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Mathematical Analysis of Petrophysical Properties and Flow Unitsin Sandstone Reservoir Rocks

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Abstract: This work is basically a study of the variations formula of petrophysical properties which are related with flow units[1] based on results of experimental tests[2]. Three surface specimens were used in this study. Porosity and permeability tests were measured in petroleum laboratory which are constructive for leading the other petrophysical properties. An experiment was carried out using sandstone core samples to investigate theeffect on its permeability and porosity. The results were demonstrated the effective factors and their effects on reservoir rocks quality.

Keywords: petrophysical properties, porosity, permeability, sandstone, flow units, experimental results

I. INTRODUCTION

Flow unit as a reservoir zone that is laterally and vertically continuous, and has similar permeability, porosity, and bedding characteristic. Gunter et al. defined flow unit as a stratigraphically continuous interval of similar reservoir process that honors the geologic framework and maintains the characteristic of the rock type. From these definitions, the flow units have the following
characteristics:

1) A flow unit is a specific volume of reservoir, composed of one or more
2) A flow unit is correlative and mapable at the interval scale.
3) A flow unit zonation is recognizable on wire-line log.
4) A flow unit may be in communication with other flow units.

A major application of petrophysics is in studying reservoirs for the hydrocarbon industry. Petrophysicists are employed to help reservoir engineers[3] and geoscientists understand the rock properties of the reservoir, particularly how pores in the subsurface are interconnected, controlling the accumulation and migration of hydrocarbons. Some of the key properties studied in petrophysics are lithology, porosity, water saturation, permeability and density. A key aspect of petrophysics is measuring and evaluating these rock properties by acquiring well log measurements - in which a string of measurement tools are inserted in the borehole, core measurements - in which rock samples are retrieved from subsurface, and seismic measurements. These studies are then combined with geological and geophysical studies and reservoir engineering to give a complete picture of the reservoir.

While most petrophysicists work in the hydrocarbon industry, some also work in the mining and water resource industries. The properties measured or computed fall into three broad categories: conventional petrophysical properties, rock mechanical properties, and ore quality.

The specimens were used in this study were collected from Aghajari formation which lies in Khuzestan, Iran. The specimens collected from surface. Porosity and permeability tests were done at petroleum institute with gas method. The results of porosity and permeability were used for calculating petrophysical factors which are essential parameters to estimate the reservoir quality. The present study illustrate relations between above mentioned parameters and rock properties in Aghajari formation.

II. Measuring Porosity and Permeability

In order to find the petrophyisical parameters of the specimens we were interested in the experimental study of the reservoir core presented which is shown in table 1.

Table – 1: measurements of ϕ and K equally in percentage and md

Sample Number	Porosity	Permeablity
1	0.23%	0.002md
2	1.58%	0.007md
3	4.15%	0.025md

III. Methods of Petrophysical Analysis

At the first of this study, specific surface area per unit grain volume and related factors were calculated.

$Svgr \ = A_{NMR\rho m}$

$$\mathrm{Svp} \ = \left(\frac{1-\phi}{\phi}\right) A_{\mathrm{NMR}\ \rho\mathrm{m}}$$

Where:

$A_{\mathrm{NMR}\ \rho\mathrm{m}} =$ NMR surface area of dry material,m^2/g

ρ_m = grain-matrix density,$\mathrm{m}^2/\mathrm{cm}^3$

S_{vgr} = specific surface area per unit grain volume,$\mathrm{m}^2/\mathrm{cm}^3$

Values of S_{vp} and S_{vgr} obtained from NMR[4]are generally higher than values obtained by PIA or the gas adsorption technique. Several studies have found that the specific surface area, measured with any of these methods, is related to the irreducible water saturation or simply water saturation.

Sand grains and particles of carbonate materials that make up sandstone and limestone reservoirs usually never fit together perfectly due to the high degree of irregularity in shape. The void space created throughout the beds between grains, called pore space or interstice, is occupied by fluids (liquids and/or gases). The porosity of a reservoir rock is defined as that fraction of the bulk volume of the reservoir that is not occupied by the solid framework of the reservoir. This can be expressed in mathematical form as:

$\mathrm{k} = \frac{\phi r^2}{8}$

where k is in cm^2($1\ \mathrm{cm}^2 = 1.013 \times 10^8$ darcys) or in $\mu\mathrm{m}^2$ (1 md = $9.871 \times 10^{-4} \mu\mathrm{m}^2$) and ϕ is a fraction.

Let Svp be the internal surface area per unit of pore volume, where the surface area A_s for n capillary tubes is n(2πrL) and the pore volume $V_p$is:

$n(\pi r^2 L)$

$$S_{vp} \ = \frac{A_s}{V_p} \ = \frac{n(2\pi rl)}{n(\pi r^2\ l)} = \frac{2}{r}$$

Let S_{vgr} be the specific surface area of a porous material or the total area exposed within the pore space per unit of grain volume. For a bundle of capillary tubes, the total area exposed, A_t, is equivalent to the internal surface area A_s; and the grain volume, V_{gr} is equal to $A_c L(l-\phi)$.

