

Performance of Salt Storage Cavities Designed to Operate with Nitrogen as Cushion Gas

M.R. Tek

The University of Michigan, Ann Arbor, Michigan, USA

ABSTRACT

In underground storage of natural gas in salt caverns, as in other environments such as depleted oil or gas reservoirs or aquifers, a significant portion of storage gas must remain continuously in the cavity to provide the pressure necessary for withdrawal of "top gas" on demand. The quantity which remains in the storage cavity for as long as storage injection/withdrawal cycles continue is called "cushion gas". The economic advantage of using a less costly inert substitute for "cushion gas" has been of interest to and the focus of research and development both in the USA and France for more than a decade. As a result of this work, it is now possible to substitute at least 10-20% of cushion gas in storage reservoirs developed in porous and permeable aquifers by direct injection of nitrogen. In salt cavities, where it is even more desirable to have a substitute cushion, it was recently shown that it is possible, practical and economically advantageous to substitute nearly 100% of cushion gas with nitrogen through the use of a membrane separating "top gas" from "cushion gas". The use of a plastic film or membrane which would convect the pressure while, at the same time, prevent mixing is now a patented process, currently under consideration for several salt storage fields.

When two separate inventories of "cushion" and "top" gas share the storage cavity, their volumetric response to cyclic pressure, temperature, injection and withdrawal operations depends on their physical properties related to their thermodynamic PVT behavior. This paper describes engineering data and economic parameters related to the design in retrofitting existing conventional storage caverns to operate with nitrogen as cushion gas. The topics discussed include: (1) Effect of operating conditions; (2) Considerations related to materials, construction, insertion, deployment and monitoring for leaks; (3) Start-up sequence, system redundancy and fail-safe requirements.

With the present and projected price structure of nitrogen and natural gas world wide, the economic advantage of using the nitrogen for cushion gas is related to present and growing future markets in salt cavities.

INTRODUCTION AND BACKGROUND

In underground storage of natural gas, that part of stored inventory which remains continuously in the storage horizon is called "cushion gas". That gas which provides the pressure energy necessary to withdraw the "top gas" on demand remains in the reservoir for as long as injection withdrawal operations continue. When natural gas is stored in porous and permeable reservoirs such as depleted oil or gas fields or aquifers, the cushion gas amounts to 40-75% of maximum inventory. When leached cavities in salt environment are used for storage, the cushion gas may represent 25-50% of maximum inventory. Therefore, a major portion of capital investment required for development of underground storage is the cost of cushion gas which must remain in the reservoir for 30 or more years. This cost can be as

high as 50-60% of total gas cost (Leroy, 1988).

The prospects for using an economical inert substitute for cushion gas in storage has been of interest for more than a decade. As a result of considerable research and development work in the USA and France, it is now possible to substitute 10-20% of cushion gas with nitrogen in aquifer storage and depleted oil or gas fields. In salt cavities, where it would be even more beneficial to have a substitute cushion, it was shown (Tek, 1991a) that it is possible and economically advantageous to substitute almost 100% of cushion gas with nitrogen or some other mixture through the use of a membrane separating the top gas from the cushion gas. Figure 1 illustrates the concept of membrane separation of cushion gas from top gas in a salt cavity. The use of a flexible plastic film which would convect the pressure, but, at the same time, interdict mixing which would di-

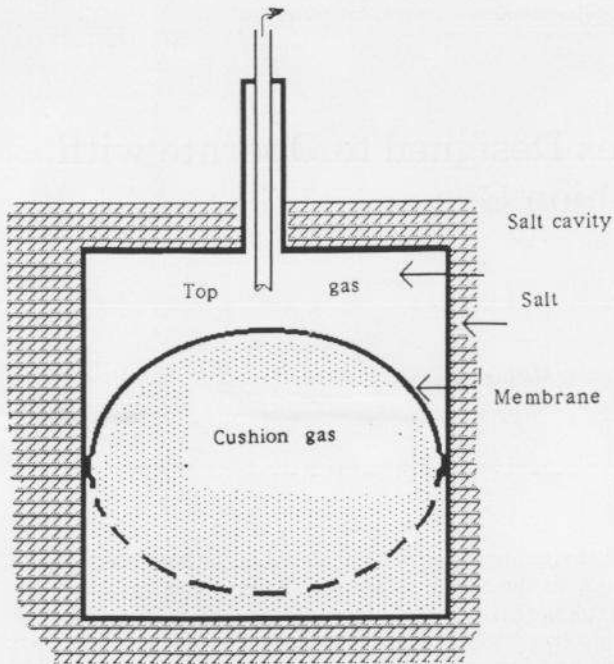


Fig. 1. Concept of membrane separation of cushion gas from top gas.

lute the top gas was patented in 1991 (Tek, 1991b). The process is currently being considered for retrofitting several salt storage fields.

