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Economical Evaluation of Different Methods of Underground Storage of Natural Gas

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Abstract

Gas storage is principally used to meet load variations. Gas injected into storage during periods of low demand and withdrawn from storage during periods of peak demand. It is also used for a variety of secondary purposes, including: Balancing the flow in pipeline systems, maintaining contractual balance, Leveling production over periods of fluctuating demand, Market speculation, Insuring against any unforeseen accidents, Reducing price volatility and Offsetting changes in natural gas demands. Gas storage facilities are gaining more importance due to changes in natural gas demands. First, traditional supplies that once met the winter peak demand are now unable to keep pace. Second, there is a growing summer peak demand on natural gas, due to electric generation via gas fired power plants.The most important type of gas storage is in underground reservoirs. There are three principal types — depleted gas reservoirs, aquifer reservoirs and salt cavern reservoirs. Each of these types possesses distinct physical and economic characteristics which govern the suitability of a particular type of storage type for a given application. At this study, according to the economic appraisal of Underground gas Storage Methods, regard to low investment cost also lower Cushion Gas necessary in Depleted Oil and Gas Reservoirs, this reservoirs are more economical. Although Aquifer and Caverns Salt too, (regard to investment costs) are economical.

Keywords: Economic appraisal, natural gas, storage, depleted reservoirs, aquifer, caverns salt.

Introduction

At present, due to the increase of the uncertainty factors, investment in gas storage has had a significant impact on investors' behavior. Moreover, the increase in the costs of this sector has discouraged the investors. On the other hand, since at present the increase in the flexibility of natural gas supply is one of the requirements of the market, the storage of natural gas has been significantly increased in the recent decades. But the type of storage tanks and their installations are very important factors in the amount of investments. Also, since the gas storage tanks has a different engineering and geological conditions, therefore this matter also will have a crucial influence on the costs of investment on such projects.

Literature Review

In this part of article we are going to examine briefly the indoor studies in the field of underground storage of natural gas.Reza Azin researcher of the department of chemistry, Persian Gulf University, in an article has studies "the natural gas storage in depleted tanks of underground oil and gas" in 1388. In this article the storage of natural gas in underground tanks has been discussed and assessed technically. Also after introducing the suitable options for gas storage, technical and practical problems of storage in depleted oil and gas tanks have been discussed. At the end of the article, storage projects in Iran have been briefly introduced[1].

Maliheh Dolatabadi, Ahmad Ramazanzadeh and Seyed Mohammad Ismail in a study have examined the concepts of underground storage of compressed natural gas in coated in rocky caves which has been published in the Journal of Oil, Gas and Energy, First Year, No. 5. In this article the compressed natural gas storage in coated rocky caves have been introduced as one of the modern methods of underground storage and the basic concepts of designing this kind of cavern have expressed from a technical perspective.

Hussein Ahani and Meysam Rajabi in a paper have examined the necessity of underground storage of natural gas in South Khorasan province. The purpose of this article is to investigate the necessity of establishing tanks in South Khorasan Province. For this purpose we have examined the major use of natural gas of province in the past few years and the way of its consumption in different months of year for consumers have been studied. Based on the investigations carried out the existence underground gas tanks can be alternative option and yet economical for gas supply in the cold months of year.

Mohammad Selsebili, Dr.Abbas Behroodi and Dr.Shahram Sherkati in a study have investigated "the feasibility of methods of natural gas storage in the north area of central Iran". In this article, the north section of central Iran has been examined geologically and various methods of natural gas storage have been compared together. Finally, gas storage in salt caves (according to conditions of space and time) has been recognized as the most appropriate method[2].

