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Permeability Prediction in Carbonate Reservoir Rock Using FZI

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Abstract

Knowledge of permeability, which is the ability of rocks to transmit the fluid, is important for understanding the flow mechanisms in oil and gas reservoirs.

Permeability is best measured in the laboratory on cored rock taken from the reservoir. Coring is expensive and time-consuming in comparison to the electronic survey techniques most commonly used to gain information about permeability.

Yamama formation was chosen, to predict the permeability by using FZI method. Yamama Formation is the main lower cretaceous carbonate reservoir in southern of Iraq. This formation is made up mainly of limestone. Yamama formation was deposited on a gradually rising basin floor. The digenesis of Yamama sediments is very important due to its direct relation to the porosity and permeability.

In this study permeability has been predicated by using the Flow zone indicator methods.This method attempts to identify the flow zone indicator in un-cored wells using log records. Once the flow zone indicator is calculated from the core data, a relationship between this FZI value and the well logs can be obtained.

Key Words: Permeability, FZI

Introduction

One of the most important rock parameters for the evaluation of hydrocarbon reservoirs is permeability. Permeability was controlled by the size of the connecting passage between pores.

Recovery of hydrocarbons from the reservoir is an important process in petroleum engineering and estimating permeability can aid in determining how much hydrocarbons can be produced from a reservoir.

Tiab and Donaldson [1] gives that the nature of reservoir rocks containing oil dictates the quantities of fluids trapped within the void space of these rocks. The measure of the void space is defined as the porosity of the rock, and the measure of the ability of the rock to transmit fluids is called the permeability. Knowledge of these two properties is essential before questions concerning types of fluids, amount of fluids, rates of fluid flow, and fluid recovery estimates can be answered.

Pasternak [2] estates that there are methods for measuring porosity and permeability have comprised much of the technical literature of the oil industry. There is no specific correlation between permeability and porosity values. In many cases the relationship between permeability and porosity is qualitative and is not directly or indirectly quantitative in any way. It is possible to have very high porosity without having any permeability at all, as in the case of pumice stone (where the effective permeability is nearly zero), clays and shales. The reverse of high permeability with a low porosity might also be true, such as in microfractured carbonates. In spite of this fundamental lack of correspondence between two properties, there often can be found a useful correlation between them within one formation

Flow Units

Bear [3] defined the flow unit as the representative elementary volume of the total reservoir rock within which the geological and petrophysical properties of the rock volume are the same.

Hear et al. [4] defined the flow unit as a reservoir zone that is laterally and vertically continuous, and has similar permeability, porosity, and bedding characteristic.

Ebank [5] defined the hydraulic flow unit as a map-able portion of the reservoir within which the geological and petrophysical properties that affect the flow of fluid are consistent and predictably different from the properties of other reservoir rock volume.

Gunter et al. [6] defined the flow unit as a stratigraphically continuous interval of similar reservoir process that honors the geologic framework and maintains the characteristic of the rock type. The concept of hydraulic flow units can be used to predict permeability with reliable accuracy.

Development of Flow Unit Concept

Amaefule et al. [7] considered the role of the mean hydraulic radius in defining hydraulic flow units and correlating permeability from core data. Their approach was essentially based on a modified Kozeny-Carmen equation:

$$K = \left(\frac{1}{2\tau^2 * S_{gv}^2}\right) * \left(\frac{\varphi_{eff}^3}{(1-\varphi_{eff})^2}\right) \quad \text{... (1)}$$

The Amaefule et al. [7] approaches were essentially based on a modified Kozeny-Carmen equation coupled with the concept of mean hydraulic radius:

$$r_{\mathrm{mh}} = \frac{\text{Cross Section Area}}{\text{Wetted surface area}} = \frac{r}{2} \quad \text{... (2)}$$

