of hydrocarbons to the environment. These inspections and tests are normally performed during routine well workovers. The steps outlined in 6.2 through 6.6 can be included, as necessary, in a workover.

6.2 Planning

As the cavern will be out of service during the workover, consideration should be given to inspecting and testing the downhole tubulars, the wellhead, and associated equipment. Plans should also include the repair or replacement of all gaskets, studs, nuts, etc., removed during the workover.

Materials and service vendors should be selected carefully. The vendors must have properly sized equipment that is in good condition and be able to meet delivery and other timing schedules without sacrificing quality. References should be checked for previous performance. The vendors also must have appropriate insurance, for example, workman's compensation, protection and indemnity, general liability, and automobile liability.

Schedule materials, service, and vendors to ensure prompt deliveries of materials and services for safety and economy.

6.3 Safety Considerations

The well should be empty of hydrocarbon and full of brine. Prior to pulling the first hanging string, brine should be circulated down the brine tubing and returned through the annulus, if possible, to assure the well is full of brine. If it is suspected that hydrocarbons could be trapped in a washout above the last cemented string, additional care should be taken.

The operator will want to consider keeping a chronological record of the workover. The following list contains some suggested items to be included in the documentation:

a. the date the well was depressured.
b. the date and times well was vented.
c. the date, time, and amount of brine added.
d. the written log of all work performed on well during workover.

Provide fire extinguishers at the well site and ensure that all fire hydrant monitors are operating properly prior to initiating any work.

When practical, install the properly rated blowout preventor and/or annular blowout preventor capable of closing in the well at full expected hydrocarbon pressure. Also, it is a good safety practice to have tubing crossovers made with shut-in valves to install in each box connection while pulling the tubing (two required).

6.4 The Workover

After proper planning and scheduling, the actual work may begin.

The well should be able to be closed in at any stage of the workover in the event product begins migrating to the surface from a roof or other trappage area. This process can be accomplished by the use of an annular or ram type blowout preventor, tubing shut-in valves, packers, or other methods. Ensure that pressure below the blowout preventor does not build up enough to push the tubing out of the well. If high pressures are encountered, vent off product below the blowout preventer if possible, or have a method of holding the tubing down.

Qualified personnel should inspect the wellhead spools, valves, and hanger areas for signs of external or internal corrosion or other damage.

All wellhead valves should be inspected, tested, and repaired or replaced as necessary.

All small pipe fittings, nipples, relief valves on the well head, and wing valves should be inspected and repaired or replaced at each workover.

The new hanging string(s) should be inspected by a qualified inspector prior to installation or re-installation in the well. During tubing string reinstallation, consideration should be given to torque/turn monitoring, special thread sealants, or coupling pressure tests (internal or external).

The casing braden-head and hanging-seal assemblies should be tested to ensure zero leakage.

6.5 Additional Tests and/or Safety Devices

There are a number of logging tools available for downhole corrosion monitoring or for detecting potential corrosion; for example, electromagnetic, multifinger caliper, and casing potential profile surveys. These tools may be used to locate potential problem areas in wells or to show that no corrosion exists. Some of these tools were developed for oil and gas wells. These tools are now being adapted to the larger diameter casings encountered in the storage industry.

Sonar calipers may be run during workovers to show the physical dimensions and volumes of the storage cavern. Such logs can be used to locate roof and or sidewall irregularities or potential trappage areas.

Sonar interface detectors are used by some operators in conjunction with sonar surveys as gross accounting verification of metered volumes into and out of a well. Another function of interface detectors is to prevent cavern overfill by giving a continuous reading at the surface of the distance from the product/brine interface to the bottom of the brine string.

6.6 Cavern Protection While Out of Service

It can be important to maintain a pad or "cap" of hydrocarbon or inert gas extending below the casing seat in a well that is not in hydrocarbon service. Some operators have strict operating criteria on this subject. Examples of potential problems include the following:

a. Saturated brine can deposit salt in the annular space and cause flow restrictions which might cause overpressure of a well.
b. Brine contact with a shale roof (bedded salt formations) for prolonged periods may cause the roof to weaken. Maintaining a hydrocarbon cap helps prevent this effect.