There has been a study entitled "the natural gas underground storage in order to preserve oil tanks" done by Azamolsadat Toosi in 1383, the expert of planning long-term management integrated programming of national oil company. Seasonal changes in natural gas consumption are mainly related to domestic – commercial sector. Since the peak of consumption of natural gas by domestic sector is at 4 cold months of year, therefore designing refining and transportation system according to seasonal needs will cause huge capital loss. It will also lead to a shortage of natural gas to meet the demands of other sectors' consumers of natural gas. Natural gas injection is one of the cases which are affected by seasonal changes of consumption in domestic-commercial sector. Injection of natural gas to oil tanks is done in order to preserve these tanks and increase the recovery of crude oil and the failure to meet these requirements, will be impose irreparable damages on the country's economy. The underground storage of natural gas in parts which are closer to the consumption points is one of the ways that can be useful in this regard. In this study in addition to a brief review of the technical and economic basis and principles of underground storage of natural gas, the results of applying this method in the balance of supply and demand in the eight hot months and four cold months of the year have been examined and solutions for long-term optimizing of supply system of country will be presented[3].

Furthermore, a study was conducted by Meysam Rajabi and Ehsan Esmail in the field of "underground storage of natural gas in underground aquifers" in 1389. In this paper, first the issues related to the underground storage of natural gas are examined and then we are going to study the considerations necessary for storage in aquifers, such as the location and type of cap rock, reservoir pressure, porosity and permeability of reservoir rock and its potential[4].

Theoretical Bases of Economic Evaluation of the Plans

It has always been a subject of controversy that whether a particular project is economical or not. Considering that is the proposed economic plan beneficial or detrimental? Since the interest rate in the economy is considered as a variable, in the economical evaluation, the question is that at what interest rate of a project is profitable and at what interest rate it is detrimental?

In each project that typically consists of two parts of costs and incomes, by estimating different measures we can realize their profitability and in the first stage of decision making (with regard to related assumptions) estimates are compared with intended minimums and then the decision is made to perform or not to perform the desired project.

For the economical evaluation of a project there are three main methods which are: Payback, Net Present Value, Internal Rate of Return

Each of the above mentioned methods is suitable for use in certain conditions. In the discussion of economical evaluation of projects two general views are considered. The first view is that whether the proposed scheme is profitable or not profitable. In this view, in the evaluation process it should be made clear that in the special economical circumstances the implementation of project will result in a profit or not.The second view is to sort some of economic plans according to their profitability.

In this view by using evaluation methods we should determine the most profitable project among two or more proposed projects and put it in the first priority and the among the remained projects we should determine the most profitable and put it in the second priority and we should continue this process until the end of projects[5].

The Method of Payback

In this method, the payback is placed as criteria for evaluating projects and if a project returns the initial investment in shorter time it will be more attractive. Thus if the project, returns the investment in a time period over the time required by the investor, then that project is considered unacceptable and the project that returns the investment in an equal or shorter period of the required time will be considered acceptable.

To do this, we first set up a table in order to determine the cumulative income of each project from the first year until the end year. Then in the column of cumulative income the project that returns the initial investment in less time the will be the priority of selection[6].

The Method of Net Present Value

In this method first all future incomes with an appropriate discount rate are converted to equivalent of incomes at the onset of the project and then the initial investment and the required operating costs of project will be deducted. The obtained number will be known as indicator of NPV in comparisons. The following equation is proposed for this purpose.

$$NPV = \sum_{I=1}^{N} Pi - I$$

NPV: Net Present Value, Pi: Present Equivalent of net income in i period (i month or i year), I: Amount of investment in the present, N: Number of periods (months or years) the useful life of the project, In above relation the amount of Pi is calculated as follows:

$$Pi = \frac{Fi}{(1+K)^{ni}}$$

In which:, Fi: Earned net income in i period, K: Discount rate (which in many cases is the market interest rate) in each period.

N: Time (number time periods from the present time) of income in i period, Therefore, the above relations can be written as:

$$NPV = (\sum_{I=1}^{N} \frac{Fi}{(1+K)^{ni}}) - I$$

In this method of evaluation if the amount of NPV is a positive number then that project is considered acceptable and profitable and if the amount of NPV is a negative number then that project is unacceptable and detrimental[7].