Tiab and Donaldson [1] considered the concept of sub-grouping reservoir volume into flow units, suggests that the term$2\tau^2$ in Eq. (1), which is classically referred to as Kozeny constant, is actually "variable constant". This means that Kozeny constant may vary for different hydraulic units, but is constant for a specific unit. Based on that, Tiab and Donaldson [1] introduced the "variable constant"K_τ referred to as the effective zoning factor:

$$K = \left(\frac{1}{K_\tau * S_{gv}^2}\right) * \frac{\varphi_{eff}^3}{\left(1-\varphi_{eff}^2\right)} \quad \text{... (3)}$$

Tiab and Donaldson [1] proposed to estimate the effective zoning factor:

$$K\tau = F_s * \tau^2 \quad \text{... (4)}$$

Carmen [8] simulated a porous medium as a bundle of capillary tubes. They combined Darcy's law for flow in a porous medium and Poiseuille's law for flow in tubes. A tortuosity factor was also included, because for a realistic model of porous media the connected pore structure is not straight capillary tubes. Carmen [8] suggested the following relationship between porosity and permeability:

$$K = \frac{r^2 * \varphi_{eff}}{8\tau^2} = \frac{\varphi_{eff}}{2\tau^2} * \left(\frac{r}{2}\right)^2 = \frac{\varphi_{eff} * r_{mh}^2}{2\tau^2} \quad \dots (5)$$

Al –Ajmi and Holditch [9], the mean hydraulic radius can be related to the specific surface area per unit grain volume S_{gv}, and the effective porosity φ_{eff}, by the following equation:

$$S_{gv} = \frac{1}{r_{mh}} * \left(\frac{\varphi_{eff}}{1 - \varphi_{eff}}\right) \quad \dots (6)$$

Combining equations (5) and (6), gives the generalized Kozeny –Carmen equation:

$$K = \frac{\varphi_{eff}^3}{(1 - \varphi_{eff})^2} * \frac{1}{F_s * \tau^2 * S_{gv}^2} \quad \dots (7)$$

The term $(F_s * \tau^2)$ is known as the Kozeny constant, which is usually between 5 and 100 in most reservoir rocks. The term $(F_s * \tau^2 * S_{gv}^2)$ a function of geological characteristics of porous media and varies with changes in pore geometry. The determination of the $\left(F_s * \tau^2 * S_{gv}^2\right)$ group is the focal point of the Hydraulic Flow Unit (HFU) classification technique.

Identification of Flow Zone Indicator (FZI) and Reservoir Quality Index (RQI)

Taslimi [10], flow zone indicator depends on geological characteristics of the material and various pore geometry of a rock mass; hence, it is a good parameter for determining HFU. Flow zone indicator is a function of reservoir quality index and void ratio.

Amaefule et al. [7] addressed the variability of Kozeny's constant by dividing Eq. (1) by the effective porosity, φ_{eff} and taking the logarithm:

$$\sqrt{\frac{K}{\varphi_{eff}}} = \frac{1}{0.0314} * \left(\frac{\varphi_{eff}}{1 - \varphi_{eff}}\right) * \frac{1}{\tau \; S_{gv}\sqrt{F_s}} \quad \dots (8)$$

Where, the constant 0.0314 is the permeability conversion factor from μm^2 to md.

Al –Ajmi and Holditch [9] defined the flow zone indictor FZI (µm) as:

$$FZI = \frac{1}{\tau \; S_{gv}\sqrt{F_s}} \quad \dots (9)$$

Reservoir quality index RQI (µm) as:

$$RQI = 0.0314\sqrt{\frac{K}{\varphi_{eff}}} \quad \dots (10)$$

and normalized porosity φ_z (fraction) as:

$$\varphi_z = \frac{\varphi_{eff}}{1 - \varphi_{eff}} \quad \dots (11)$$

Eq. (8) becomes:

$$RQI = FZI * \varphi_z \quad \dots (12)$$

Taking the logarithm of both sides of Eq. (12) yields:

