Gas Processing Journal

Vol. 1 No. 1, January 2013
ISSN (Print): 2322-3251
PP. 9-18

Selection of the Best Efficient Method for Natural Gas Storage at High Capacities Using TOPSIS Method

Ehsan Khamehchi[1*], Seyed Hamidreza Yousefi[2] and Alireza Sanaei[3]

[1,2] **Department of Petroleum Engineering, Amirkabir University of Technology, Iran**
[3]**School of petroleum and geological Engineering, University of Oklahoma, USA**

(Received:15 September 2012, Accepted: 11 November 2012)

Abstract: *Nowadays one of the most important energy sources is natural gas. By depletion of oil reservoirs in the world, natural gas will emerge as the future energy source for human life. One of the major concerns of gas suppliers is being able to supply this source of energy the entire year. This concern intensifies during more consuming seasons of the year when the demand for natural gas increases, resulting in a lot of problems such as pressure depletion in the pipelines. One of the most effective policies to prevent pressure depletion is gas storage in warm seasons of the year when public demand is low. In this paper three different methods of underground and surface gas storage at high capacities have been discussed which are as follows: depleted oil and gas reservoirs, liquefied gas storage, and gas hydrates storage. In this study, the NPV function for economical evaluation of these three natural gas storage methods was employed. Finally, after assessing the technical and economical aspects of these methods, the TOPSIS model was constructed and depleted oil and gas reservoirs storage selected as the best natural gas storage method at high capacities.*

Keywords: *Natural Gas Storage, Net Present Value, TOPSIS Method*

1. Introduction

Natural Gas consists of methane, ethane and propane. It is colorless, tasteless and odorless in its pure form and one of the cleanest, safest and most useful of all energy sources. (Atoyebi, 2010)

Nowadays the importance of natural gas is rapidly growing as one of the main energy sources and feedstock for petrochemical industries. With the recent rapid growth in the

* **Corresponding Author Address:** Department of Petroleum Engineering, Amirkabir University of Technology, No. 424, Hafez Avenue, Tehran, Iran
Authors' Email Address: [1]{khamehchi@aut.ac.ir}, [2]{s.hamidreza.yousefi@gmail.com}, [3]{alirezasanaei.aut@gmail.com}

necessity of energy, natural gas has had an increasing role in meeting these needs on a worldwide basis.

With the rapid growth of industries, availability of natural gas, lower costs for exploration and production, and less pollution with respect to fossil fuels. Oil is giving way to gas. The demand for natural gas in 2010 showed a 100% growth with respect to 2000. Also, the number of countries enjoying gas resources is more those having oil resources. Natural gas storage and transportation are two major problems which are of global importance. Thus, choosing the best method for Gas Storage at high capacities is a very critical decision.

Energy consumption is very rapid and there is a necessity to store a high volume of gas for the future in this paper, the methods enhancing high gas storage capacity are studied and discussed. Then they are investigated economically using the NPV function. NPV (Net Present Value) is an important economic parameter used for long-term projects in order to evaluate whether the project is economical or not. Finally the most efficient method for storing gas in high capacities is suggested by TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method considering different efficient parameters.

2. Gas storage methods

Generally, gas storage methods are categorized into two parts: surface and underground.

Underground Gas Storage (UGS) consists of depleted oil & gas reservoir storage, Aquifer storage and salt cavern storage.

Surface storage consists of Gas holder storage, Liquefied Natural Gas (LNG), Compressed Natural Gas (CNG) storage, Natural Gas Hydrate (NGH) storage, Absorbed Natural Gas (ANG) storage, Gas To Liquid (GTL) storage, Pressure Liquid Natural Gas (PLNG) Storage and pipeline capacity storage. Among the above methods, LNG and depleted reservoir are commonly used for gas storage in high capacity. NGH is also a new technique that has been suggested for high capacity gas storage. In this proposal these three methods are selected and investigated technically and economically

3. Technical investigation of gas storage

LNG, NGH and depleted reservoir storage are technically discussed in this part and the design conditions, advantages, disadvantages and operational problems of each are studied.

