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THE MASS OF SALT EQUATION FOR ESTIMATING THE STORAGE CAPACITY OF AN UNDERGROUND GAS STORAGE SALT FORMATION

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ABSTRACT

Estimation of the storage capacity of an underground gas storage salt formation was presented. An equation was propounded for estimating salt formation storage capacity which was based on the mass of salt produced from the formation. The propounded equation also introduces a coefficient termed Salt Formation Storage Coefficient otherwise called Muon Coefficient which is read from a chart called the Muon Chart. The applicability of the Muon Chart and thus the equation was based on certain assumptions which were listed in the Theory. The single limitation of this new equation was also shown in the Theory of this work. This new equation is termed Mass of Salt Equation because it makes use of the mass of salt produced from the formation in estimating the storage capacity of the salt formation. The Mass of Salt Equation was actually applied to compute the storage capacity of a salt formation, Formation AN-01, located South-East Nigeria. A Microsoft visual basic program was also developed based on the Mass of Salt Equation that can estimate salt formation storage capacity.

Keywords: underground, natural gas, storage, salt, formation, capacity, mass, equation, coefficient, Muon, chart

INTRODUCTION

Underground natural gas storage service provides for inventory management, supply backup and access to natural gas to maintain the balance of the system. There are typically three (3) major types of underground natural gas storage (Anyadiegwu, 2012):

1. Depleted reservoirs in oil or gas fields
2. Aquifers
3. Salt formations

    1. Depleted reservoirs: Depleted reservoirs are those formations that have already been tapped of all their recoverable natural gas. This leaves an underground formation, geologically capable of holding natural gas. Experience has shown that use of depleted oil reservoirs adds recovery of substantial quantities of oil that otherwise might not have been recovered. This is achieved by the complete gas re-pressuring and repeated gas cycling of reservoirs of highly volatile oil. The process may be an economical secondary recovery practice. Gas storage in oil reservoir has benefits over storage in other types of enclosures. Gas can be safely stored to pressures at least as high as the initial reservoir pressure without possible leaks (Tek, 1987).
    2. Aquifers: In the absence of depleted oil or gas reservoirs or when such reservoirs are unsuitable for gas storage, consideration will be given to the use of water bearing structures called aquifers as a storage medium. Before an aquifer can be used as a storage medium, tests are conducted to determine the suitability of such

aquifer to hold gas without leakage to overlying or underlying formations. There is high cost of investment per unit volume of gas stored since it requires drilling new wells as compared to depleted reservoirs.

3. Salt Formations: Underground salt strata occur in the form of salt beds or salt domes. These salt beds outcrop at the surface in some areas while they may be found at depths up to 7000ft in others and in thickness range of 1 to 400 feet. Most salt beds contain thin layers of shale, anhydrite etc which cause some problems in the formation of cavities. However, salt domes are usually the best formations for underground storage.

The process of washing out a cavern in rock salt is inexpensive and quite simple. A shaft is drilled into a subterranean salt stratum and the salt is dissolved and brought to the surface by pumping in fresh water and pumping out the brine, leaving an opening of the desired size within the stratum. Three methods of developing the salt cavity are: Bottom injection, Reverse circulation and Progression technique. When creating caverns in salt layers, fracturing may be employed to facilitate the cavern construction. Two or more wells may be sunk and connected by fracturing. The bed may then be washed out to provide a large storage area. Fracturing probably cannot be used in salt domes because the general homogeneity of physical properties may not lend itself to controlled horizontal fracturing (Katz, 1959).

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 salt formation taken into consideration is the Storage Capacity (Verification of Inventory). Storage Capacity of a salt formation refers to the volume of gas that can be stored in the salt formation in accordance with its design.

There had been methods and models for the estimation of the storage capacity of an underground gas storage salt formation, but there had never been a model or an equation that would estimate the storage capacity of a salt formation based on the content of the formation. The content of the formation in this context is the salt the formation contains.