SECTION 7—CAVERN INTEGRITY TESTING AND MISCELLANEOUS SURVEYS

7.1 Mechanical Integrity or Certification Testing

7.1.1 GENERAL

Caverns should be tested before they are placed in operation to verify pressure integrity and capability of the cavern to contain the stored commodity within design limitations. Generally, the cavern roof/casing shoe test pressure should not exceed the design maximum allowable pressure at those points. All caverns are unique to some extent. Any procedure used to confirm the integrity of a cavern should be developed and conducted based on competent engineering judgement and analysis and should be designed for that particular cavern.

Hydrostatic, nitrogen/brine interface, and product/brine interface tests are three methods of certification testing generally used. However, the application of these methods or any variations thereof should be dependent on the specific design and operational constraints imposed upon the cavern to be tested. The test procedure should be developed and conducted based on competent engineering judgement and analysis.

7.1.2 BRINE FULL HYDROSTATIC PRESSURE TEST

A brine full hydrostatic pressure test provides verification of the pressure integrity of the cavity proper (but would not test the cased portion of the well as stringently as other methods). A brine full hydrostatic test is generally used to test a new cavern well before dissolution has started and before any hydrocarbon has been injected. Additionally, this method may be appropriate for testing a cavern when the well itself is known to be competent (because the well has been tested previously by an appropriate method) and when the cavity has been enlarged by controlled dissolution.

A variation of this test method (using a small amount of hydrocarbon to provide a "blanket" in the annulus to below the casing shoe) can additionally provide verification of the integrity of the cased portion of the well. The addition of a blanket provides a method of applying normal operating wellhead pressures during the test without exceeding the allowable casing shoe pressure. This method can be used to prove the integrity of either a new or existing cavern system, but has inherent (and obvious) safety implications which must be considered.

A properly conducted hydrostatic test requires the collection of precise pressure data. The test can have a duration of up to several days depending upon cavern size and, importantly, stability of the cavern and the fluid contained therein.

7.1.3 NITROGEN/BRINE INTERFACE TEST

A nitrogen/brine (or product/brine) interface observation style of test is a method for testing the integrity of a cavern's wellhead, casing, tubing and the cemented annulus between the production casing and the formation (at the casing shoe area). An interface observation test normally requires the assumption that the cavity proper has integrity. Such an assumption is normally valid (excluding any reason to suspect otherwise for the particular cavern, such as an obviously excessive pressure loss during the test.)

An interface observation test is typically conducted prior to initial storage of hydrocarbon.

7.2 Frequency of Testing

The integrity of new caverns should be determined prior to initial storage of hydrocarbons. Federal, state, or local regulations may require periodic retesting at prescribed intervals. A retest should be conducted whenever operational or other data indicates that a condition may exist which could adversely affect cavern integrity.

At some facilities, operational records, if sufficiently complete and accurate, (of wellhead pressures, inventory, etc.) can be used in lieu of a formal procedure to retest a cavern for mechanical integrity (and if use of such records is acceptable to the appropriate regulatory agency).

7.3 Sonar Caliper Surveys

Sonar caliper logs or surveys are utilized to determine the size, shape, and directional growth (if any) of a cavern. Sonar surveys are normally performed during a cavern workover after the hanging strings have been removed. However, some sonar companies are capable of performing "through-pipe" surveys. In some cases, through-pipe surveys negate the need to pull the hanging string(s) and may not require that the cavern be emptied of product. It should be recognized that running sonar surveys through casing is not yet an industry-proven technology. Results are sensitive to a number of factors; for example, condition of casing string, number of casing strings, saturation of cavern brine, presence of roof traps, etc. The survey contractor should be consulted to determine the feasibility of obtaining a valid through-pipe survey on a particular cavern.

A sonar survey may be run periodically, if possible, to provide an indication of cavern growth. It is recommended that a sonar survey be run periodically to confirm the growth of the cavern over time as compared with the established design and operating criteria (particularly those caverns that are intentionally enlarged by product displacement with fresh water). Particular attention should be given to the location and configuration of the cavern top and bottom, to reveal any upward solutioning or roof falls. Also, lateral dissolution of the cavern sides should be monitored with respect to the integrity of adjacent caverns.

