SOME ASPECTS REGARDING THE UNDERGROUND STORAGE OF NATURAL GAS IN SALINE DEPOSITS

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ABSTRACT

Natural gases represent the energy that can be stored in large quantities, in the same state as that in which it is used to the final consumer, without being subject to transformations and disruption. One of the fundamental problems of gas industry is taking over the peaks of hourly and seasonal consumption, caused by the random nature of the gas demand, depending on the nature of the industrial consumers (with a relative constant gas demand) and those non-industrial (mainly household consumers with large hourly and seasonal fluctuations) and the possibilities of import, with approximately uniform and limited capabilities, in the period of day or all of the cold season.

The underground storage of natural gas represents a solution for gas supply of consumers in the case of damages to the pipelines, and the coverage of the peaks of consumption in cold season. Compensations for the required gas flows for heating are doing by transferring from the fields with a high dynamic potential in underground storage near the big consumers.

The construction of the cavern in the saline deposits in view of the underground natural gas storage shall be made by the deep wells with direct or indirect circulation. By direct circulation, freshwater is injected through the working space with the smallest diameter, and the brine is evacuated in the annular space. The advantages of this method are: (1) eliminates the danger of dissolution of the salt from the surrounding area of the shaker of the last column cemented, due to the near-saturation concentration of ascended brine; (2) reducing the consumption of the insulating fluid given the lower cross-sectional diameter of the cavern ceiling; (3) performing a cavern of ovoid elongated shape with a maximum cross-sectional diameter at the base. By reverse circulation, freshwater is pumped in the annular space between the two casings, and the brine is evacuated in the casing with the smallest diameter. The advantage of this method is development of high ascending speeds in the inside of the casing with a small diameter, ensuring an efficient evacuation of insoluble material which will be deposited at the cavern bottom.

The underground gas storage in the saline deposits has the following advantages: (1) the large area of salt bodies spreading on the Earth; (2) the duration of the production process is few weeks, being possible to carry out several cycles per year; (3) the operating costs are lower than in the depleted reservoirs or aquifers.

In the paper, the authors review some aspects regarding the underground storage of natural gas in the saline deposits in terms of selection criteria of salt cavern, designing, drilling technology, factors of stability, salt cavern deformation, production behavior.

Keywords: *saline deposits, underground gas storage, selection criteria, cavern designing and construction, stability and production behavior*

INTRODUCTION

Underground storage of natural gas is a practical solution for: (1) gas supplying of consumers in case of the damages of large gas pipelines, by temporary replacement of primary gas sources, (2) balancing of gas consumption – domestic gas production – natural gas import over a year with direct consequences on natural gas purchase prices and the attractiveness of the contracts, (3) coverage of peaks consumption in the cold season by balancing the gas flows required for heating; (4) transfer of gas from fields with a high dynamic potential into underground storages near major consumers.

Underground storage of natural gas in saline deposits is easier to apply because: (1) the salt deposit has a low permeability (10^{-21}-10^{-24} m^2) which allows good sealing; (2) has good mechanical properties; (3) is soluble in water, which makes the cavern easier to build; (4) large salt deposits are spreading on the Earth. [1]

GEOLOGICAL AND TECHNOLOGICAL SETTING

Selection criteria of the saline deposits for underground gas storage. In order to be eligible for underground storage of natural gas, saline deposits must meet some selection criteria. Thus, the caverns formed in the salt massifs for the purpose of natural gas storage used in various projects around the world (Germany, Portugal, China) have the following characteristics [2]:

1) depth: 1000-3000 m;
2) thickness: tens to hundreds of meters.
3) volume: 30,000,000-500,000,000 m^3.
4) pressure gradient at the shoe of the operating casing: 1.50-2.50 bar/10 m.
5) pressure gradient at the average depth of the cavern: 2 bar/10 m;
6) pressure: 25-225 bar.

Design and building of a salt cavern. Usually, building of a salt cavern by dissolution/leaching consists of exposing the salt deposits in a drilled hole, inject freshwater in the hole, allow time for dissolution and disposal of the resulting brine from the hole. As the salt dissolves, the hole enlarges into the form of a cavern.

The following phases are recorded for the building of the salt caverns: (1) selection of the location; (2) drilling and casing of the wells; (3) salt sealing; (4)

brine disposal; (5) wells completion; (5) cleaning the cavern and filling; (6) final trials; (7) operation. [3]

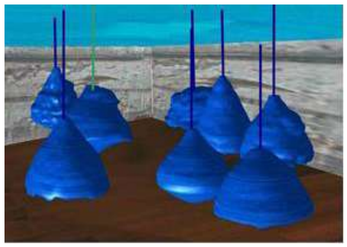

Fig. 1. The shapes of several existing salt caverns of Jintan salt mine. [4]

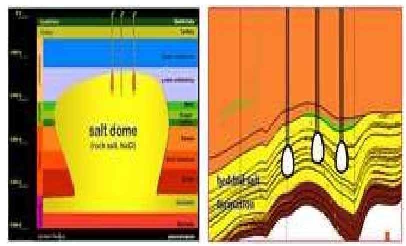

Fig. 2. Salt caverns in different salt deposits. [5]

