ISSN-L: 2223-9553, ISSN: 2223-9944
Vol. 4 No. 3 May 2013

# THE NEW SYSTEM EQUATION FOR DETERMINING THE QUANTITY OF GAS LOSS FROM AN UNDERGROUND NATURAL GAS STORAGE SYSTEM

**Muonagor Chukwuemeka Michael** [1], **Anyadiegwu Charley Iyke** [2]

Petroleum Engineering Department, Federal University of Technology,
Owerri, NIGERIA.

[1] tissadeking@yahoo.com, [2] drcicanyadiegwu@yahoo.com

## ABSTRACT

*The determination of quantity of gas loss from an underground natural gas storage system was presented. A system equation was propounded for the determination of the quantity of gas loss from an underground gas storage system. The variable parameters that the equation considered were the initial and final pressures, initial and final temperatures and initial and final compressibility factors of the storage gas while the constant was 35.3021 which is a factor for relating the pressure, temperature and compressibility factor of the gas at standard conditions. A Microsoft visual basic program was also developed based on the equation which can determine the quantity of gas loss from an underground natural gas storage system.*

**Keywords:** System, quantity, gas, loss, reservoir, aquifer, salt, cavern, pore, volume, underground, equation, storage, pressure, temperature, compressibility, factor

## INTRODUCTION

Underground natural gas storage fields grew in popularity shortly after World War II. At the time, the natural gas industry noted that seasonal demand increases could not feasibly be met by pipeline delivery alone. In order to meet seasonal demand increases, the deliverability of pipelines (and thus their size), would have to increase dramatically. However, the technology required to construct such large pipelines to consuming regions was, at the time, unattainable and unfeasible. In order to be able to meet seasonal demand increases, underground storage fields were the only option. There are three main types of underground natural gas storage facilities via depleted reservoirs, aquifers, and salt formations.

### Depleted Reservoirs

These are the most prominent and common form of underground storage. They are the reservoir formations of natural gas fields that have produced all their economically recoverable gas. The depleted reservoir formation is readily capable of holding injected natural gas. Using such a facility is economically attractive because it allows the re-use, with suitable modification, of the extraction and distribution infrastructure remaining from the productive life of the gas field which reduces the start-up costs. Depleted reservoirs are also attractive because their geological and physical characteristics have already been studied by geologists and petroleum engineers and are usually well known. Consequently, depleted reservoirs are generally the cheapest and easiest to develop, operate, and maintain of the three types of underground storage.

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 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.

A number of factors determine whether or not a depleted gas field will make an economically viable storage facility. Geographically, depleted reservoirs should be relatively close to gas markets and to transportation infrastructure (pipelines and distribution systems) which will connect them to that market. Since the fields were at one time productive and connected to infrastructure distance from market is the dominant geographical factor. Geologically, it is preferred that depleted reservoir formations have high porosity and permeability. The porosity of the formation is one of the factors that determines the amount of natural gas the reservoir is able to hold. Permeability is a measure of the rate at which natural gas flows through the formation and ultimately determines the rate of injection and withdrawal of gas from storage.

**Aquifers**

Aquifers are underground, porous and permeable rock formations that act as natural water reservoirs. In some cases they can be used for natural gas storage. Usually these facilities are operated on a single annual cycle as with depleted reservoirs. The geological and physical characteristics of aquifer formation are not known ahead of time and a significant investment has to go into investigating these and evaluating the aquifer's suitability for natural gas storage.

If the aquifer is suitable, all of the associated infrastructure must be developed from scratch, increasing the development costs compared to depleted reservoirs. This includes installation of wells, extraction equipment, pipelines, dehydration facilities, and possibly compression equipment. Since the aquifer initially contains water there is little or no naturally occurring gas in the formation and of the gas injected some will be physically unrecoverable. As a result, aquifer storage typically requires significantly more cushion gas than depleted reservoirs; up to 80% of the total gas volume. Most aquifer storage facilities were developed when the price of natural gas was low, meaning this cushion gas was inexpensive to sacrifice. With rising gas prices aquifer storage becomes more expensive to develop. A consequence of the above factors is that developing an aquifer storage facility is usually time consuming and expensive. Aquifers are generally the least desirable and most expensive type of natural gas storage facility.

**Salt formations**

Underground salt formations are well suited to natural gas storage. Salt caverns allow very little of the injected natural gas to escape from storage unless specifically extracted. The walls of a salt cavern are strong and impervious to gas over the lifespan of the storage facility.

Once a suitable salt feature is discovered and found to be suitable for the development of a gas storage facility a cavern is created within the salt feature. This is done by the process of cavern leaching. Fresh water is pumped down a borehole into the salt. Some of the salt is dissolved leaving a void and the water, now saline, is pumped back to the surface. The process continues until the cavern is the desired size. Once created, a salt cavern offers an underground natural gas storage vessel with very high deliverability. Cushion gas requirements are low, typically about 33 percent of total gas capacity.