The Mass of Salt Equation propounded in this work is used to estimate the storage capacity of an underground gas storage salt formation based on the amount of salt produced from the formation ie the amount of salt that is displaced to create space for gas storage. The Mass of Salt Equation introduces a coefficient termed Muon Coefficient which is the Salt Formation Storage Coefficient. This Muon Coefficient relates the mass of salt produced in the cavity for gas replacement and the volume of gas replaceable. This work also introduces a chart termed Muon Chart used for reading the Muon Coefficient at different assumed cavity temperature.

THEORY

In developing the mass of salt equation for estimating the storage capacity of a salt formation for underground natural gas storage, certain parameters are taken into consideration, which include the mass of the salt produced from the formation and the formation volume factor of the storage gas.

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When water is pumped into the salt formation to dissolve the salt and cavity is formed, the solubility of the salt in water in g/cm^3 which is amount of salt in grams that can dissolve in 100 cm^3 of water at that particular temperature can be expressed as:

$$Sol = M_{salt}/V_w \quad \text{.......} 1$$

Where M_{salt} = Mass of Salt produced from the Formation, g

V_w = Volume of Water Injected divided by 100 cm^3, cm^3

The density of the salt solution formed at that particular temperature is also expressed as:

$$\rho_{soln} = (M_{salt} + \rho_w V_w)/V_{soln} \quad \text{.......} 2$$

Combining eqs 1 and 2 gives:

$$V_{soln} = M_{salt} (Sol + \rho_w) / (Sol * \rho_{soln}) \quad \text{.......} 3$$

Where V_{soln} = Volume of the Salt Solution Formed, cm^3

ρ_w = Density of the Water, g/cm^3

ρ_{soln} = Density of the Salt Solution, g/cm^3

The storage capacity of the salt formation in cm^3 can be expressed as a function of V_{soln} as:

$$V_{sc} = M_{salt}(Sol + \rho_w)/(Sol * \rho_{soln} * Bg) \quad \text{.......} 4$$

The parameters can be expressed in field units to give the mass of salt equation for determining the storage capacity of a salt formation as:

$$V_{sc} = (\Phi * M_{salt})/B_g \quad \text{.......} 5$$

Where;

V_{sc} = Storage Capacity of the Salt Formation, scf

M_{salt} = Mass of Salt in the Formation, lb

B_g = Storage Gas Formation Volume Factor, rcf/scf

Φ = A Constant termed Muon Coefficient read from the Muon Chart as shown in Fig 2. The Muon Coefficient is a correlation of the solubility and density terms in eq 4 multiplied by their conversion factors to field units.

Assumptions of the Muon Chart, Muon Coefficient and the Mass of Salt Equation

1. The salt formation wall is highly impermeable
2. The salt in the formation is sodium chloride
3. The salt formation is such that it has enough space to accommodate thecavity formed by the formation salt and injected water.

Limitation of the Mass of Salt Equation

The mass of salt equation gives no account of what would possibly become of the salt formation if it does not have sufficient space to accommodate the cavity formed by the formation salt and the injected water.

A Microsoft visual basic program was developed using eq 5, the mass of salt equation for the estimation of storage capacity of a salt formation. The sample of the Microsoft visual basic program for estimation of storage capacity is shown in Figure 1 below.

