NATURAL GAS STORAGE ENGINEERING

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Summary

Underground storage of natural gas is an efficient process that balances the variable market demand against the constant supply of natural gas from the pipelines for engineering and economic advantages. Storage reservoirs are unique warehouses that store natural gas in times of low demand and provide a ready supply of gas in times of high demand. The various attributes that impacts design and performance of the gas storage reservoirs namely *inventory*, *deliverability*, and *containment* are presented in detail. In addition, the various methods that are used for inventory analysis are discussed.

1. Introduction

When gas is produced in one locality and consumed in another, economical transportation is essential. The most cost-effective and efficient natural gas transportation mode is through pipelines which operate at or near their design capacity. Steady need for natural gas seldom occurs. Therefore, to balance the variable market demand against the constant supply of natural gas from long-distance pipelines, gas storage preferably near the market is employed. When the pipeline capacity exceeds the market demand, the natural gas is injected into the underground storage reservoirs.

When market demands exceed pipeline supply, the gas is withdrawn from the storage reservoirs to supplement the supply from pipelines. In addition, gas storage provides a ready supply of gas in case of the unforeseen supply disruptions.

To minimum requirements for considering an underground prospect for gas storage include:

a) A structure overlain by a caprock. The water in the water filled caprock seals the tight rock from penetration by the gas phase and prevents the gas from rising vertically, due to buoyant forces or from moving laterally and causes the gas to accumulate in the storage zone below the caprock.

b) Sufficient depth to allow the storage to take place under pressures. The pressure will allow satisfactory quantities of gas be stored into a given space and permit gas to flow readily into and out of a storage horizon.

c) A high porosity and permeability storage zone beneath the caprock that permits gas to be stored in sufficient quantities and to permit the gas to flow into and out of it readily.

d) Water below the storage zone to confine the stored gas.

All of these conditions are normally met in underground petroleum reservoir where hydrocarbon have been found trapped below a caprock and confined by underlying water for millions of years. That is why many gas storage fields are partially depleted gas (or oil) fields which have been converted to storage. Where depleted oil and gas reservoir are not available, gas can be stored in water bearing sandstones or aquifers. Aquifer storage accounts for significant potion of the gas stored underground today. When a closed structure capped by caprock quality rock is found, gas can be injected and stored in the porous sand. However, the integrity of the caprock and the quality of the sand for gas storage must be first confirmed by drilling and testing wells. In addition to natural underground structures, gas can also be stored in manmade cavities such as solution cavities in salt beds or mined caverns. Solution cavities in salt beds have been used for gas storage.

Depleted gas reservoirs are normally pressurized to back to their original discovery pressure when they are converted to storage reservoirs. However, if a good cap-rock is present, a top storage pressure higher than discovery pressure can be considered. This practice has two advantages, the larger storage capacity and higher flow capacity. However, compression requirements, market needs, production problems, and economics must be considered when selecting the storage top pressure. A storage top pressure above the discovery pressure should not be selected when the caprock is thin or mechanical conditions are questionable. Aquifer storage reservoirs, on the other hand, require gas injection at pressures above the initial value in order to displace the water and create the gas reservoir.

There are typically two types of storage facilities; "base-loading" and "peak-shaving". Base-loading facilities are capable of storing sufficient volume of natural gas to provide constant seasonal market demands. They require long injection and withdrawal cycles, turning over the natural gas in the storage usually once a year. Peak-shaving facilities on the other hand, are designed to be turned over several times in one year in response to extreme short term demand for gas. As a result, they hold much less natural gas than base-load facilities. Salt cavities are the most common type of peak-shaving storage facility.

Design, operation, and monitoring of underground storage reservoirs involve recognition of three basic requirements or attributes:

a) Inventory which represents the volume of the gas that resides in the storage horizon.

b) Deliverability which represents the ability of the storage field to deliver the gas to the market. Deliverability depends on the pressure which is a function of the volume of the gas in the storage; therefore deliverability is related to inventory.

c) Containment which represents the ability of the storage field to prevent movement of gas away from the storage horizon. Migration of gas away from the storage horizon results in attrition of the inventory and consequently loss of the deliverability. The gas loss due to migration often depends on the pressure in the storage filed which is related both to inventory and deliverability.
These attributes are discussed in detail below.