The engineering aspects related to various schemes for separating cushion gas from top gas and for use of nitrogen as cushion have been published by Tek (1991a). Considerations related to materials, construction, insertion and deployment of a separating membrane, as well as specific start-up sequence and fail-safe requirements were discussed in that paper. The object of this paper is to deal in more detail with the thermodynamic performance of two different gases as top and cushion, basic design considerations and economic evaluation. A specific example of a typical set of design calculations is included in order to provide a guideline for the methodology involved.

CONCEPT OF MULTI-SEASONAL PEAKING IN STORAGE

With environmental constraints related to coal, safety issues related to nuclear and geo-political concerns related to oil, natural gas, the premier fuel, easy to transport, simple to store, clean and efficient to burn and, perhaps, also cheaper to buy, is becoming more and more favored for generation of electric power.

The pipelines which carry the natural gas from producing fields to consuming markets require un-

derground storage fields to modulate their constant throughput against the variability of both supply and demand. When demand exceeds the design rate of the pipeline, "market storage" at the downstream end makes up the difference. On the upstream end, when supply falls short of the pipeline's capacity, "field storage" compensates to maintain a high load factor. The storage fields at either end have two important characteristics. These are seasonal "top gas" and "peak day deliverability". Storage reservoirs designed to meet seasonal demand cannot, in general, provide sufficient peak day deliverability.

In storage, "peak day" is characterized by the coldest day in winter as related to high demand for heat. In electric generation, peak demand for natural gas also occurs in summer as related to the hottest day. Such high demands for natural gas, whether in winter or summer, require high deliverability, but, only for short periods of time. The frequency of peak demands is related to the frequency of cold or heat waves. The service which would be particularly suited to meet peak demands of high deliverability for short durations are best provided by salt cavities if they are reasonably close to pipeline terminals or electric power sites. Between depleted fields, aquifers and salt caverns, it has been said that no storage field can surpass the seasonal top gas capability of a large aquifer. By the same token, it is well known that no aquifer can economically compete with the deliverability from a salt cavern. A typical heating season in the northeast or midwest USA runs between 140 and 160 days. This leaves a balance of 200–220 days to replenish the seasonal gas withdrawn with reasonable amount of compression. If and when salt cavities exist or can be developed near electric power generation facilities, they can meet high demand during several peak periods to supplement natural gas from pipelines during both summer and winter. Their inventory can be replenished from existing supply facilities during the days between peak periods.

PERFORMANCE OF SALT CAVERNS WITH SUBSTITUTE CUSHION

When two different gases, separated by a flexible membrane, share a salt cavity, their response to injection/withdrawal (I/W) of top gas is a function of their thermodynamic P-V-T properties. The pressure prevailing in the top gas results from I/W operations manifesting compression–expansion–heat effects. The pressure, i.e., the normal stress is convected from outside to inside of the membrane where it results in the pressure of cushion gas nearly