Some regulatory authorities specify the minimum frequency of sonar surveys and minimum acceptable distances between cavern walls or between cavern walls and property lines.

7.4 Geophysical Logs

Some regulatory authorities require periodic logging of caverns to determine the position and thickness of the salt roof. The "interface" log is a specialized density log which measures relative density in the immediate area of the tool. This log is commonly used to locate depth to the cavern floor, bottom of tubing strings, product/brine interface, bottom of production casing and to determine if there is a washout above the bottom of the production casing (and depth to the roof of that washout). The gamma ray log (also known as *shale log*) is often used for correlation purposes to tie into known formation intervals (such as the top of the salt layer in bedded salt formations). The gamma ray or shale log can also be used to verify depth to the cavern roof and the presence of debris piled around the bottom of the brine tubing.

7.5 Elevation Surveys

Enough surface monuments should be installed in the general vicinity of the wellheads so that relative elevation changes between the monuments, the wellheads, and off-site control point(s) can be determined. Annual surveys at approximately the same time of the year will provide the most accurate data for detecting or measuring subsidence. Vertical control surveys should be to at least third order accuracy and tied to an off-site National Geodetic Survey bench mark. Periodic surveys over the life of the cavern will determine if subsidence is occurring. Some regulatory authorities require periodic elevation surveys.

7.6 Records and Reports (Also See Section 12)

A comprehensive report should be prepared containing a description of the test or survey procedures used, a summary of all activities and data associated with the test or survey, a narrative summarizing data interpretation, and an assessment of results, including all supportive field data and documents (including copies of any electric logs or sonar survey reports).

7.6.1 RETENTION

Reports of tests or surveys should be considered a permanent record and retained for the useful life of the facility.

7.6.2 REPORTING

Results of tests and surveys shall be reported in accordance with applicable rules and regulations of the regulatory agency (or agencies) who have jurisdiction over the underground storage facility.

SECTION 8—ENVIRONMENTAL AND REGULATORY CONSIDERATIONS

The operation of underground storage facilities, including periodic inspection, monitoring, operational and incident reports, and testing requirements, shall be in accordance with applicable rules and regulations of federal, state, or local authorities having jurisdiction in matters pertaining to underground storage and the movement of commodities into and out of such storage.

The operator should fully evaluate, understand, and comply with applicable federal, state, and local requirements for each underground storage facility, which could include but is not limited to, the following:

a. Pipeline safety regulations—hazardous liquids.
b. Pipeline safety regulations—natural and other gas.
c. Air pollution control regulations.
d. Drinking water regulations.
e. Waste management regulations.
f. Water pollution control regulations.
g. Regulations and permits concerning drilling and solution mining of caverns.
h. Underground injection control (UIC) program.
i. Boiler and pressure vessel regulations.
j. Spill Prevention Control and Countermeasure (SPCC) Plans.
k. National Pollutant Discharge Elimination System (NPDES).
l. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).
m. Resource Conservation and Recovery Act (RCRA).
n. Occupational Safety and Health Act (OSHA).
o. Superfund Amendments and Reauthorization Act (SARA) Title III.

SECTION 9—SECURITY

9.1 General

Federal, state, and local laws/regulations may govern minimum security requirements. Additionally, many companies now have minimum security guidelines that must be reviewed and utilized.

Security measures should be appropriate with respect to the location, population density, political stability, terrain, and environment of areas adjacent to the facility. Items 9.2 through 9.6 should be considered in the development of a comprehensive security plan for each facility.

9.2 Area Patrol

Patrolling should take place either by a dedicated security workforce or by operational personnel during every shift. The frequency may need to be increased in the odd shift, weekend, and holiday periods. Patrols should observe for unauthorized entrance, tampering, leaks, or other unusual conditions. A formal action plan should be in place and personnel adequately trained.

9.3 Controlled Access

Access control will vary as a function of the items identified in 9.1, but personnel entering the area should be positively identified (sign-in, badges, etc.) and enter through a controlled point. This point may be an automatic, a keyed, or a guard-controlled gate. Some companies use one designated gate for all contractor personnel.