2. Inventory

Inventory represents the total volume of the natural gas in the storage field at any given time. It represents the sum total of native gas and injected gas. It varies from a minimum value at the conclusion of withdrawal to a maximum value at the conclusion of injection. The total volume in storage is calculated from pressure surveys or the pressure-content performance using volumetric and material balance equations. The gas volumes in storage are classified into two categories:

a) Working Gas (Top Gas) which is the regularly injected and withdrawn gas each cycle. It varies from season to season depending upon the demand. The amount of working gas is determined by metering gas in and out of the storage reservoir. Its upper limit is defined by the designed maximum pressure for the storage reservoir and the capacity of the surface facilities such as compression, dehydration, pipeline and others. Factors which are considered for selecting the maximum pressure include caprock integrity as well as the threshold pressure, depth, and geometric spillpoints.

b) Cushion Gas (Base Gas) which is the gas that is left behind at all times in the reservoir during the storage operations. Each storage reservoir is designed for a minimum rate of delivery to meet its market demand. To assure this rate is available even during the last day of the withdrawal season a minimum pressure level must be maintained in the storage field. Otherwise, expensive and unfeasible surface equipment must be utilized. The cushion gas can be subdivided into three categories as illustrated in Figure 1. It is possible to withdraw some limited amount of cushion gas, when necessary, after all of the working gas is produced with the available equipment at the surface. This portion of the cushion gas is the "economically recoverable cushion with existing equipment." The remaining cushion gas is not recoverable with existing equipment and can be divided into two parts. The first part is physically recoverable but requires expensive and uneconomical surface equipment. The second part is physically nonrecoverable. For example, when water invades the gas zone in a water-drive reservoir, a fraction of gas is dispersed in small quantities and becomes immobile and is physically nonrecoverable. Similarly, when a depleted oil reservoir is converted to storage, the gas that remains in solution with oil at the abandonment pressure is physically nonrecoverable.

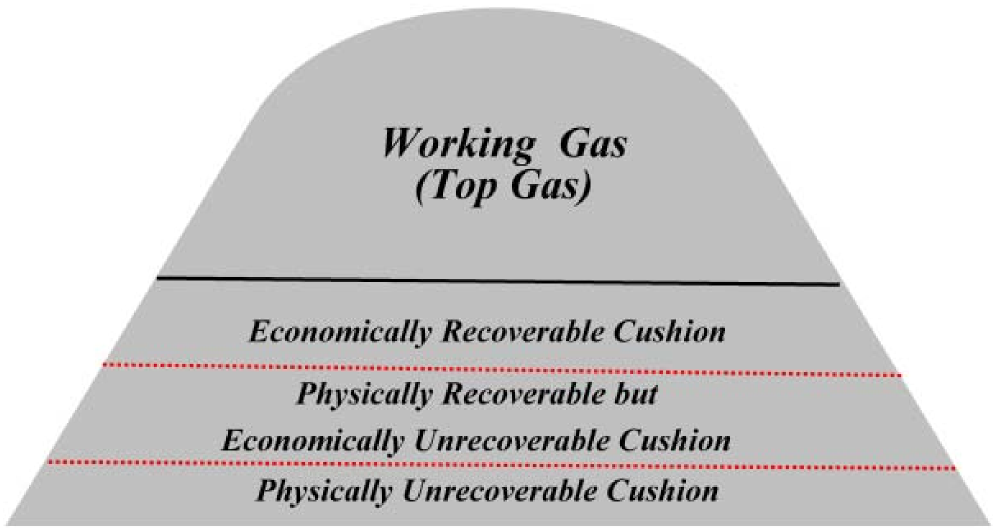

Figure 1. Working and Cushion gas in a Storage Reservoir

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Biographical Sketches

Kashy Aminian was born in Tehran, Iran in 1953. He holds Ph.D. (1982) and M.S.E (1978) in chemical engineering from University of Michigan and B.S. (1976) in chemical engineering from Tehran University.

He has been a Professor of Petroleum & Natural Gas Engineering for the past 16 years at West Virginia University in Morgantown West Virginia. He has 28 years of distinguished service in both industry and academia. He has extensive experience in natural gas reservoir and storage engineering and has published over 75 technical articles. Aminian is a member of Society of Petroleum Engineers (SPE)

Shahab D. Mohaghegh was born in Tehran, Iran in 1960. He holds Ph.D. (1991) in petroleum and natural gas engineering from Pennsylvania State University and M.S. (1987) and B.S. (1985) in natural gas engineering from Texas A&I University.

He is a Professor of Petroleum & Natural Gas Engineering at West Virginia University in Morgantown West Virginia since 1991. He is the founder of Intelligent Solutions Inc. and has been its president since 1996. He has been featured as a distinguished author in Society of Petroleum Engineers flagship journal (Journal of Petroleum Technology – JPT) and has been selected as SPE's distinguished lecturer. He has published over 100 technical articles. Mohaghegh is a member of Society of Petroleum Engineers (SPE).