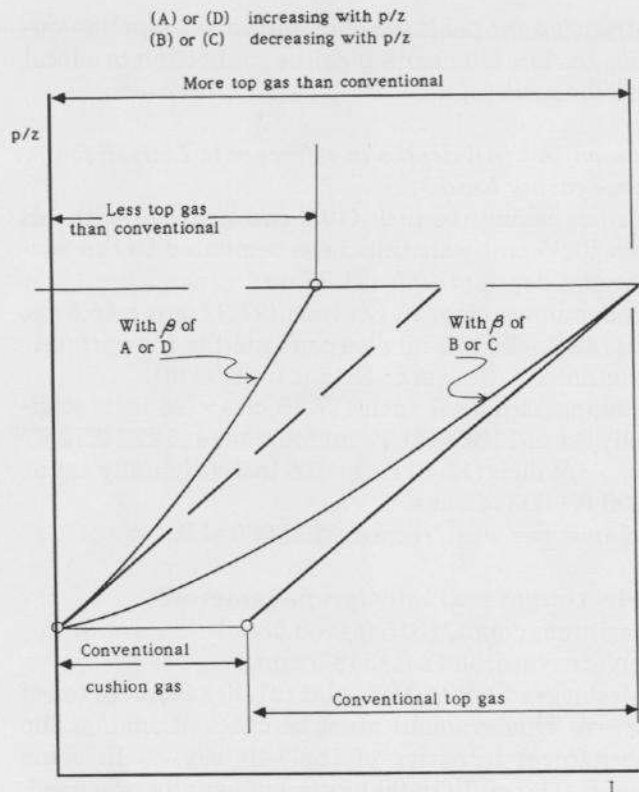


Fig. 2. Effect of β on pressure-content hysteresis.

equal to that of the top gas on the outside. If α designates the volume fraction of the cavity occupied by top gas, it was shown by Tek (1991a) that

$$(z_{N_2}/z) \alpha / (1 - \alpha) = I_T / Q_{SC} \quad (1)$$

where z designates the compressibility factor, I the inventory and Q_{SC} the cushion gas amount. The subscripts N_2 and T respectively designate the nitrogen cushion and top gas. Q_{SC} designates substitute cushion.

As the pressure in the cavity changes, the volume fraction α as a function of Q_{SC} and the ratio of compressibility factors called β can be calculated:

$$z_{N_2}/z = \beta \quad (2)$$

$\beta = \beta(p)$ at the prevailing cavern temperature

In underground storage, it is customary to represent the pressure-content performance of the top inventory in the form of a relationship between p/z , the pseudo-pressure, and I , the inventory. Since β is a function of pressure, temperature and the compositions of top gas and cushion gas, it can be shown that the performance of a storage cavity can be represented by a chart called the hysteresis chart depict-

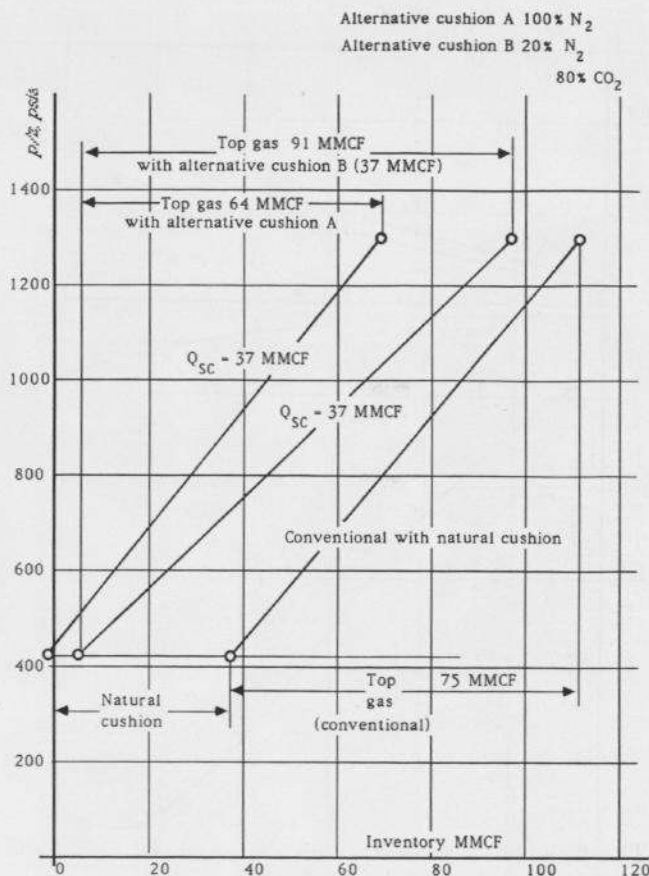


Fig. 3. Comparison of storage performance with and without alternative cushion.

ing p/z vs. I , the inventory:

$$I = (p/z) 378.6V/RT 10^9 - \beta Q_{SC} \quad (3)$$

where I and Q_{SC} are top gas and cushion gas inventories in BCF, p the cavern pressure in psia, T the cavern temperature $^{\circ}R$ absolute, β and z dimensionless, $R = 10.73 \text{ psia} \times \text{ft}^3/\text{lb mole } ^{\circ}R \text{ abs}$.