$$\text{Log RQI} = \text{Log FZI} + \text{Log } \varphi_z \quad \dots (13)$$

Al –Ajmi and Holditch [9] considered that in a Log-Log plot of RQI versus φ_z all the samples with similar FZI values lie on a straight line with a slope of one; and data samples with the same FZI values, but significantly different from the preceding one, will lie on another, parallel, unit-slope lines; and so on Perez [11]. Samples that lie on the same straight line have similar pore throat attributes, and thereby constitute a unique HFU. Each line represents a HFU and the intercept of this line with $\varphi_z = 1$ is the mean FZI value for that HFU. Each flow unit is characterized by FZI. Amaefule et al. [7] determined the basis of HFU classification is to identify groups of data that form unit-slope straight lines on a Log-Log plot of RQI versus φ_z, as shown in fig. (1).

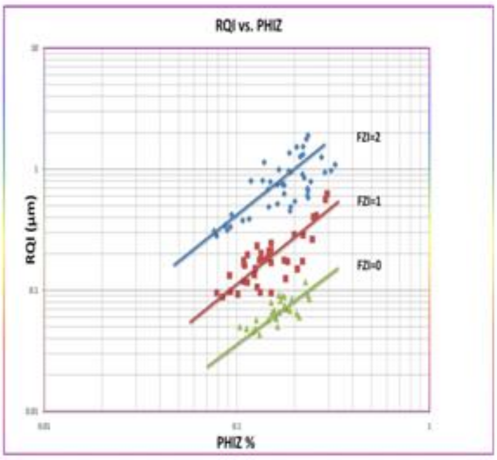

Fig. 1, Reservoir quality index vs. normalized porosity, Murtadha [13]

FZI Correlation with Well Logs

FZI is then correlated with certain combinations of logging tool responses to predict permeability values in cored and un-cored intervals of wells. This method attempts to identify the flow zone indicator in un-cored wells using log records. Once the flow zone indicator is calculated from the core data, a relationship between this FZI value and the well logs can be obtained, (Pablo [12]).

Al –Ajmi and Holditch [9] showed that to calculate permeability in un-cored wells, correlations were developed between well log measurements and FZI values from core data using two statistical ways; parametric method or non-parametric transformation of variables regression.

The FZI is then correlated with certain combinations of logging tool responses to develop regression models for permeability predictions in cored and un-cored intervals or wells, (Amaefule et al. [7]).

Equations (10) through (12) are used to compute the functions for preparing a log-log plot of RQI versus φ_z for each reservoir unit of all the wells. The data that have similar FZI values fall on a straight line (of the same slope); and all the data on the same straight line can be considered to have similar pore throat attributes (the same hydraulic unit) governing the flow. The permeability can be computed for those points on the same straight line (with same FZI) as shown in fig. (2):

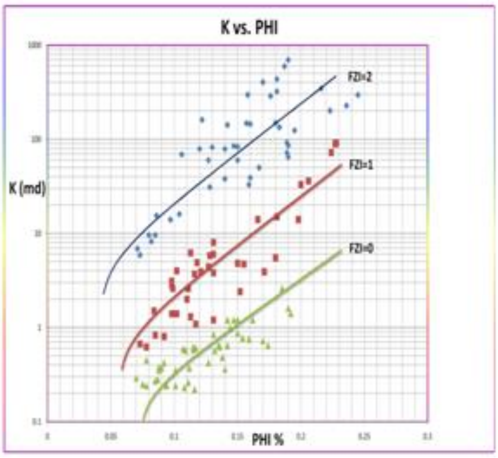

Fig. 2, Core permeability vs. core porosity, Murtadha [13]

Using the eq. (14) to calculate the permeability in the uncored wells:

$$K = 1014 * FZI^2 * \frac{\varphi_{eff}^3}{\left(1-\varphi_{eff}\right)^2} \qquad \ldots(14)$$

Fig. (3) represents K–predicted by FZI vs. K–core and Fig. (4) represent K–predicted by FZI and K–core vs. depth.