The technology of building the salt cavern. The building of a salt cavern is done by deep wells by means of freshwater circulation. The wells are equipped with two concentric tubing strings, the outside string for protection and the inside string for injection or evacuation. Two methods are used to salt dissolution through pumping of freshwater:

1) *Direct circulation*: freshwater is injected through the working space with the smallest diameter, and the brine is evacuated in the annular space. The advantages of this method are: (1) eliminates the danger of dissolution of the salt from the surrounding area of the shaker of the last column cemented, due to the near-saturation concentration of ascended brine; (2) reducing the consumption of the insulating fluid given the lower cross-sectional diameter of the cavern ceiling; (3) performing a cavern of ovoid elongated shape with a maximum cross-sectional diameter at the base. [6]

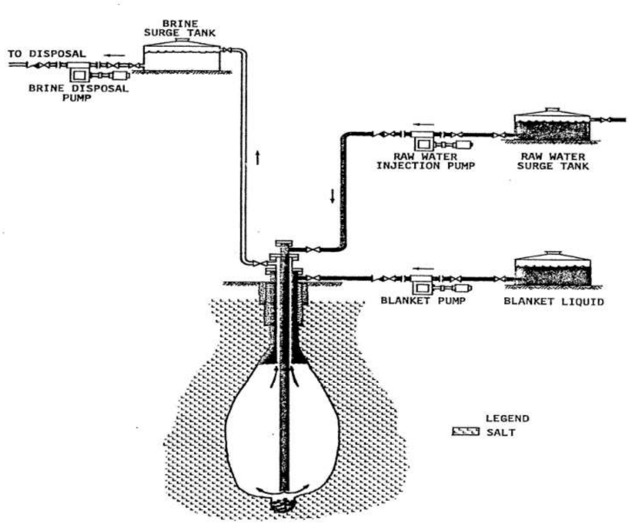

Fig. 3 Salt cavern building using direct circulation. [6]

2) *Reverse circulation*: freshwater is pumped in the annular space between the two casings, and the brine is evacuated in the casing with the smallest diameter. The advantage of this method is development of high ascending speeds in the inside of the casing with a small diameter, ensuring an efficient evacuation of insoluble material which will be deposited at the cavern bottom.

In order to make an upper limit in the vertical dimensioning of the salt cavern and to prevent dissolution of the salt around the last cemented casing, a light nonleaching and noncorrosive fluid is injected into the annular space between last casing and production tubing. The inert fluid blanket may be a type of liquid petroleum products, liquefied gases or air. When brine is discharged into the sea or other waters, the inert fluid blanket is propane-butane which is separated and released into the atmosphere, making it environmentally and economically.

The salt leached caverns are connected to the surface via concentric tubing strings for moving the natural gas in and out of the cavern. At the surface level the well-head, equipped with valves, occupies a very limited space, and all associated piping is buried underground. The pumping facilities, metering equipment and related support facilities such as control buildings and fire protection systems are centralised into a single area thus ensuring minimal land occupation and environmental impact.

Factors that influence the dissolution process. Among the most important factors that influence salt saturation of freshwater are: (1) pumped flow rate; and (2) diffusion phenomena occurring at the wall of the cavern.

Within the pumped flow rate, meaning the circulation flow, the saturation of the freshwater through its circulation has a very large weight in the dissolution process [7] and is determined by:

1) Fluid temperature differences in the cavern and thermal balancing tendencies. These temperature differences that exist between freshwater injected and almost stagnant brine in the cavern lead to thermal convection phenomena and therefore also to an internal secondary circulation between fluid packages with different temperatures.

2) The tendency of the gravitational separation of the fluids from the underground storage depending on the density, namely the degree of saturation. Due to the lower density the freshwater or unsaturated packages tend to rise in the tank before the densest. Their movement leads to a stirring with a tendency to uniformity of saturation, and hence an internal secondary circulation between the brine packages of different concentrations, and due to these phenomena, the salt wall remains in constant contact with an unsaturated fluid.

3) Chemical composition and solubility of elements forming the mineralogical complex under development. The chemical composition of the rock directly influences the dissolution rate of the solid salt, which can vary within appreciable limits. Prior to the launch of such a project, it is necessary to analyze the cores from the interval during which the underground deposit is to be made, for the determination of the mineralogical composition and the dissolution rates.

4) Pressure gradients that appear in the store during circulation. They lead to different flow rates in the cavern sections and secondary circulation by replacing fluid from the wall with a less saturated fluid. The phenomenon is significant only in the first stage, because with the increase of the deposit diameter, its efficiency decreases.

GEOTECHNICAL SETTING

Factors that influence the stability of salt caverns. Building of salt caverns for gas storage purposes involves assessing as accurately as possible the structural behavior of the underground openings, their size and the deformation velocity of the salt at relatively constant temperatures for long periods of time.