Figure 2 shows β as a function of p/z at a typical cavern temperature for nitrogen and 3 other substitute cushion gas mixtures indicated as curves A, B, C and D. It is interesting to note that pure nitrogen or nitrogen rich combustion products have linear trends increasing with the pseudo-pressure p/z . The mixtures of CO_2 and N_2 , on the other hand, show nonlinear trends decreasing β with p/z .

The effect of increasing β with p/z compared to decreasing β with p/z on the hysteresis charts is shown qualitatively in Fig. 2. As will be shown later in design example, it appears that a CO_2 rich nitrogen mixture would result in the type of curve to provide more seasonal top gas than pure nitrogen or typical combustion by-product of natural gas, as depicted in Fig. 4.

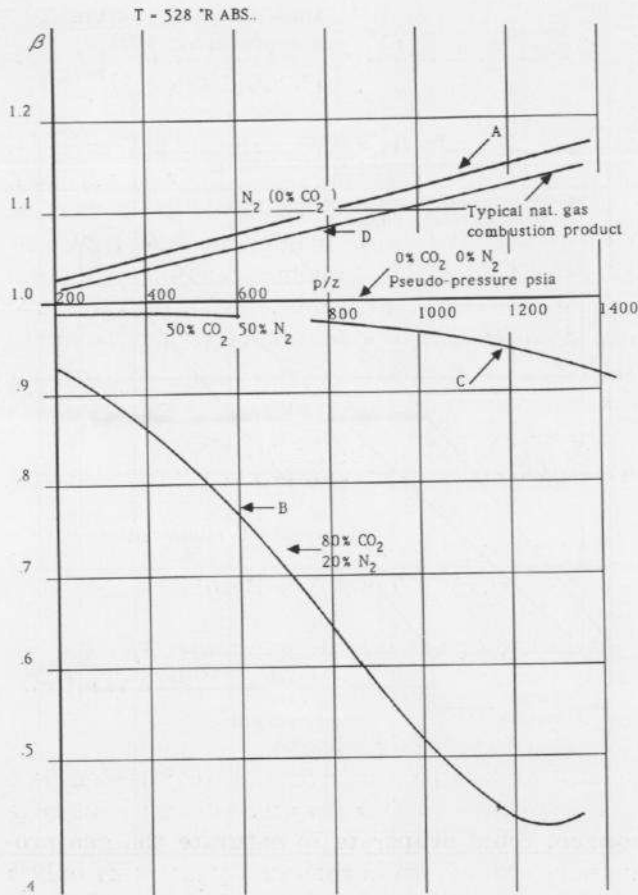


Fig. 4. Effect of cushion gas composition on z factor ratio β .

DESIGN OF A SALT STORAGE FACILITY WITH NITROGEN AS CUSHION GAS

Development of salt cavities for peak shaving storage service has been the focus of interest recently as related to recognition of demand based market prices and tariffs.

The design of a salt cavern storage facility first involves engineering and decisions related to site selection, fresh water supply, brine pond, brine disposal, drilling and leaching facilities, as well as considerations of lead time and project management.

Because of the large number of existing salt cavities currently under consideration for retrofitting to natural gas storage service with high deliverability characteristics, the example discussed below will be confined to description of engineering design work involved in retrofitting an existing small cavern to peak shaving storage service with nitrogen or some other inert mixture to be used as cushion gas.

Project description

The facility to be designed is a salt cavity to be

retrofitted for peak shaving storage of pipeline quality gas located near a pipeline connection to a local distribution system.

Cavern "A" (All depths in reference to Kelly, 6 ft above casing head.)

Surface casing: 16 inch (40.6 cm) nominal with 3/8 inch (0.95 cm) wall thickness cemented to the surface at a depth of 70 ft (21.35 m).

Production casing: 10 3/4 inch (27.31 cm) x 45.5 set at 1142 ft, (348.31 m) also cemented to the surface.

Original TD of cavern: 1315 ft (401.08 m).

Hanging strings: 7 inch (17.78 cm) x 26 inch originally set at 1152 (351.13 m) (now set at 1223 (372.77 m), 4 1/2 inch (11.43 cm) x 9.5 inch originally set at 1290 ft (393.45 m).

Volume: per wash records, 230,000 bbls.