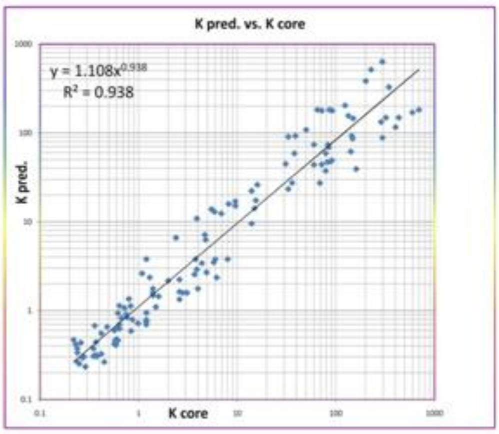

Fig. 3, K-predicted by FZI versus K-core, Murtadha [13]

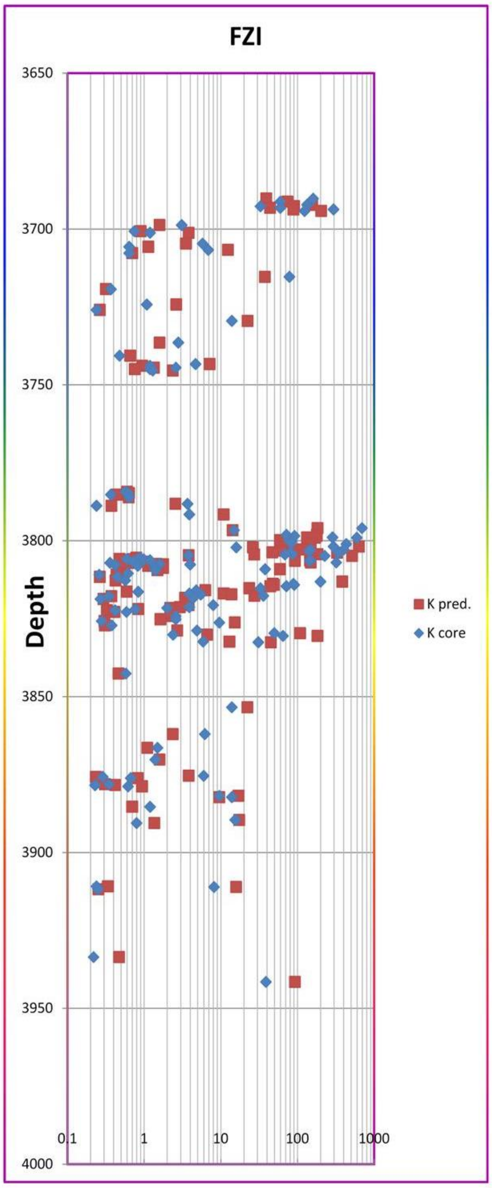

Fig. 4, K–predicted by FZI and K–core vs. depth, Murtadha [13]

Conclusions

- FZI method is very accurate method in estimating permeability in uncored well. Good agreement has been obtained between core permeability and calculated permeability by FZI method.
- FZI method gave three groups for Yamama reservoir, each group represent type of rocks, each type have the similar porosity and similar properties which can be used to divide the reservoir.

Nomenclature

Symbol	Description	Unit
F_s	Effective pore throat shape factor	(---)
K	Permeability	md
k_τ	Function of pore-pore throat size and geometries, tortuosity and cementation	(---)
r	Pore throat radius	µm
r_{ah}	Mean Hydraulic radius	µm
S_{gv}	surface area of grains exposed to fluid per unit volume of solid material	cm^2/cm^3

Greek Symbols

φ_{eff}	Effective porosity	fraction
H_z	Normalized porosity	fraction
τ	Tortuosity	(---)

Abbreviations

FZI	Flow Zone Indicator
HFU	Hydraulic Flow Unit
RQI	Reservoir Quality Index

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