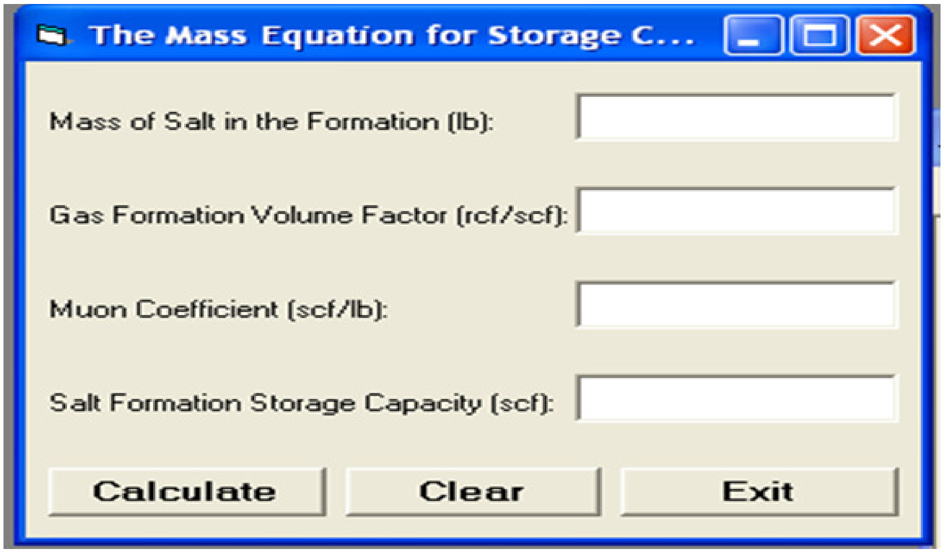

Figure 1. Microsoft Visual Basic Program for Storage Capacity Estimation

The Muon Chart from which the Muon Coefficient is read at different Assumed Cavity Temperatures from 1^0C to 100^0C is as shown in Figure 2.

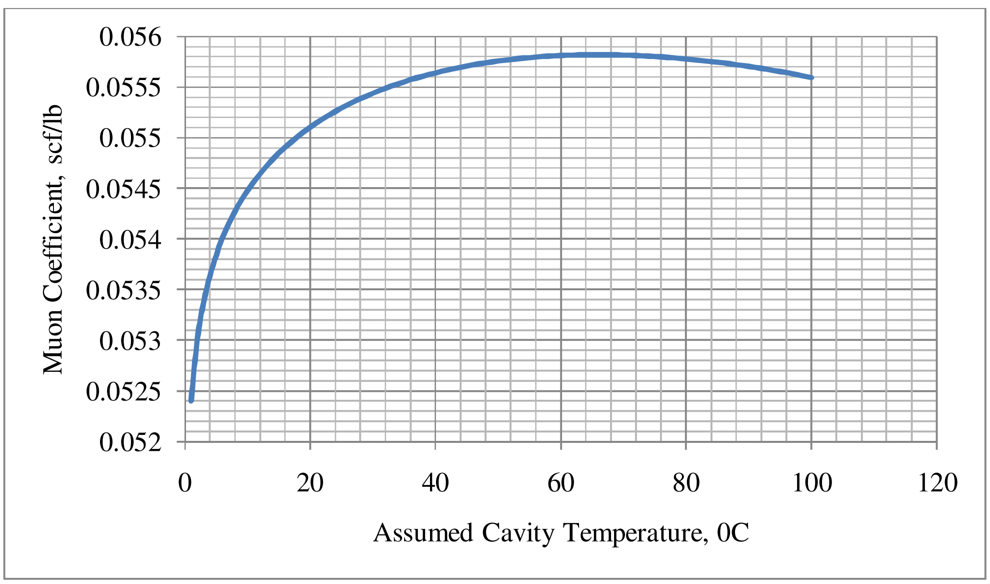

Figure 2. The Muon Chart

RESULT

Case: Formation AN-01

Formation AN-01 located in South-East Nigeria is to be used for underground gas storage. The mass of the salt produced from the formation is measured to be 500 MMlb. The formation volume factor of the storage gas is 0.004165. The produced cavity has a temperature of 2.5^0C.

Using Figure 3, the Muon Coefficient is read at 2.5^0C as 0.0531

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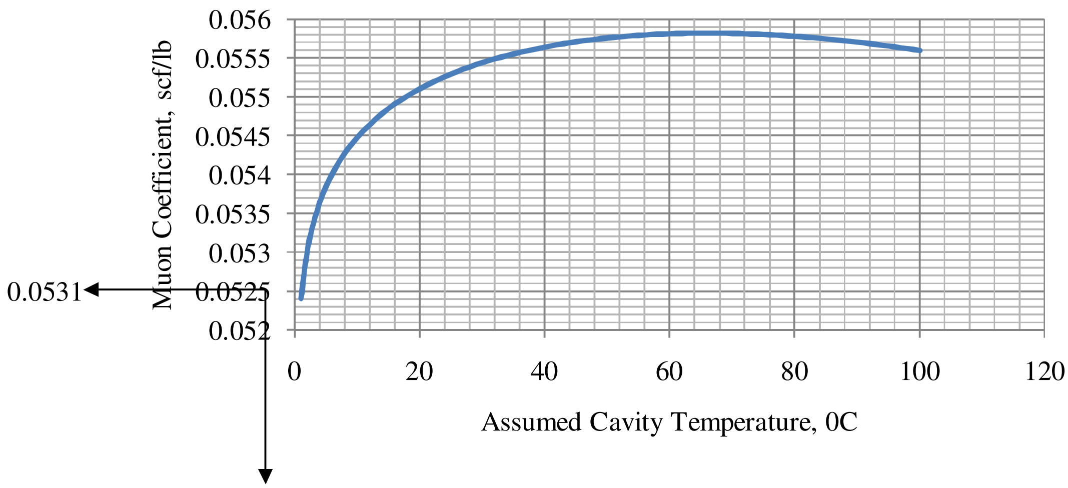