Selection of main design parameters

Maximum depth, 1315 ft (408.08 m)

Top of cavern, 1142 ft (348.31 m).

Select a gradient of 0.95 psi/ft (21.49 kPa/m) to top of cavern. This gradient must be checked against the mechanical integrity of the salt cavity. In some states, 0.8 psi/ft (18.09 kPa/m) is usually practised. Maximum cavern pressure, $0.95 \times 1142 = 1100$ psia (7584.23 kPa).

Cavern temperature, $T \approx 68^\circ\text{F}$ (20°C); 528°R abs (293°K abs).

Cavern capacity, $n = pV/zRT$

$p/z = 1300$ psia; $R = 1545$ ft x lbf/lb-mole $^\circ\text{R abs}$ (8314.5 joules/kg-mole- $^\circ\text{K}$) $n = 1300 \times 1,290,300 \times 144/1545 \times 528 = 296,028.24$ moles.

Capacity in standard cubic feet, $296,028 \times 378.6$

$= 112,076,2930$ SCF

$= 112$ MMCF 3.136 MMCM

Minimum storage pressure = 400 psia (2757.90 kPa) assumed

pseudo-pressure $p/z = 430$ psia (2964.75 kPa)

Quantity of cushion gas = 37.07 MMCF (1.036 MMCM)

Cushion gas ratio $37.07/112 = 0.33$

Quantity of nitrogen to be used as cushion gas = 37 MMCF (1 MMCM).

It must be noted that the size and depth of the cavern chosen for this example are much smaller than the normal caverns used for underground storage. For this reason, as the economics will later show, the nitrogen in such a small quantity may be purchased as liquid nitrogen at about 3 times the price of gaseous nitrogen without significantly affecting the economic outcome.

For nearly pure nitrogen as alternative cushion gas, cavern temperature = 68°F and 0.6 gravity pipeline quality natural gas as top gas, it was shown by

Tek that:

$$\beta = z_{N_2}/z = 1.06 + 1.42 \times 10^{-4} (p - 400) \quad (2)$$

where p is the cavern pressure in psia.

In order to track hysteresis performance, i.e., p/z vs I , for a salt cavern in storage service with alternative cushion gas, it can be shown (Tek, 1991a) that:

$$I = (p/z) 378.6V/10.73 \times T \times 10^9 - \beta Q_{SC} \quad (3)$$

$$I = (p/z) 378.6 \times 1.2903 \times 10^6/10.73 \times 528 \times 10^9 - \beta(p)Q_{SC}$$

In order to analyze the effect of alternative cushion on storage performance, the β values were calculated as function of pressures for 3 different cushion gas compositions. These were for pure nitrogen, 50% N_2 , 50% CO_2 mixture and 80% CO_2 , 20% N_2 mixture. The β curves are shown in Fig. 4. The cavity performance equation was numerically reduced to

$$I = 8.6 \times 10^{-5} p/z - \beta(p) 0.037$$

The results are shown in Table 1 and Fig. 3.

TABLE 1

Inventory-pressure results with and without alternative cushion gas

p/z psia*	I, BCF		
	Without alt. cushion	Alt. cushion A, 100% N_2	Alt. cushion B, 80% CO_2 , 20% N_2
1300	0.112	0.069	0.096
1000	0.086	0.045	0.067
800	0.068	0.027	0.044
600	0.052	0.012	0.024
430	0.037	-0.002	0.005

*Metric conversion factors given under "Nomenclature" at the end of this paper.

It can be seen that with alternative cushion B (20% nitrogen, 80% CO_2), the cyclic top gas produced 91 MMCF would even be 20% higher than the cyclic top gas without alternative cushion. If, on the other hand, nearly pure nitrogen with no CO_2 is used as cushion, the cyclic top gas becomes 15% less than the cyclic top gas without alternative cushion.