9.4 Boundary/Perimeter Control

Controlling the property boundary can vary from barbed wire fences in rural areas to full industrial chain link fence with gates in heavily populated areas. Personnel fencing around rotating equipment/process areas should be considered to protect against curious people (children, passersby, etc.) entering even in remote locations. Remote valves and equipment may require chain and padlock.

9.5 Security Plans

A security plan should be incorporated into the site overall emergency plan. The security plan should consider such subjects as bomb/terrorist threats, fires, injuries, thefts, and personnel disruptions (see also Section 10).

9.6 Locks

A series keyed system is generally used in industry. Master, submaster, and specific keys allow appropriate entrance and access by the workforce from management to the individual field workers. In addition, mechanical or vehicle barrier protection may be desirable to protect against mobile equipment or vehicle damage.

SECTION 10—EMERGENCY PLANS

10.1 General

An emergency plan must be developed for each storage facility. All local, state, and federal rules and/or laws must be reviewed. Emergency plan format and content may be specified by the parent company. In general, the plan must be comprehensive, yet clear and concise. It should be easily understood and easily used, so that both field personnel and management will use the plan in a critical situation. Training, both initial and refresher, is essential.

10.2 Suggested Contents

As a guide, the plan could contain the following subjects:

a. Spill/gas releases (both product and brine).
b. Fire.
c. Explosion.
d. Personnel injury and illness.
e. Process upset.
f. Reactive chemical conditions.
g. Line content contamination.
h. Loss of services/utilities.
   1. Instrument air/nitrogen gas.
   2. Electricity.
   3. Steam.
   4. Water.
   5. Process computer.
   6. Material feeds or receipts.
   7. Major equipment.
i. Pipeline failures.
j. Terrorist threat/phone calls.
k. Evacuation procedure.
l. Communication procedure.
m. Emergency shutdown.
n. Road blocking or public protection.
o. Return to work.
p. Authorized and unauthorized visitors.
q. Adjacent facilities events.
r. CAER coordination (community awareness and emergency response).
s. Severe weather procedures (tornado, flood, freeze, hurricane, lightning, etc.).
t. Training/drills.

10.3 Mutual Aid Organizations

Many companies have chosen to form organizations with the community in which their underground storage facilities reside. Mutual aid organization operation allows emergency planning on a multi-company and community scale, much like the individual emergency plan at the plant site. Additionally, the community residents, business leaders, school officials, city officers, and the fire and police/sheriff personnel become informed and trained as to the emergency possibilities, evasive measures, and communication system.

SECTION 11—SAFETY AND TRAINING

11.1 Safety Engineering Design Criteria

11.1.1 GENERAL

Many publications and standards cover engineering requirements for piping specifications. The most prominent are API standards, Title 49 CFR Parts 192 and 195, American Society of Mechanical Engineers standards, and U.S. national standards. In addition, individual operators have engineering standards for pumps, compressors, separators, dehydrators, etc. Wellhead safety and experiences with rotating equipment that are unique to storage facilities should be considered in the design criteria.

A hazardous operations review should be performed with records retained. Any changes made to existing facilities should have the hazardous operations review made prior to facility modification.

11.1.2 CAVERN SAFETY EQUIPMENT

One of the operator's main concerns is to ensure that the cavern is operated safely—products are kept contained and fire and explosions are avoided. The safety items in 11.1.2.1 through 11.1.2.13 should be reviewed for installation based upon the operation, product characteristics, and plant location.

11.1.2.1 Surface Emergency Shutdown Valves (Product and Brine)

Emergency shutdown valves should be fail-closed valves. They should be set to close automatically in the event of unacceptable conditions such as high pressure, low pressure, high flow, and fire. Consideration should be given to having emergency shutdown valves closable from a remote location such as the control room and other areas where personnel are likely to be located.