Figure 3. The Muon Chart for Formation AN-01

The storage capacity is estimated with the Mass of Salt Equation given as eq 5 as:

$V_{sc} = (0.0531 * 500 * 10^6) / 0.004165$

$V_{sc} = 6.37$ Bscf

The Microsoft visual basic program for estimating the storage capacity of the salt formation using the Mass of Salt Equation is as shown in Fig 4 below.

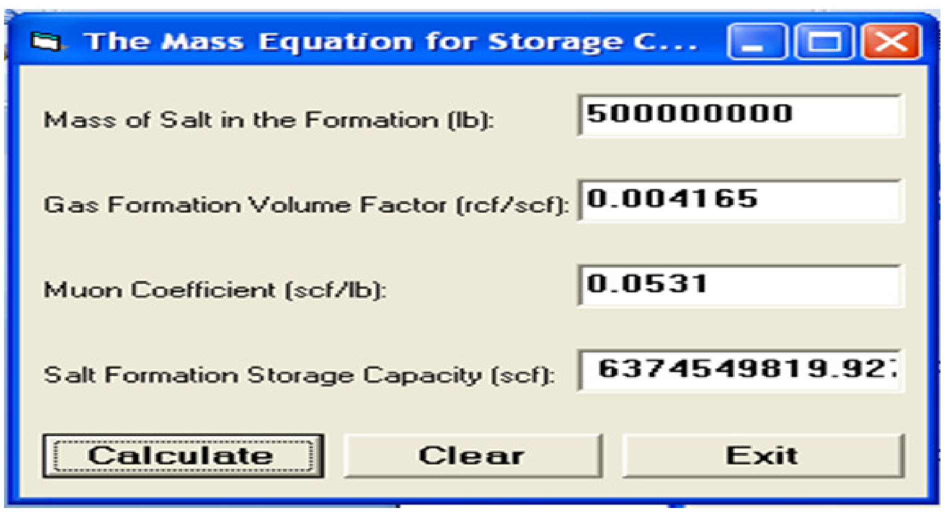

Figure 4. Microsoft Visual Basic Program for Formation AN-01 Storage Capacity Estimation

CONCLUSION

At the end of this work, it is shown that the storage capacity of a salt formation can be estimated. The Mass of Salt Equation shown in equation 5 for estimating the formation storage capacity is scientifically balanced as it defines the storage capacity of the formation in terms of the mass of the salt produced from the formation.

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NOMENCLATURE

B_g = Storage Gas Formation Volume Factor, rcf/scf

Bscf = Billion Standard Cubic Foot

lb = Pounds

M_{salt} = Mass of Salt produced from the Formation, lb

MMlb = Million Pounds

rcf = Reservoir Cubic Foot

scf = Standard Cubic Foot

Sol = Solubility

V_{sc} = Storage Capacity of the Salt Formation, scf

V_w = Volume of Water Injected divided by 100 cm^3, cm^3

V_{soln} = Volume of the Salt Solution Formed, cm^3

ρ_{soln} = Density of Salt Solution

ρ_w = Density of the Water, g/cm^3

ρ_{soln} = Density of the Salt Solution, g/cm^3

Φ= Muon Coefficient or Salt Formation Storage Coefficient, scf/lb

^0C = Degrees Celsius