Calculation of deliverability

Use equation given by Tek (1987) for flow through casing-tubing annulus:

$$Q = \frac{(D_1 + D_2)(D_1 - D_2)^{1.5}}{T_a z_a} \left[\frac{p_s^2 - e^s p_w^2}{0.000667 f (e^s - 1)} \right]^{0.5} \quad (4)$$

$L = 1217$, $G = 0.6$; $D_1 = 9.76$ inches (24.79 cm); $e^s = e^{0.0375 \times 0.6 \times 1217/528 \times 0.83} = 1.06$; $D_2 = 3.50$ inch (8.89 cm); $T = 528$ °R abs; $z_a = 0.915$ estimated; assume $f(\text{Moody}) = 0.016$ (subject to later check by Reynolds' Number). Now, for cavern pressure 636 psia (4385.07 kPa) and surface line pressure $P_w = 500$ psia (3447.38 kPa), the deliverability may be calculated as:

$$Q = \frac{13.26 \times (6.26)^{1.5}}{528 \times 0.915} \left[\frac{(636^2 - 1.06 \times 500^2)}{0.000667 \times 0.016 \times 0.06} \right]^{0.5}$$

$$= \frac{13.26 \times 15.66}{528 \times 0.915} \left(\frac{404496 - 265000}{0.000667 \times 0.016 \times 0.06} \right)^{0.5}$$

$$= 200,6134.09 \text{ MCF/D or } 200.6 \text{ MMCF/D}$$

(5.62 MMCM)

Dehydration requirements

In storage service, dehydration requirement is a function of how much free water, present in storage horizon, could evaporate to saturate the gas produced. If the cavern is reasonably dry with only a small amount of brine in a properly designed sump, there would be little if any need to dehydrate. In storage service designed to provide peak shaving capability several times a year, a dehydration system may be designed based on low injection and not on high withdrawal rates. The high rates occur for only a few days or hours during each demand period. In multi-seasonal peaking, since the number of days available for injection would permit much lower rate of injection than the peak withdrawal rates the cavern is designed for, the dehydration requirement dollars need not be so high. While it must be recognized that freeze-ups in periods of high demand could have serious consequences, there are several options which would permit keeping the size of dehydration plant reasonably small. These are:

1. *Use of local distribution company's own dehydration capability.* The local company or its supplier could over-dehydrate their main stream sufficiently so that when the peak shaving load from the salt cavity is co-mingled with it, the dew point of the gases mixed would remain within allowable range.

2. *Preventive measures to keep the water from evaporating.* If the brine at the bottom of the cavern is confined to a sump, it can be covered with certain special oil (Wyrick, 1991; Haddenhorst, 1991) to control the rate of evaporation.

3. *Using the small dehydration unit between the periods of high demand.* Indeed, by continually recycling the cavern inventory through the small dehydration plant, one can control the dew point below a critical level.

4. *By using properly designed membranes to contain the cushion gas at the bottom.* The plastic material arranged to contain the alternative cushion gas may be designed to minimize the area of contact between the brine at the bottom and the storage gas at the top.

ECONOMIC CONSIDERATIONS

Total capital cost

The overall cost of developing an underground storage facility in layered or domal salt environment is presently \$8/MCF based on total inventory. This compares with the total cost of aquifer storage development of \$5/MCF storage capacity and \$3/MCF stored in depleted oil or gas reservoirs. In general, the unit cost per MCF stored decreases with increasing cavity volume. One major element of the overall cost is naturally the geographic location tied to the presence of accessible salt on the one hand and to the market on the other. The cost of pipeline connection from storage site to a terminal or existing pipeline is approximately \$10/ft per inch of pipeline, at present, in the US. That figure compares reasonably with a unit pipeline connection cost in France of about FF 1-1.4×10⁶/km (1984 France). There are also other major cost components which come into the picture. Among these, availability of fresh water supply, brine disposal, pumping systems, gathering and disposal lines may be cited. It is estimated that 5-10% of the total cost in a salt cavity storage facility may involve initial screening, exploration and site selection work.

The total capital cost discussed above includes

TABLE 2

Capital cost components in development of salt cavities for storage

Land	4%
Cavern development	33%
Compression, regulation metering, dehydration	21%
Pipeline connection	12%
Buildings and misc.	2%
Interest	16%
Cushion gas	10%
Contingency	2%
	100%

interest during the construction and in general involves a lead time of 3 years. Based on a recent paper (Mitchell, 1991), the various components of capital costs may be represented as a percent of total cost as given in Table 2. It should be noted that Table 2 involves costs related to a conventional salt cavity and not one using alternative cushion gas.

While generalizing cost estimates from a single case is a risky business, one can, nevertheless, observe that the largest components in total project cost involve cavern development, surface equipment, interest and cushion gas.