In the above relation K is the discount rate per period (e.g. per year) and n is the number of time periods (e.g. years) after the initial investment which in this date the income of F is gained, but in many projects income is gained gradually and over the year. In such cases the value of the incomes earned during the year should be converted to their equivalents at the beginning of each year and then be used as F in above relations.

Internal Rate of Return Method: In this method we are looking for interest rates that when by using those interest rates we discount future incomes to the first time of project (investment time) then the discounted income should be equivalent with the amount of investment. This interest rate is called the internal rate of return[8].

Based on the assessment of this method, if the internal rate of return of a plan is greater than the investment interest rate, then project is considered profitable and if it is less, then the project will be evaluated as detrimental.

For determining the internal rate of return of a project with an initial capital I and N investment return of the F1 to FN we do as follows:

Equivalent value of N incomes of Fn (which N….n = 1, 2, 3) with r the interest rate at the onset of project is:

$$P = \sum_{I=1}^{N} F_N (1+r)^{-n}$$

And if we use l to show the spent investment of the plan at the start of project, the project's internal rate of return (r) is obtained by solving the following equation:

$$f(r) = (\sum_{I=1}^{N} F_N (1+r)^{-n}) - I, f(r) = 0$$

Above equation is a non-linear equation which can easily be solved by numerical methods and project's internal rate of return is calculated.

Important Factors in Installations for the Storage of Natural Gas

Important factors are involved in the structure of natural gas storage tanks. One of these factors is the maximum gas that can be placed in the storage tank which is called "total storage capacity". This gas volume consists of recoverable gas and base gas (gas that remains in the tank). Base or Koshin gas is the volume of gas that remains in permanent form in storage installations. In fact Koshin gas is a gas that cannot be recovered from the tank, but the recovery rate and gas recovery from the reservoir depends on it.

When the volume of gas is more than amount of base gas we call it recoverable gas which is injected into storage tanks and then it is recovered. The level of ability to recover from a tank is referred to the gas volume that can be recovered in a day from tank. In contrast, the "injection rate" refers to the amount of gas that can be injected into a gas storage tank in a day. Injection and recovery of gas has a direct relationship with the total volume of gas in the tank and in fact it will have a significant effect on the gas pressure in the tank[9].

When the volume of gas stored in a tank increases the capacity of the gas recovery from the tank also increases. All the mentioned factors are never constant in a tank and the rate of recovery and gas injection in the tank change with the gas volume of it. Moreover, the volume of Koshin gas and recoverable gas and also total storage capacity will vary according to changes in equipment and operational factors.

There are two important factors in the natural gas storage facilities[10].

The amount of recovered gas in a day to cover the critical factors created in the gas supply system and other factor is the amount of recovered to compensate seasonal variations of natural gas.

Gas storage tanks are usually a variety of salt cavities layers, aquifers and depleted oil and gas reservoirs (gas storage tanks) and they are different due to the geological characteristics so this matter leads to differences in their use and development costs.Freshwater is injected into cavities of salt layer until the salt of layers is dissolved in water and then it removed from the tank. These types of tanks are limited by the size of the salt dome and its geological conditions. Compared with depleted oil and gas reservoirs for storage, salt layer cavities have a higher investment costs for recoverable gas. In other words, the storage capacity of these tanks is significantly lower as compared to other tanks so the costs of construction of a salt storage is higher than investment costs in oil and gas tanks and it is less than investment costs in underground water aquifers. In addition, approximately 20-30% of the total capacity of the tanks in the reservoir of cavities of salt layer is constituted by the base gas and remaining by recoverable gas. Salt dome tanks also have

greater ability in recovering and injecting gas daily and due to strategic reasons they are very important; Because at the time of crisis hold a high degree of reliance. The possibility of injection and recovery from these tanks is 10 to 12 times a year and mostly they are used during peak in essential and critical times.Another type of tanks of underground storage of natural gas is aquifer tanks or aquifers. These tanks consist of permeable rock that contains water in itself. Aquifer tanks have high construction costs and further the amount of gas accumulation or gas volume that must be used as a base gas in a tank to make it possible to recover the gas is very high; In such a way that they have stated that the base gas of these tanks is about 60 to 80 percent of total volume of gas in the tank. In addition there is no possibility to inject and recover gas from aquifer tanks more than one or two times in a year[11].