Salt caverns are usually much smaller than depleted gas reservoir and aquifer storage facilities. A salt cavern facility may occupy only one one-hundredth of the area taken up by a

ISSN-L: 2223-9553, ISSN: 2223-9944
Vol. 4 No. 3 May 2013

depleted gas reservoir facility. Consequently, salt caverns cannot hold the large volumes of gas necessary to meet base load storage requirements. Deliverability from salt caverns is, however, much higher than for either aquifers or depleted reservoirs. This allows the gas stored in a salt cavern to be withdrawn and replenished more readily and quickly. This quick cycle-time is useful in emergency situations or during short periods of unexpected demand surges.

According to Katz and Tek (1981), the most essential features of the underground storage salt formation are:

a. Storage capacity (verification of inventory)
b. Storage retention against migration and determination of the amount of leakage
c. Assurance of deliverability

In this work, the particular characteristic of an underground storage system taken into consideration is Storage Retention against Migration and Determination of Quantity of Gas Loss. Quantity of Gas Loss in this context refers to the amount of gas that escapes the storage system at a given pressure drop as a result of an unconformity in the storage system wall.

According to Glenn et al., (1979), if known volumes of injected storage gas per psi do not reproduce the historical pattern of injection and withdrawal pressures with time, the storage reservoir is therefore not functioning properly and there might be leakage.

In depleted oil or gas reservoir storage or in aquifer storage the presence of a suitable cap rock is of paramount importance for the retention of natural gas within the structural boundaries of the reservoir. The cap rock that constitutes the overburden to a natural petroleum reservoir obviously does possess proved integrity to retain the gas at least up to discovery pressure (Tek et al., 1966).

There had been methods and models for the determination of quantity of gas loss from an underground gas storage system, but most of them only consider quantity of gas loss at pressure drop without taking the corresponding temperature change into consideration.

The New System Equation propounded in this work is used to estimate the quantity of gas loss from an underground gas storage system at both pressure drop and temperature change since it is natural that the temperature of the gas in the system could change over time.

## THEORY

In developing the system equation for determining the quantity of gas loss from a gas storage system, several parameters are taken into consideration, which include:

1. Pressures of the system before and after the gas loss
2. Temperatures of the system before and after the gas loss
3. Compressibility factors of the gas in the storage system before and after the gas loss
4. Volume of the storage system
5. The pressure, temperature and z-factor at standard conditions which are14.73psia, $520^0$R and 1 respectively.

From General Gas Law:

$$P_{sc}V_{sc}/(T_{sc}Z_{sc}) = PV/(TZ) \qquad \ldots\ldots 1$$

Where $P_{sc}$ = Pressure at Standard Conditions, 14.73 psia

$V_{sc}$ = Volume of Gas at Standard Conditions

$T_{sc}$ = Temperature at Standard Conditions, $520^0R$

$Z_{sc}$ = Compressibility Factor at Standard Conditions, 1

The Volume of Gas in storage at any given time can be expressed as:

$V_{sc} = (T_{sc}Z_{sc}/P_{sc}) * PV/(TZ)$ ............................................... 2

$V_{sc} = 35.3021 * V * P/(TZ)$ ............................................... 3

The decrease in the volume of gas in storage is the difference in the volume of gas in storage at 2 different times ie at $P_1$, $T_1$, $Z_1$ and $P_2$, $T_2$, $Z_2$ respectively. This difference in the volume is termed the quantity of gas loss from the storage system. The equation for determining the quantity of gas loss from the gas storage system is given below:

$G = [35.3021 * V * (P_1/(T_1Z_1)] – [35.3021 * V * (P_2/(T_2Z_2))]$......... 4

$G = 35.3021 * V * [(P_1/(T_1Z_1)) – (P_2/(T_2Z_2))]$........................... 5

Where;

G = Estimated Quantity of Gas Loss, scf

$P_1$ = Initial Pressure of the Storage System, psia

$T_1$ = Initial Temperature of the Storage System, $^0R$

$Z_1$ = Initial Compressibility Factor of the Gas in the Storage System

$P_2$ = Final Pressure of the Storage System, psia

$T_2$ = Final Temperature of the Storage System, $^0R$

$Z_2$ = Final Compressibility Factor of the Gas in the Storage System

V = Volume of the Storage System, scf

For an underground gas storage salt cavern, V is the cavern volume while for a depleted reservoir or aquifer, V is expressed as the pore volume of the reservoir or the aquifer in scf using the equation below (Muonagor and Nnakaihe, 2011):

PV = 43560 * Formation Area * Formation thickness * Porosity……6

35.3021 is a factor for Expressing the Pressure, Temperature and Compressibility Factor of the Gas in the Storage System at Standard Conditions

A Microsoft visual basic program was developed using eq 5, the equation for the determination of quantity of gas loss from an underground gas storage system. The sample of the Microsoft visual basic program is shown in Figure 1 below.