The use of salt caverns created by salt dissolution involves, when it is put into operation, replacing the brine with the gas to be stored and vice versa. The life span of gas deposits in salt caverns is closely correlated with their stability over time and implicitly with the mechanics of the salt massifs. In the salt massif, the creation of a cavern causes redistribution of tensions in time and space and in the same time generates a field of displacements, which is also dependent on time and space. Tensions and displacements are influenced by several factors, so there is another type of salt behavior in each area of interest studied. [8]

Cavern stability is assessed by quantifying these stress and strain states generated during salt dissolution and during operation as deposits. There are two phases in redistributing tensions around the salt cavern [7]:

1. Phase I is generated by the brine pressure during the cavern building. In this case the pressure generated by the brine limits the manifestation of pressures from the salt massif, but caverns can be destroyed by block dislocation, depositing at the base of the cavern and leading to changing of its shape and size;
2. Phase II is generated by the cavern acting as a gas storage when cyclical pressure changes occur in the cavern, the pressure having maximum values during natural gas extraction.

The state of tension is changing during the gas injection to strengthen the cavern walls due to the increase in the pressure of the natural gas. During the gas extraction, high values of concentrated stress occur in the direction of decreasing the resilience potential of the cavern walls. The extraction of the gas can be done at constant volume or under constant pressure, in which case geomechanical phenomena specific to each process can occur. These phenomena that overlapped with the effects generated by each process, amplified the damage around the cavern.

If the effect of changing the tension state can be considered to be approximately constant for each cycle, the secondary effect that accompanies it will have an increasing intensity. The lower the minimum pressure of the gas in the cavern and the longer the value of the gas, the more the fissures and breakage areas will be more pronounced. The cumulative effects that lead to the structural weakening of the salt massif around the cavern are loss of tightness, in which case it would compromise the storage quality.

In the building of the salt cavern for the underground storage of natural gas an economic analysis of the potential losses must be made. These losses may be: (1) irrecoverable losses, which are the amount of natural gas assimilated to the walls of the cavern due to the permeability of the salt massif; (2) partially recoverable losses, represented by the quantity of natural gas solubilized in brine; (3) fully recoverable losses, represented by the amount of natural gas to be left in the cavern to maintain its stability. [8]

Calculation of cavern deformation. Due to the minimal pressure in the cavern during emptying, problems arise in establishing the cavern and preventing deformation due to salt plasticity. This phenomenon is called convergent deformation and determines the gradual loss of the useful volume of the cavern.

The equations describing this phenomenon take into account the deformation of the cylinder or the sphere cavern shape and have the following formula [7]:

$$\frac{\Delta V}{V} = -200 \times A \times \exp\left(-\frac{Q}{RT}\right) \times \left(\frac{\sqrt{3}}{2}\right)^{n+1} \times \left[\frac{2(P_0 - P_i)}{n \times \sigma_c}\right]^n \times t \quad \text{(cylinder shape)}$$

$$\frac{\Delta V}{V} = -150 \times A \times \exp\left(-\frac{Q}{RT}\right) \times \left[\frac{3(P_0 - P_i)}{2n \times \sigma_c}\right]^n \times t \quad \text{(sphere shape)}$$

where:

A, Q and n – parameters that depend by the temperature and the considered model;

T – absolute temperature in the salt deposit;

P_0 – triaxial pressure “in situ” (approx. 2 bar/10 m depth);

P_i – pressure in the cavern (bar);

R – salt constant (cal/mol·K).

σ_c – constant for effort in the stabilized material (kg/cm)

Reducing salt caverns spreads in all directions and reaching to the surface can cause the subsidence phenomenon with negative effects on the environment.

Typically, the calculations for modeling the cavern in the salt massifs use the following values:

R = 1.98 [cal/mol·K]

σ_c = 0.07 [kg/cm]

$A = 3.27 \times 10^{-17}$ [in/in per sec]

Q = 12,900 [cal/mol]

n = 5

These values were determined in the laboratory researches after various analyses of salt samples collected by the operating wells.

CONCLUSIONS

Underground gas storage is an efficient process that combines the constant supply of natural gas through transport pipelines with variable market demands that depend on the season or economic considerations.

Besides the function of covering the consumption peaks, underground gas deposits also have the strategic role of ensuring the supply of gas in case of emergencies (natural disasters, earthquakes, etc.). In the warm season, when pipeline transport capacity exceeds consumption demand, natural gas is stored to be extracted most often during the cold season, when gas consumption increases greatly, or according to the economic considerations of that period. Coverage of seasonal consumption peaks can be done by underground gas storage located near major consumer centers.

The underground gas storage in the salt caverns has the following benefits: (1) the large area of salt massifs spreading on the Earth; (2) small cushion gas requirement (≈ 20-30%); (3) high deliverability rate; (4) short duration of the production process (10-20 days), being possible to carry out several cycles per year; (5) the operating costs are lower than in the depleted reservoirs or aquifers.

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