3.1. Underground Gas Storage

An Underground Gas Storage system can be defined as a combination of a constant supply with a variable demand for economic advantage. The whole process is comprised of injecting natural gas into the subsurface reservoir during periods that demand falls below the gas supply. When demands exceed the supply, the gas will be withdrawn from a reservoir (Soroush and Alizadeh, 2008).

The most important characteristics of an underground storage reservoir are its capacity to hold natural gas for future use, high deliverability rate, being nearest to the consumption centers, existence of structure overlain by a caprock to accumulate gas in the storage zone, sufficient depth to allow the storage to take place under pressure, no existence of fault, a porous and permeable rock beneath the caprock that permits gas to be stored and flow readily, and water below the storage zone to confine the stored gas (Khamehchi and Rashidi, 2006).

There are several volumetric measures used to quantify the fundamental characteristics of an underground storage facility and the gas contained within it. These measures are as follows. (Atoyebi, 2010):

- Total gas storage capacity is the maximum volume of gas that can be stored in an underground storage facility in accordance with its design, which comprises the physical characteristics of the reservoir, installed equipment, and operating procedures particular to the site.
- Total gas in storage is the volume of storage in the underground facility at a particular time.
- Base gas (or cushion gas) is the volume of gas intended as permanent inventory in a storage reservoir to maintain adequate pressure and deliverability rates throughout the withdrawal season.
- Working gas capacity refers to total gas storage capacity minus base gas.
- Working gas is the volume of gas in the reservoir above the level of base gas. Working gas is available to the marketplace

Below is an explanation of UGS methods. Aquifer and Salt Cavern Storage are discussed briefly, but Depleted Reservoirs are discussed in detail.

3.1.1 Aquifer storage

For storage in aquifers, the gas storage capability of the aquifer must initially be confirmed by drilling and testing wells. In an aquifer, the pressure needs to be higher than the original pressure in order to be able to inject any gas. These types of UGS are used when there are no Depleted Reservoirs. These reservoirs account for only 10-15% of the total UGS.

3.1.2 Salt cavern storage

The development of storage caverns in salt for gas storage has been a popular alternative to surface storage. Important factors for design consideration include cavern shape, cavern depth, in-situ temperatures, and gas pressure cycle (Ammer and Sames, 2000). The Salt Cavern provides very high withdrawal and injection rates. Cavern construction is costly, but the ability to perform several withdrawal and injection cycles each year reduces the cost of this project.

3.1.3 Depleted oil & gas reservoir storage

The most common type and best candidate of UGS is the storage of gas in depleted oil and gas reservoirs because of their wide availability. The first step in performing this project is the conversion of production reservoirs to storage reservoirs. Due to the capability of caprock, known geological properties of reservoir, and the existence of porous and permeable rock, wells, surface facilities, and pipeline systems, investment costs are reduced, and therefore performing the project is simpler than other types of UGS.

For further benefits, re-injecting gas is associated with an increase in pressure within the reservoir, which can also lead to a period of increased oil recovery. These reservoirs currently provide 70% of the gas storage volume. The first gas storage project in Depleted Reservoirs was made in Canada in 1915.

In order to maintain working pressures in depleted reservoirs, about 50 percent of the natural gas in the formation must be kept as cushion gas. However, since the depleted reservoirs were previously filled with natural gas and hydrocarbons, they do not require the injection of gas that will become physically unrecoverable as this is already present in the formation. This provides a further economic boost for this type of facility, particularly when the cost of gas is high. Typically, these facilities are operated on a single annual cycle; gas is injected during the off-peak summer months and withdrawn during the winter months of peak demand (Azin, 2008).

The storage facility consists of components such as: Underground reservoirs, wells, Gathering System, Compressor, Central Point Metering, Central Point Separator, Central Point Dehydrator, Transmission Line (Flanigan, 1995).

3.2. LNG storage

Liquefied natural gas or LNG is a natural gas (predominantly methane, CH_4) that has been converted temporarily to liquid form for ease of storage or transport. It is an odorless, colorless, non-toxic, non-corrosive natural gas which has been liquefied at pressures close to atmospheric pressure by cooling it to approximately -162°C (-260°F). Liquefied natural gas takes up about 1/600th the volume of natural gas in the gaseous state (Atoyebi, 2010). A typical LNG process (LNG chain) includes extracting and transporting the gas to a processing plant where it is purified by removing any condensates such as water, oil, mud, as well as other gases like CO_2 and H_2S and sometimes solids as mercury. The gas is then cooled down in stages until it is liquefied. LNG is finally stored in storage tanks. Figure 1 depicts a typical LNG chain (Coyle et al., 2003).