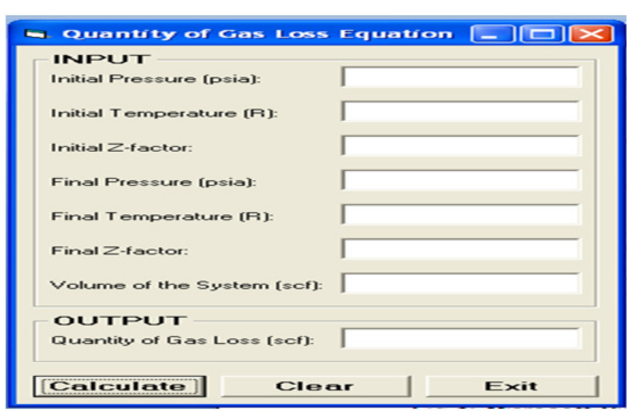


Figure 1. Microsoft Visual Basic Program for Determination of Quantity of Gas Loss from an Underground Gas Storage System

ISSN-L: 2223-9553, ISSN: 2223-9944
Vol. 4 No. 3 May 2013

## RESULT

### Case 1: Salt Cavern AD9

The storage data for the underground gas storage salt cavern is shown in Table 1 below:

**Table 1. Storage Data for Cavern AD9**

| | |
|---|---|
| Initial Cavern Pressure | 3309 psia |
| Initial Cavern Temperature | $578^0$R |
| Initial Cavern Gas Z-factor | 0.853 |
| Final Cavern Pressure | 3216 psia |
| Final Cavern Temperature | $577.4^0$R |
| Final Cavern Gas Z-factor | 0.84 |
| Cavern Volume | 18 MMscf |

The quantity of gas loss from salt cavern AD9 is estimated with eq 5 as:

$$G = 35.3021 * 18000000 * [(3309/(578*0.853)) – (3216/(577.4*0.84))]$$

$$G = 51.34 \text{ MMscf}$$

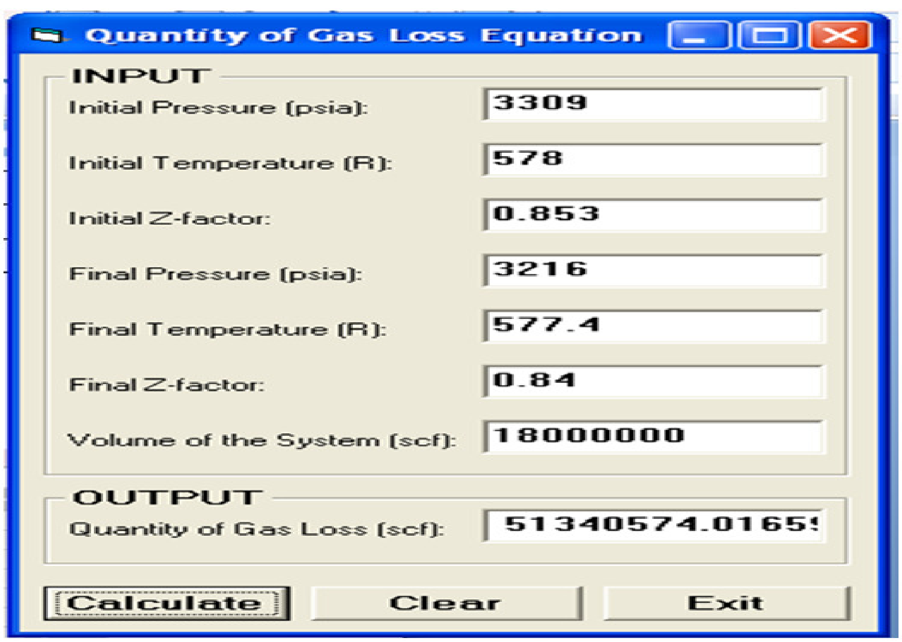


Figure 2. Microsoft Visual Basic Program for Determination of Quantity of Gas Loss from Cavern AD9

The Microsoft visual basic program for determining quantity of gas loss from salt cavern AD9 is as shown in Fig 2.