11.1.2.2 Sonar Interface Detectors

Sonar interface detectors allow approximate product inventory verification and serve to help prevent well overfills, which can result in surface product spills. Sonar interface detectors are clamped to the bottom of the longest hanging string and read the distance from the detector to the brine/product interface. Interface level information can be used to adjust cavern operations as appropriate. However, in some caverns, interface detectors cannot be used due to cavern geometry, shale outcrops, or other factors. Some disadvantages to the interface detector are the following: (a) tool and wireline may require frequent maintenance; (b) lubricator or packoff on the wellhead is a potential leak source in an emergency condition; and (c) the wireline could part and foul the brine valves, including any emergency shutdown vales, in the event of a brine tubing failure. See 3.3 for additional information on sonar interface detectors.

11.1.2.3 Firewater Systems

Firewater (deluge or monitor) can be used to cool a wellhead and associated piping in the event of fire at that location or at an adjacent well. Note that radiant heat damage is a major concern in well fires. The sprinkler should be capable of being remotely or locally activated by thermoswitches or meltable plugs/links. Refer to NFPA Standards 13 and 15. Thermal shields may also be appropriate for some circumstances.

11.1.2.4 Decomposition Suppressors and Temperature Trips

Ethylene gas is capable of decomposition under certain pressures and temperatures. Decomposition could be started by a compressor, purge operations, or fire impingement and proceed to the wellhead. Consideration should be given to the installation of a decomposition suppressor so that decomposition would not proceed into the cavern. Design and location must be specific to the individual conditions, flow rates, and line lengths.

11.1.2.5 Television Camera Surveillance

Television camera surveillance provides a way to monitor wellhead activity/security. It also helps to estimate fire or leak size in the event of a spill.

11.1.2.6 Gas Detection/Fire Detection

Gas vapor detectors can provide a means of early warning of a spill in the event that a leak occurs and the product stored is gaseous. The detectors can be tied to the station control system for alarming and can be wired to automatically close the wellhead emergency shutdown valves. Additional coverage can be obtained through the placement of multiple flammable gas detectors throughout the area.

11.1.2.7 Safety Strings

A safety string is the concentric pipe string placed between the brine string and the product string/casing. A safety string may be considered based upon the cavern's operations, the stored product's characteristics, and the cavern's location. The safety string is terminated at a sufficient height above the brine string's lowest setting such that, during cavern filling operations, product would enter the safety string before it would return to the surface through the brine string. A high pressure switch monitoring the safety string's pressure can serve to close the wellhead emergency shutdown valves prior to well overfill. The safety string should be kept filled with fresh water and periodically flushed to prevent brine entry and possible plugging due to salt deposition. Brine entry could negate the safety string's pressure-sensing role.

11.1.2.8 Weep Holes

Weep holes are small cutouts near the bottom of the longest hanging string (brine string). Weep holes allow product to flow into the brine being displaced from the well prior to the product/brine interface reaching the bottom of the hanging string. Pressure transmitters, excess flow meters, product-in-brine detectors, gas detectors, and/or product/brine separation systems can detect this product in the brine and can provide early indications of the interface approaching the bottom of the hanging string.

11.1.2.9 Pressure Transmitters

Pressure transmitters at or near the wellhead in both the product and brine piping can alert the operator of abnormal operations requiring investigation. Low product pressure, high product pressure, high brine pressure, and the convergence of product and brine pressures can be tied into alarms or initiation of emergency shutdown systems.

11.1.2.10 Excess Flow Detectors

Excess flow detectors in both brine and product piping can alert the operator of abnormal operations requiring investigation and be tied into alarms or initiation of emergency shutdown systems.

11.1.2.11 Product-in-Brine Detectors

Product-in-brine detectors may include capacitance probes, densitometers, and pipeline interface detectors. The introduction of product into the hanging string can be detected in the brine piping, resulting in the initiation of alarms, or emergency shutdown systems.

11.1.2.12 Product/Brine Separation Systems

Product/brine separation systems are used to separate small quantities of hydrocarbons from brine resulting from minor leaks or absorption as well as serving as a backup to other safety devices (also see 4.8).

11.1.2.13 Emergency Shutdown Systems

Emergency shutdown systems should be tested for proper operation in accordance with applicable federal, state, and local regulations or as determined by the operator based on storage site configuration and operating requirements.