High risks of geology and high construction costs of these tanks have caused the gradual growth and development of installations of underground storage in such tanks and the number of these tanks when compared to other tanks is placed in lower levels.

The most common storage tanks that already exist in the world is the depleted oil and gas tanks that is used for storage of oil and gas production. Depleted oil and gas reservoirs conversion to a gas storage tanks has a lot of advantages that one of the most important of them is that the tank's structure is recognizable. Since previously the tank was used for oil and gas production it has been proven that tank has a high reliability for gas storage. In addition, installations and pipelines are located near the tank. Investment costs for depleted oil and gas tanks are not high in comparison to other tanks.

Table-1
Assumptions of the Economical Construction of Storage Tanks

	Assumptions of Study
1391	Base year
4 years(1392-1395)	Construction period
25 years(1396-1420)	Period of operation
25 percent	Payback Rate
20 percent	Inflation rate
12260 rials per dollar	Exchange rate
3 percent	Rate of increase in prices of products of gas oil
10 percent	Rate of increase in natural gas prices
1000 BTU Per cubic foot	Heating value of natural gas
5/736 BTU million per barrel	Heating value of gas oil
121 dollars per barrel (the average of March to August 2012)	Gas oil price
5% of investment costs	Operating costs

In some reports and scientific papers the amount of base gas or accumulated gas for these tanks is predicted about 50 to 60 percent of the total volume of gas in the tank. While in the October 2011 publication of pipelines and gas the amount of base gas was reported to be very little and this was because of existence of oil and gas in depleted tanks. On the other hand some of depleted oil and gas tanks have a high capacity to recover gas during the peak times.

Economical Analysis of the Construction of Storage Tanks

According to the issues mentioned above the economical analysis of the construction of storage tanks of depleted oil and gas, aquifers and salt domes have been carried out according to the economic assumptions of table-1.

Investment Costs for the Construction of Storage Tanks: Based on the Pipeline and Gas Journal (October 2011) investment costs for depleted storage tanks, aquifers and salt domes are described in table-2.

Table -2
Cost of investment in the construction of storage tanks - Million Dollars

Salt Dome Tanks	**Aquifer Tanks**	**Depleted tanks of oil and gas**	**Tank Type**
9/10	2/17	6/8	Investment costs (per million cubic feet)

Source: Pipeline and Gas Journal (October 2011)

Including the mentioned costs as the construction costs of the storage tank, cost of injection and recovery of gas for each cubic meter of depleted oil and gas reservoirs is 3/0 dollars, injections and recovery from the aquifer reservoir is 61/0 dollars per cubic meter of gas and injection and recovery from salt domes for each cubic meter of gas costs 39 /0 dollars. Since the amount of base gas is very effective in the economical analysis, hence the amount of base gas stored in depleted oil and gas reservoirs has been mentioned 10 percent, 70 percent in aquifer tanks and 25% in salt domes.

In other words, the amount of injected gas in the first year should be higher than the amount of base gas in the tanks which were mentioned above. For example, if we want the amount of gas we recover from the reservoir be 500 million cubic meters per year, when the reservoir is that of the depleted oil and gas tank the amount of injected gas must be 550 million cubic meters in the first year that the remaining 50 million cubic meters should remain in the tank and 500 million cubic meters should be recovered. Injected gas will be the same as 500 million cubic meters after the second year. Construction schedule for each of the three types of tank are same for better

comparison, in a way that it is assumed that in the first year (1392) 20 percent, 30 percent in the second year,30 percent in the third year and in fourth year 20 percent of the project should be constructed.

Operating costs for construction of storage tanks is 5% of the investment costs and the rate of annual increase in costs have been considered with regard to the inflation of 15%.