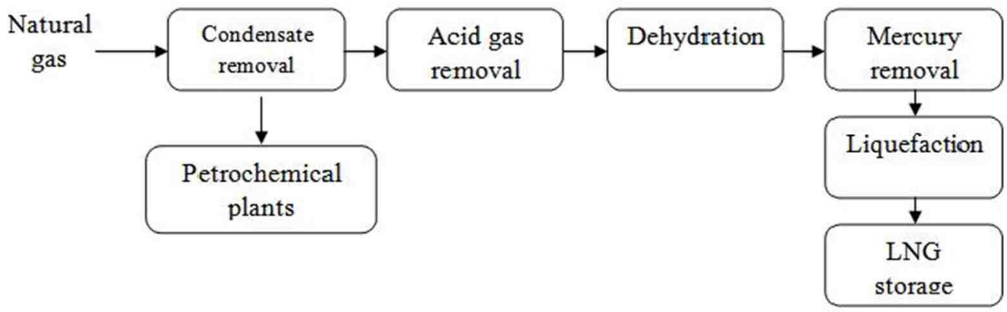

Fig. 1. A typical LNG chain

Modern LNG storage tanks are typically full containment type, which have a prestressed concrete outer wall and a high-nickel steel inner tank, with extremely efficient insulation between the walls. Large tanks are low aspect ratio (height to width) and cylindrical in design with a domed steel or concrete roof. A full containment tank may have a nominal capacity up to 160000 m^3 and a design pressure of 290 mbar (4 psig). LNG must be kept cold to remain a liquid, independent of pressure. Despite efficient insulation, there will inevitably be some heat leakage into the LNG, resulting in vaporization of the LNG. This boil-off gas acts to keep the LNG cold. The boil-off gas is typically compressed and exported as natural gas, or is liquefied and returned to storage (Atoyebi, 2010).

3.3. NGH storage

The formation of natural gas hydrates is a well-known problem in the petroleum and natural gas industries (Gudmundsson et al., 1994), but nowadays with significant development of technology NGH can be used as a novel method of natural gas storage. Natural gas hydrates are ice-like mixtures of natural gas and water in which gas molecules are trapped within the crystalline structures of frozen water. 160 to 180 volume units of gas at standard conditions can potentially be packed into 1 volume unit of gas hydrates (Godbole et al., 1988). In addition, Natural gas stored in hydrates would be inherently safer because gas is essentially encased in ice; natural gas stored in hydrates would be released slowly, in case of storage tank rupture (Rogers, 1999). In this method of gas storage, there is no need for high pressures or very low temperatures. For NGH storage at atmospheric pressure, the hydrates should be stored at a subzero temperature near equilibrium (e.g. -32°C), but achieving this temperature requires much energy and is thus costly. In the Gudmundsson NGH storage method natural gas hydrates are stored adiabatically in a well-insulated tank, and so the storage can be operated at -15°C which is more economical (Gudmundsson et al., 1994).

Figure 2 schematically depicts the NGH storage method (Javanmardi et al., 2003).