11.1.3 Rotating Equipment

Storage surface facilities normally employ centrifugal and reciprocating equipment to move the products to or from storage. Key loss prevention/safety items which may be considered for this equipment are listed as follows:

a. Emergency shutdown valve.
b. Instrumented safety alarm/shutdowns.
  1. Vibration (both drive and mover).
  2. High pressure.
  3. Low pressure.
  4. Low lube oil pressure/level.
  5. High temperatures.
c. Tandem or double seals.

11.1.4 MAINTENANCE ACCESS

If the surface equipment is being modified or initially installed, sufficient thought should be given to maintenance access. Items to consider include the following:

a. Ease of personnel access: Can bolts be turned/loosened without getting the maintenance person into awkward positions?
b. Can the mobile hoisting equipment reach the equipment safely?
c. Does the lift have to be made over pressurized equipment/pipelines?
d. Can the equipment be easily de-energized both from the driver and product source?
e. Can mechanical or vehicle barriers be removed easily?

11.2 Personnel Safety

Develop a written safety program for employees. It is recommended that each employee review and comprehend the contents of the safety manual on at least an annual basis.

As appropriate, the program should emphasize the unique characteristics of storage wells and associated systems such as brine and fresh water, and provide for the following:

a. Periodic safety meetings.
b. Regularly scheduled safety meetings which include first aid training and the use of fire equipment in fighting a product fire.
c. The reporting of unsafe conditions.
d. Head, face, and eye protection.
e. Fire protection accessories as needed.
f. Designated smoking areas.
g. Interpretation of windsock information on wind direction and strength.

Employees shall be trained, as appropriate, to respond to emergency situations. A record of personnel trained and subject matter covered during the training period should be maintained.

Safe working conditions and a safe work environment should be provided to employees.

11.3 Contractor Safety

Develop a written plan which considers the following items as they apply to contractors. Ensure that the written contractor-safety data be reviewed before a contract agreement is made, and again by the contract supervisor before work at the job site begins.

a. Job site, including access, parking, break, and smoking areas.
b. Required personnel protective equipment.
c. Emergency alarms, response, and evacuation routes.
d. Hot work (including hot tapping) restrictions and/or permit procedures.
e. Injury and accident reporting.
f. Vehicle and equipment operation.
g. Rules and regulations compliance responsibility.
h. Lock, tag, and flag procedures (electrical and mechanical).
i. Line cutting.
j. Excavation work.
k. Confined space entry.
l. General housekeeping of job site.
m. Awareness of all product or chemicals handled at or near the job site, to include location and availability of material safety data sheets.

API Recommended Practice 2220 provides additional information on improving the working relationship between the facility operator/owner and contractors.

11.4 Operator Training

Develop a written plan for training and testing of operators. The plan should include as appropriate apprenticeship and formal training programs, and should consider as applicable the following items: (a) processes, (b) pumps, (c) valves, (d) motors, (e) instrumentation, (f) emergency shutdown devices and procedures, (g) safety procedures, (h) personal protective equipment, (i) fire protection and suppression equipment and procedures, (j) routine maintenance, (k) stored product properties (material safety data sheets), (l) product sampling and measurement, (m) applicable pipeline operations, and (n) the facility's emergency response plans.

In addition, operators may wish to provide to personnel directly involved with the operation of hydrocarbon storage wells, the basic knowledge of the following subjects: basic salt dome or bedded salt geology, storage cavern development and shapes, cavern hydraulics, product/brine interface detection, well and wellhead components, and well washing operations.

SECTION 12—RECORDS

12.1 General

This section outlines the basis for establishing and maintaining a records system for ongoing operation of underground storage caverns and associated surface facilities. The records activity is divided into five categories. The individual owner/operator should determine with whom, and where, in his operation the physical records should reside.

The categories of records to be kept consist of design and construction, regulatory compliance, maintenance, ongoing operations, and general (operations log). Records retention schedules should be developed by the owner as dictated by individual company policy, statutory requirements, and common sense.