Savings from use of alternative cushion

The cost of natural gas on the commodity futures market as of this writing is about \$2/MCF and expected to go to a low of perhaps \$1.50/MCF next summer (The Wall Street Journal, 1991). Even with the present depressed level of natural gas prices, the savings to be realized by using substitute cushion gas in new or retrofitted storage cavities are substantial and project outstanding economies in the next 5-10 years.

The main alternative cushion indicated in this or previous paper by Tek (1991a) is inert nitrogen. There are two sources for generating nearly pure nitrogen at prices substantially lower than natural gas. These are

1. Air Liquide Pressure Swing Adsorption Process and
2. Generon Dow/BOAC Membrane Separation Technology.

The Air Liquide process is electricity intensive and produces nitrogen at present for \$1-1.25/MCF. The nitrogen generators by the Generon Membrane Separation Technology appear to have the capability to cut the cost of *in situ* generated nitrogen down to the \$0.75-1/MCF range (Stuart and Stevenson, 1991).

It is important to note that the research work related to this paper indicated that, with a proper composition, a mixture of CO₂ and nitrogen has a declining β value with pressure which results in a favorable p/z vs inventory performance. Such a mixture as shown in Fig. 4 not only saves the price differential between natural gas and the generated inert but, at the same time, it also provides even more top gas per cycle than it would by using natural gas as cushion.

Generation of CO₂ rich combustion gas involves combustion, multi-staged cooling, compression and dehydration. Its cost is naturally tied to the cost of natural gas. If the price of natural gas is \$2/MCF, then the cost of generating such a mixture is reported to be about \$2/MCF (Leroy, 1988). If, on the other hand, an inert gas generator recently

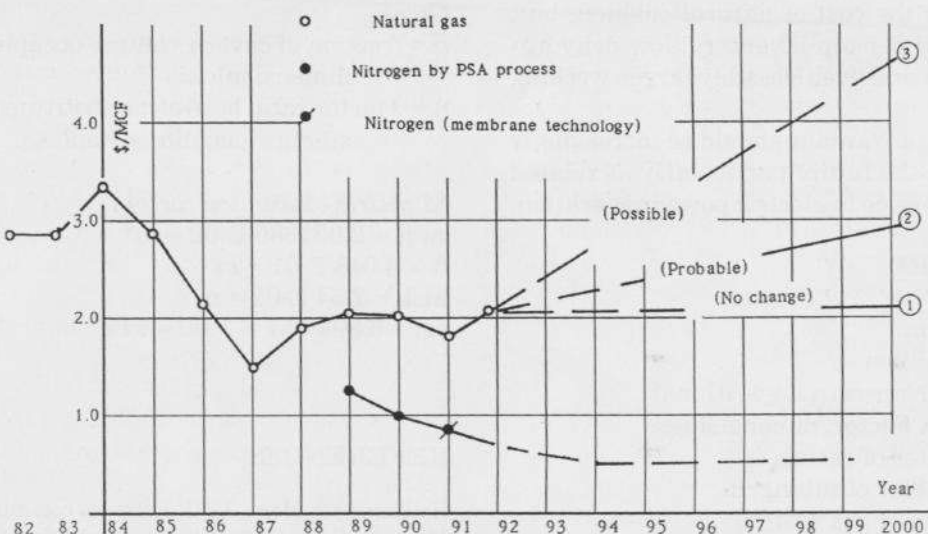


Fig. 5. Price of natural gas and N_2 .

developed in France is used, the cost of generating 1 MCF comes down to \$1.25/MCF when the natural gas is \$2/MCF. This more recent process combines the exhaust from combustion to drive the compressors. Since both inert gas generators have been developed for direct injection into aquifers, they involve special equipment for catalytic removal of nitrogen oxides and pressures as high as 2200 psia (15168.47 kPa). For applications to generate inert gas for use as alternative cushion in salt cavity storage, the cost is expected to be somewhat lower because there will be no need for such high pressures or NO_x removal. At any rate, with present trends in technology, it is not unreasonable to think that the cost of alternative inert cushion in the next 10 years will tend to approach 50–60¢/MCF.