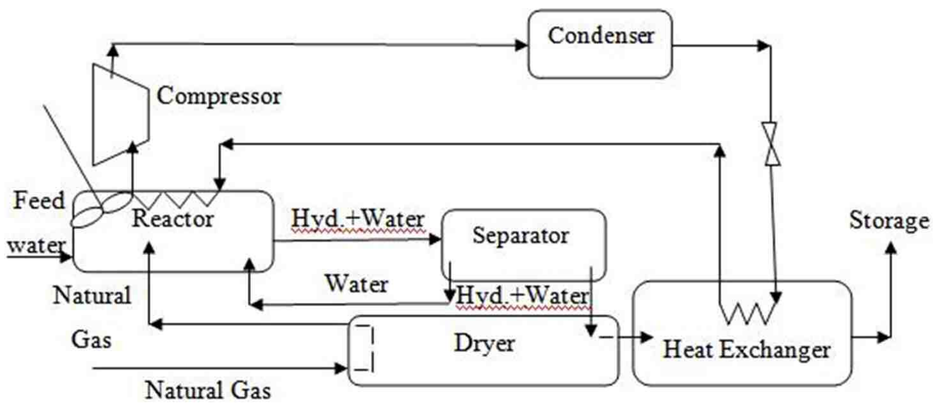

Fig. 2. Schematic NGH Production Process

4. Economical investigation of gas storage

Now the economical feasibility of the discussed gas storage methods will be evaluated by using the NPV function. NPV is one of the best parameters in evaluating the profitability of a long-term project.

4.1. NPV function

NPV is the difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyze the profitability of an investment or project. If the NPV of a prospective project is positive, it should be accepted. However, if NPV is negative, the project should probably be rejected because cash flows will also be negative. NPV can be calculated from equation 1.In this formula each cash inflow/outflow is discounted back to its present value (PV) and then they are summed. Therefore NPV is the sum of all the terms.

$$NPV = \sum_{i=0}^{t} \frac{R_t}{(1+rate)^t} \quad (1)$$

Where: t is the time of the long-term project and rate is the discount rate and R_t is the net cash flow (the amount of cash, inflow minus outflow) at time t.

In all gas storage methods the profitability begins when transportation and export of natural gas goes on. So in this paper the income of the projects is considered zero for each year, therefore the NPV number is negative, and the less absolute value of the NPV number is at a higher optimum than the other methods. Thus, the negative NPV number doesn't mean that the project is unprofitable, but rather indicates that the profitability should be considered in the future years after transportation.

4.2. Economic evaluation of gas storage using NPV

In evaluating the expenses of a project two kinds of expenses are studied. The first expense is CAPEX (Capital Expenditure) which is used by a company to acquire or upgrade physical assets such as equipment, property, or industrial buildings. The second one is the cost of operations or maintenances of a plant known as OPEX(Operational Expenditures) Consisting of insurance expenses, plant repair ,maintenance expenses, and other ongoing costs. In this study, in order to obtain the NPV value, the expenses of each of the three methods calculated separately. The discount rate is considered 10% in this study. For a more accurate comparison, gas storage capacity per year is considered equal for these three methods. Table 1 and Figure 3 indicate the calculation results for the studied gas storage methods (Coffin and Lebas , 2007;Javanmardi et al, 2003).

Table1. Comparison of storage methods with NPV

Storage method	Duration (year)	Total CAPEX (million$)	Total OPEX (million$)	Gas storage capacity per year (10^6 Cuft.)	NPV value (million$)	NPV ($) per 1Cuft.
Depleted Reservoirs	3	636.1	70.7	145000	-477	-0.0034
LNG	4	1452.2	76.4	145000	-1205	-0.0083
NGH	3	936.1	49.3	145000	-811	-0.0056