Since the construction of storage tanks are done to supply the gas for winter or crisis, it is assumed that gas must be injected to the tanks during the 8 hot months of the year and at 4 cold months when there is the shortage of gas in the country, gas can be recovered from the tank and be consumed.

The current situation of gas production and consumption in Iran shows that the gas consumption in residential and commercial industry and also during summer and winter is supplied with no problems, however, the country's power stations' consumption, because of gas supply of the residential and commercial sectors which are of higher priority, in many cases are faced with many problems and in many cases the power stations are forced to use liquid fuel instead of gas.Hence in current economical evaluation it is assumed that the recovered gas must be assigned for the use of power stations and instead of using liquid fuels which is mostly gas oil, it must be released and exported. Gas oil prices have been assigned on the basis of gas oil prices of Persian Gulf FOB (average price for March to August 2012) 121 dollars per barrel.Therefore potential revenue obtained from the release of the fuel of power station by taking into account the capacity of recoverable gas has been considered as the revenues and the costs of the project include construction costs of the tanks, operational costs and the cost of gas supply[12].

The cost of providing gas is assigned according to the current price of gas in the country which is 700 rials per cubic meter. By taking into account that government intends to make the domestic price of gas and its production closer to world prices the growth rate has been assigned 10 percent for each year[13].

Conclusion

Based on the mentioned assumptions in pervious section and costs of investment in depleted oil and gas reservoirs, aquifers, and salt domes and counting gas prices at $ 121 a barrel and natural gas 700 rials per cubic meter ,the economic analysis for the above tanks is described in table 3.

The results of Economical analysis for the construction of tanks show that by considering the existing reservoir construction costs and their benefits, implementation of the project is economical in each of three states. In other words, given that the benefits of release and export of gas oil is higher than construction costs of storage tanks (all three types),project is economically feasible, although the benefits of constructing a storage reservoir like depleted oil and gas reservoirs are more economical.

It should be noted that the above economical evaluation assume the capacity of tank 500 million cubic meters and changes in the capacity of tank can cause other results. In other words, an economic evaluation is done according to assumptions listed in the previous section and changes in any of these assumptions could affect the project economics and it can make the project uneconomic.

Since the cost of investment and operation costs are based on tank capacity, the results of the economic analysis shows that no matter how much storage capacity is less (or more) the investment costs for tanks will be less (or more) and as a result present value of the project will change however the project will still be economically feasible.

According to reservoir capacity of 500 million cubic meters, until the investment costs for depleted oil and gas tanks is increase 447 million dollars, 401 million dollars in aquifers and 436 million salt dome tanks, the project is economically feasible, but when the costs rises more than these amounts the project will not be justifiable. In other words, the above figures wreck the investment costs for a tank with a capacity of 500 million cubic meters. Although studies have indicated that the construction of storage tanks considering the mentioned costs are economic, but it should be noted that in the discussion of natural gas storage the economical aspect of the project is not the only issue. In many countries the cost of reservoir construction is very high and also these countries provide the required gas for injection through imports with international rates but they have constructed natural gas storage tanks strategically.

The discussion of the storage of natural gas in our country should not only be related to economic factors, because the increase of gas consumption and in other words the peak of gas consumption occur in winter and considering that some of gas consumption of northern provinces of country is imported and considering that the consumption of gas in our country and Turkmenistan increases in the winter and this country reduces its exports to Iran in the crisis and peak of cold, the attention must be paid to the issue of natural gas storage to prevent critical pressure of gas consumption, such as what occurred in the winter of 86.

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Table- 3
Results of Economic Analysis - Million Dollars

Salt Dome Reservoir	Aquifer Reservoir	Depleted Oil and Gas Reservoirs	
174	274	137	Present value of the fixed investment cost of the project
81	127	64	Present value of the project's operating costs
127	173	112	Cost of providing gas
382	574	313	Present value of the total costs of project
704	704	704	Present value of project revenues
322	130	391	Net Present Value (NPV)
54%	35%	65%	Internal Rate of Return (IRR)
1 year	3years	1 year	Payback period

Source: Calculations of researcher

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