12.2 Design and Construction Records

Design data and "as-built" drawings and equipment documents should form the basis for facility equipment and asset files. API drilling and completion reports, area geology mapping, and associated logs should be an integral part of the files. Any sonar logs used to determine the shape and volume of the cavern should also be part of these files.

Further, it is recommended that all facility modifications, revisions, and additions be promptly added to the files, and that piping and instrument drawings be kept current and reflect all changes.

12.3 Regulatory Compliance Records

The operator should retain all necessary permits and records as required by federal, state, and local agencies and authorities. Such regulatory authorities may establish operating parameters and periodic reporting requirements, and may establish statutory requirements for specifications and frequency of periodic inspection and maintenance.

12.4 Maintenance Records

Maintenance requirements for an underground storage facility may vary greatly, depending upon size, geographical locations, and complexity of the operation. The attendant records of maintenance activities may likewise vary greatly depending on the owner/operator.

12.4.1 ROUTINE MAINTENANCE

For purposes of this section, routine maintenance shall encompass all those activities that are readily apparent to the untrained individual, such as general housekeeping. Numerous systems exist for controlling, budgeting, and reporting those activities.

12.4.2 PREVENTIVE MAINTENANCE

It is recommended that the operator establish, and keep current, a formal records system for all significant maintenance activities. Particular emphasis should be placed on those activities that assure a continued safe operation and protection of assets. Ideally, periodic inspection, testing, and repair frequencies should be set by the operator for selected equipment items. In some locales, jurisdictional authorities have established specifications and minimum time intervals. It is suggested that the following items be considered:

a. Pressure safety valves.
b. Automatic well shut-in valves and associated controls.
c. Cathodic protection systems.
d. External corrosion.
e. Well workover schedules.
f. Well integrity testing schedules.
g. Instrument (including meters) testing and calibration.
h. Level indication and overfill monitoring devices.
i. Product analyzer calibration.
j. Firewater pumps and controls.
k. Condition of brine pond.

This list is by no means all inclusive. The purpose of this section is to stress the importance of adequate documentation of maintenance performed on equipment. Workovers of underground storage caverns are major maintenance events. Thorough, accurate, and detailed documentation of the entire project should be of major importance to the operator.

12.5 Ongoing Operations Records

Operating personnel accumulate a significant amount of data in the performance of their function. Much of the data is of importance from the business standpoint, and equally important is the data which reflect overall condition and performance of the facility. It is suggested that standardized forms be developed for the operation that cover all of the required data input.

A typical cavern operating report would include well number, working capacity, product movement in or out, and ending inventory. Further, the report would cover a specified time interval (8 hour shift, 12 hour shift, 24 hour ending at 7:00 a.m., etc.). Where applicable, the report should indicate the source of incoming product and the destination of outgoing product.

Typical operator data for an in-service storage well could include product pressure and temperature, cavity pressure, brine pressure and temperature, brine pond level, cavern interface level, pipeline conditions, flow rate, and flow totalizer readings. This data should be accumulated by time of day.

Appropriate log sheets should be developed for the operators' use in recording operational data. This record is particularly needed where product volumes are metered in and out of numerous wells, accounting for simultaneous transfer and injection. A file should be kept for each cavern which documents metered or estimated inventory in the cavern. From this it can be estimated when the cavern will be full or empty.

All underground storage well product and brine pressures should be monitored and recorded on a routine basis.

Surface facilities important to the operation, such as product dryer systems and on-line analyzers, should be monitored and key parameters recorded.

Equipment condition-monitoring reports covering such items as motor control centers, transformers, battery charges, inverters, pumps, motors, and cathodic protection rectifiers should be maintained. A monitoring interval should be established.

Where applicable, management of the brine system may be a major operational function. Appropriate record systems should be established to facilitate that function.

12.6 Operations Log Book

It is highly recommended that the operator establish an operations log book. All pertinent activities not recorded elsewhere concerning the facility operation should be entered by the personnel on duty. The operations log book will provide for shift continuity and will retain potentially important documentation of events. Any phenomenon concerning cavern performance that appears to be abnormal should be documented in the operations log book. The supervisor should then consult with the underground storage design group to discuss these events.

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