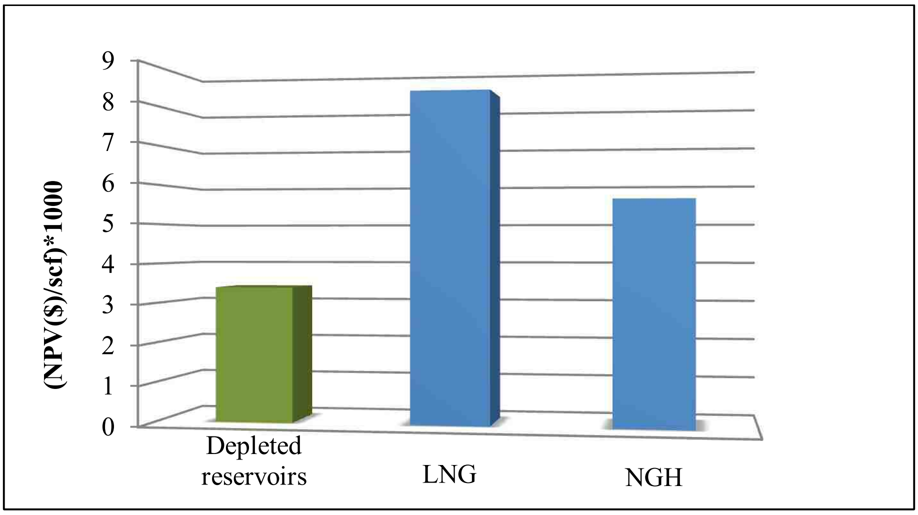

Fig. 3. Comparison of expenses for different gas storage methods

5. TOPSIS method

The MCDM (Multiple Criteria Decision Making) techniques which are used in diverse fields such as engineering, economics, management science, transportation planning and etc, are the process of finding the best option from all of the feasible alternatives. In almost all such problems the multiplicity of criteria for judging the alternatives is pervasive. That is, for many such problems, the decision maker wants to solve a MCDM problem. The structure of the alternative performance matrix is expressed as shown in Table 2:

Table 2. Structure of the alternative performance matrix

	C_1	C_2	…	C_n
A_1	x_{11}	x_{12}	…	x_{1n}
A_2	x_{21}	x_{22}	…	x_{2n}
⋮	⋮	⋮	⋮	⋮
A_m	x_{m1}	x_{m2}	…	x_{mn}
W	W_1	W_2	…	W_n

Where A_1, A_2, ..., A_m are possible alternatives among which decision makers have to choose, C_1,C_2,...,C_m are criteria with which alternative performance are measured, x_{ij} is the rating of alternative A_i with respect to criterion C_j and Wj is the weight of criterion C_j . Although the importance of the weights can be defined directly, they can be obtained by pairwise comparisons. If the assessments of the weights are in pairwise comparisons, the importance of the weights can be determined by different methods such as the eigenvector method, weighted least square method, entropy method, AHP, and LINMAP. In this study entropy method is used to obtain the weight of criterion.

In this study TOPSIS method is employed for choosing the best gas storage method. TOPSIS method is a popular approach to MCDM problem which was first developed by Hwang and Yoon (Hwang and Yoon, 1981).It is based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. The procedure in this method is summarized as below:

1. Calculation of normalized decision matrix: The normalized value n_{ij} is calculated as shown in equation below:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, i = 1,...,m, j = 1,...,n \qquad (2)$$

2. Using normalized matrix N and weight W_j , the weight matrix V can be constructed as:

$$v_{ij} = n_{ij} w_{ij}, i = 1,...,m, j = 1,...,n \qquad (3)$$

3. Determination of the positive ideal and negative ideal solution:

$$A^{+} = \{v_1^{+},...,v_n^{+}\} = \left\{\left(\max_i v_{ij}, j \in J\right), \left(\min_i v_{ij}, j \in I\right)\right\}$$
$$A^{-} = \{v_1^{-},...,v_n^{-}\} = \left\{\left(\min_i v_{ij}, j \in J\right), \left(\max_i v_{ij}, j \in I\right)\right\} \qquad (4)$$

4. Calculation of the separation of each alternative from the positive ideal (d^+) and negative ideal (d^-) solution measures:

$$d_i^{+} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{+}\right)^2}, i = 1,...,m$$
$$d_i^{-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{-}\right)^2}, i = 1,...,m \qquad (5)$$

5. Calculation of the relative closeness to the ideal solution:

$$CL_i^{*} = \frac{d_i^{-}}{d_i^{-} + d_i^{+}} \qquad (6)$$

6. Ranking the alternatives: the nearest CL^* to 1 shows the highest priority among different alternatives. (Lotfi et al., 2011;Momeni, 2006)

5.1. TOPSIS method for gas storage selection

Table 3 below indicates the structure of the matrix for selecting the best gas storage methods. In this matrix different criteria such as NPV function, safety factor, storage capacity, environmental effect and deliverability rate are considered. The ranking value range is from 0 to 10 which increase from poor to the best. For instance, in the NPV parameter, storage in depleted reservoirs has the least expenses in comparison to the two others and thus has the highest rank. NGH storage is safer with respect to the other mentioned methods since gas is encased in ice crystalline, LNG is in liquid form and safer than UGS which is in gas form. For the evaluation of storage capacity, it is obvious that UGS has a high rank since the reservoir has a large volume; however LNG and NGH tank storage have much less capacity as compared to UGS. While taking into account the environmental considerations, the cleaner one has a higher rank. Since there is no change in natural gas form in UGS, its deliverability is higher; while both in LNG and NGH, the natural gas must initially be regasified for consumption.