Thus:

$S_{vgr} \ = \frac{n(2\pi rl)}{A_c\, l(1-\phi)} = \frac{2\pi nr}{A_c(1-\phi)} = \frac{\pi nr^2}{A_c} \left(\frac{2}{r}\right) \frac{1}{(1-\phi)}$

Combining Equations gives:

$S_{vgr} \ = \ S_{vp}\left(\frac{\phi}{1-\phi}\right)$

Which is shown in table 2:

Table – 2: contents of S_{vgr} and S_{vp}

Sample number	S_{vgr}	S_{vp}
1	0.0034801	1.509606866
2	0.033039614	2.058075216
3	0.07247851	1.673991607

All the above equations used in deriving the relationship between the permeability and porosity Equations are based on the assumption that the porous rock can be represented by a bundle of straight capillary tubes. However, the average path length that a fluid particle must travel is actually greater than the length L of the core sample. The departure ofa porous medium from being made up by a bundle of straight capillary tubes can be measured by the tortuosity coefficient, ***t*** which is expressed as:

$$\mathrm{t} = \left(\frac{L_a}{L}\right)^2$$

$F\Phi = (\frac{L_a}{L})^2$

IV. Mathematictahle Oroyf Flowu Nits

$K = (\frac{1}{K_t\, S^2{}_{vgr}})(\frac{\phi_e{}^3}{(1-\phi)^2})$

Where:
k = permeability,μm^2
ϕe = effective porosity
S_{vgr} = specific surface area per unit grain volume

The parameter KT, called here the pore-level effective zoning factor is a function of pore size and shape, grain size and shape, pore and grain distribution, tortuosity, cementation, and type of pore system, e.gintergranular, intercrystalline, vuggy, or fractured. This parameter varies between flow units, but is constant within a given unit.The parameter K_T for a homogeneous sandstone formation can be estimated from:

$$K_T = \frac{1}{J_1^2}$$

V. Flow Unit Characterization factors

1) Reservoir quality index (RQI)

$K = (\frac{1}{K_t\, S^2{}_{vgr}})(\frac{\phi_e{}^3}{(1-\phi)^2})$

Dividing both sides of above equation by porosity and taking the square root of both sides yields:

$\sqrt{\frac{K}{\phi}} = \frac{1}{S_{vgr}\sqrt{K_t}}(\frac{\phi_e}{1-\phi_e})$

If permeability is expressed in md and porosity as a fraction, theleft-hand side of equation:

$RQI = 0.0314\sqrt{\frac{K}{\phi_e}}$

where RQI is expressed in micrometers or μm (1 μm =10^{-6} m).

2) Flow zone indicator (FZI)

The flow zone indicator is defined:

$FZI = \frac{1}{S_{vgr}\sqrt{K_t}}$

Thus aboveequation can be written as:

$RQI = FZI(\phi_z)$

where ϕ_Z is the ratio of pore volume to grain volume:

$$\phi_Z = \frac{\phi_e}{1-\phi_e}$$

3) Tiab flow unit characterization factor (H_T)

$H_T = K_T s_{vgr}^2 = \frac{1}{K}(\frac{\phi^3}{(1-\phi)^2})$

$$H_T = \frac{1}{FZI^2}$$

$$H_T = \frac{\phi_R}{K}$$

where ϕ_R is given by:

$k = \frac{\phi_R}{K_T s_{vgr}^2}$

where ϕ_R is :

$$\phi_R = \frac{\phi_e^3}{(1-\phi_e)^2}$$

4) Free fluid index (FFI)

The bulk volume water is commonly used to indicate whether or not a reservoir is at its irreducible water saturation, S_{wir}.
It is equal to the product of total porosity and water saturation, s_w:

$BVW = \phi S_w$

Table – 3: Flow unit characterization factors

Sample N.O	RQI	Formation Factor	Tortuosity Factor	L_A	FFI	FZI	H_T
1	0.029280651	189035.9168	434.7826087	1042.57207	0.00247925	11.81028692	0.007169339
2	0.020900185	4005.768306	63.29113924	397.7786421	0.0154140.017	1.227158314	0.664046989
3	0.024371127	580.6357962	24.09638554	245.4403468	0.044734289	0.544797447	3.369223895

VI. Conclusion

In summary, the closed-form equations presented here provide simple calculations for the petrophysical parameters of specimens used for porosity and permeability components [5]. These expressions deduced from the mathematical methods which are constructive for evaluation of reservoir quality. We can conclude in theory based on surface specimens which are used in this study, the Aghajari formation has a similar condition in surface and depth. Results demonstrate this hypothesis.

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