### Case 2: Reservoir Y-20

The storage data for the underground gas storage reservoir is shown in Table 2 below:

**Table 2. Storage Data for Reservoir Y-20**

| | |
|---|---|
| Initial Reservoir Pressure | 3531 psia |
| Initial Reservoir Temperature | $676^0$R |
| Initial Reservoir Gas Z-factor | 0.86 |
| Final Reservoir Pressure | 3300 psia |
| Final Reservoir Temperature | $675^0$R |
| Final Reservoir Gas Z-factor | 0.856 |
| Reservoir Thickness | 40 ft |
| Formation Area | 50 acres |
| Porosity | 0.25 |

The pore volume of reservoir Y-20 is estimated using eq 6 as:

PV = 43560 * 50 * 80 * 0.25

PV = 21.78 MMscf

The quantity of gas loss from reservoir Y-20 is estimated with eq 5 as:

G = 35.3021 * 21780000 * [(3531/(676*0.86)) – (3300/(675*0.856))]

G = 279 MMscf

The Microsoft visual basic program for determining quantity of gas loss from reservoir Y-20 is as shown in Figure 3 below.

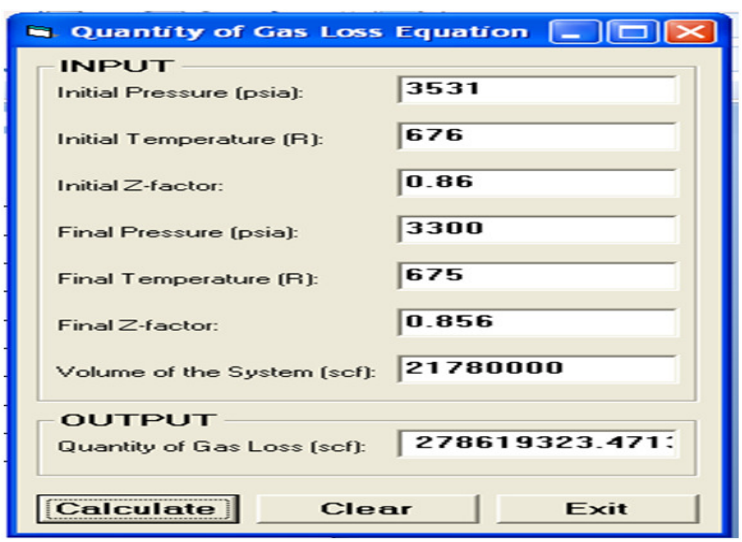


Figure 3. Microsoft Visual Basic Program for Determination of Quantity of Gas Loss from Reservoir Y-20

## CONCLUSION

At the end of this work, it is shown that the quantity of gas loss from an underground gas storage system at a given pressure drop could be determined using the propounded new system equation.

ISSN-L: 2223-9553, ISSN: 2223-9944
Vol. 4 No. 3 May 2013

The new system equation is found to be very simple to use and more comprehensive than previous equations for gas loss determination, as it takes cognizance of temperature changes even as pressure reduces, unlike previous equations and laws that concentrate only on pressure change.

## REFERENCES

Glenn A.K. &Cuthbert J.F. (1979). *Gas Storage Problems and Detection Methods*; paper presented at the1979 SPE Annual Technical Conference and Exhibition, Las Vegas, Nevada, 23-26 September.

Katz D.L. & Tek, M.R. (1981).*Overview on Underground Storage of Natural Ga*s. JPT, June, PP 943-951.

Muonagor C.M. & Nnakaihe S.E. (2011). *Secondary Oil Recovery by Waterflooding*, Case Studies: Reservoirs in Niger Delta; B.Eng Thesis, Department of Petroleum Engineering, Federal University of Technology, Owerri, Nigeria.

Tek M.R. & Wilkes J.O. (1966). *New Concepts in Underground Storage of Natural Gas*, Prepared by University of Michigan Catalog No.: L00400e.

## NOMENCLATURE

ft = Foot

G = Estimated Quantity of Gas Loss, scf

MMscf = Million Standard Cubic Foot

$P_1$ = Initial Pressure of the Storage System, psia

$P_2$ = Final Pressure of the Storage System, psia

$P_{sc}$ = Pressure at Standard Conditions, 14.73 psia

PV = Pore Volume

Psia = Pounds per Square Inch (atmosphere)

$^0R$ = Degrees Rankine

scf = Standard Cubic Foot

$T_1$ = Initial Temperature of the Storage System, $^0R$

$T_2$ = Final Temperature of the Storage System, $^0R$

$T_{sc}$ = Temperature at Standard Conditions, $520^0R$

V = Volume of the Storage System, scf

$V_{sc}$ = Volume of Gas at Standard Conditions

$Z_{sc}$ = Compressibility Factor at Standard Conditions, 1

$Z_1$ = Initial Compressibility Factor of the Gas in the Storage System

$Z_2$ = Final Compressibility Factor of the Gas in the Storage System