Table 3. Comparison of storage methods by MCDM

Criterion / Alternative	NPV	Safety	Storage Capacity	Environmental Effects	Deliverability
UGS	9	3	9	5	9
NGH	7	7	5	5	5
LNG	3	5	7	3	5

After calculating the mentioned parameters in the TOPSIS procedure and calculating the relative closeness to the ideal solution the UGS method had the nearest CL^* to 1 and selected as the best alternative. Table 4 shows the final CL^* values for three mentioned alternatives:

Table 4. Final Ranking

Alternative	UGS	NGH	LNG
CL^*	0.988	0.537	0.196

6. Conclusion

Natural gas is an important energy resource and one of the most important feed of different industries, so with the growth in its consumption, there are more requirements for natural gas storage. In this study, three different storage methods are assessed from technical and economical aspects. Among these methods, depleted reservoir storage has a very high capacity and is less costly with respect to the other methods. In LNG storage, the gas volume becomes 600 times less than its standard condition and has a relatively high capacity, but this method requires very low temperatures. In gas hydrates storage, there is no need for high pressures or very low temperatures, but its capacity is less than the others and the gas volume becomes 160 times less. Also NPV calculations show that depleted reservoirs have the lowest CAPEX and OPEX among the others. With respect to the mentioned technical features and NPV calculations and the comparison results acquired by MCDM (TOPSIS method), finally storage in depleted reservoirs is chosen as the best gas storage method.

References

Ammer, J., & Sames, G. (2000, October). Advances for improved storage: Deliverability enhancement and new storage facilities. In *SPE Eastern Regional Meeting*.

Atoyebi, T. (2010, July). The preferred natural gas conservation option: Underground storage of natural gas. In *Nigeria Annual International Conference and Exhibition*.

Azin, R., Nasiri, A., Entezari, A., & Montazeri, GH. (2008, June). Investigation of underground gas storage in a partially depleted gas reservoir. In *Canada SPE Gas Technology Symposium.*

Coffin, P., & Lebas, G. (2007, December). Converting the pecorade oil field into an underground gas storage. In *International Petroleum Technology Conference*.

Coyle, D., Durr, C., Shah, P., & Brown, K. (2003, October). LNG: A proven stranded gas monetization option. In *Colorado SPE Annual technical Conference and Exhibition.*

Flanigan, O. (1995). *Underground gas storage facilities: Design and implementation*. Gulf Professional Publishing.

Godbole, S. P., Kamath, V. A., & Ehlig-Economides, C. (1988). Natural gas hydrates in the Alaskan Arctic. *SPE formation evaluation*, 3(1), 263-266.

Gudmundsson, J. S., Parlaktuna, M., & Khokhar, A. A. (1994). Storage of natural gas as frozen hydrate. *Old Production & Facilities*, 9(1), 69-73.

Hwang, C. L., & Yoon, K. (1981). *Multiple attribute decision making*. Berlin: Springer.

Javanmardi, J., Nasrifar, K., Najibi, S. H., & Moshfeghian, M. (2003, February). Natural gas hydrate, an alternative for transportation of natural gas. In*Proceeding of the 12th International Oil, Gas and Petrochemical Congress*, Tehran, Iran (pp. 24-26).

Khamehchi, E., & Rashidi, F. (2006, May). *Simulation of underground natural gas storage in Sarajeh Gas Field*. Iran: In SPE Technical Symposium of Saudi Arabia Section.

Lotfi, F. H., Fallahnejad, R., & Navidi, N. (2011). Ranking efficient units in DEA by using TOPSIS method. *Applied Mathematical Sciences*, *5*(17), 805-815.

Momeni, M. (2006). *New topics in operations research.* Tehran: Management School Publications.

Rogers, R.E. (1999). Natural gas hydrates storage project, phase II. Conceptual design and economic study, Final report. DOE Contract DE-AC26-97FT33203, U.S. Department of Energy.

Soroush, M., & Alizadeh, N. (2008). Underground gas storage in a partially depleted gas reservoir. *Journal of Canadian Petroleum Technology*, 47(2).