Figure 5 shows a comparison between the price of natural gas (past, present and projected) and the price of nitrogen as inert cushion substitute. Three possible future trend scenarios are indicated in Fig. 5 for the price of natural gas. While the price of natural gas changes almost 100% between summer and winter, the annual average is expected to increase approximately 10–13% per year between now and the year 2000. That is indicated as the scenario no. 3 labelled "possible". It projects \$4.60 by the year 2000. The projection no. 2, indicated as "probable", reaches a price of \$3/MCF by 2000, an average increase of slightly over 4% per year. Even if the price of gas did not increase (scenario no. 1, labelled "no change"), one would still expect a saving of $2.10 - 0.60 = \$1.50/\text{MCF}$ by replacing the cushion gas with an inert alternative.

On a cavern dedicated to storage with 10 BCF capacity and with 3 BCF cushion, the saving presently indicated would be about \$4.5 million. If one includes a 3 year lead time between now and completion of such a project, and, if one uses the probable no. 2 scenario, the saving in cushion gas alone would be about \$5.5 million.

Further savings in higher deliverability per stored top inventory and lower costs in compression and dehydration requirements would also be realized as well as the cost of interest during construction.

Operating costs

The operating costs include the property taxes, working capital, fuel, operation and maintenance, and general and administration costs. For financing, the cost of capital is usually based on 45% debt, 10% preferred stock and 45% equity with interest on the debt, the rates of return on preferred stock and return equity respectively set as 12, 11 and 15%.

In determining the demand rate for the storage gas to be sold, a simplified annual cost of service methodology is used which treats fixed and variable components with proper rates of escalation (Mitchell, 1991).

CONCLUSIONS

1. The use of inert cushion gas substitute in salt caverns dedicated to storage of natural gas is conceptually sound, mechanically practical and economically feasible.

2. The economic advantage involves not only sub-

stantial saving in the cost of natural cushion, but, high deliverability per top inventory, low dehydration requirements and even possibly larger working volume per cycle.

3. The economic advantage should be increasingly more favorable in the future particularly as related to peak shaving service in electric power generation.

NOMENCLATURE

B designates billion
 MM designates million
 $e = 2.718$ (base of Neperian Logarithms)
 f = Moody Friction Factor, dimensionless
 D_1 = inside diameter of casing, in.
 D_2 = outside diameter of tubing, in.
 G = specific gravity of gas = $M/29$
 I_T = top gas inventory, BCF
 L = length of casing tubing annulus, ft
 M = molecular weight lbm/lb-mole
 p = pressure, psia
 Q = rate of flow MCF/D
 Q_{SC} = substitute cushion gas inventory, BCF
 V = cavity volume, cu.ft.
 $s = 0.0375 GL/T_{aZ_a}$ (dimensionless exponent)
 T = cavern temperature, °R abs.
 z = the compressibility factor, dimensionless

Subscripts

N_2 = nitrogen
 SC = substitute cushion
 T = top gas.

Greek

α = fraction of cavern volume occupied by top gas, dimensionless
 β = z factor ratio between substitute cushion and storage gas, dimensionless.

SI metric conversion factors

cu ft $\times 2.831685 \text{ E-}02 = \text{m}^3$
 ft $\times 3.048 \text{ E-}01 = \text{m}$
 inch $\times 2.54 \text{ E-}02 = \text{m}$
 psi $\times 6.894757 \text{ E} + 00 = \text{kPa}$

REFERENCES

- Haddenhorst, Hans, 1991. Personal communication.
 Mitchell, G.K., 1991. Marketing and financing strategies for solution mined gas storage facilities. Paper presented and distributed at SMRI Spring Meeting April 28-30, 1991, Atlanta, Georgia, USA.
 Leroy, C., 1988. Economic Data on Underground Storage, Training Manual. Sofregaz, Clichy, France.
 Stuart and Stevenson, 1991. Nitrogen Generators. (Pamphlet.) Houston, Texas.
 Tek, M.R., 1987. Underground Storage of Natural Gas. Gulf Publishing Co., Houston, London, Paris, Tokyo, 389 pp.
 Tek, M.R., 1991a. Use of inert cushion substitutes in salt cavity storage of natural gas. Paper presented and distributed at SMRI Spring Meeting, April 28-30, 1991, Atlanta, Georgia, USA.
 Tek, M.R., 1991b. Method for underground storage of gas. U.S. Patent 5,052,856, Oct. 1, 1991, Washington, D.C., USA.
 The Wall Street Journal, Nov. 14, 1991.
 Wyrick, J., 1991. Personal communication.