USING WELL LOGGING DATA TO PREDICT PERMEABILITY OF A COMPLEX FORMATION

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ABSTRACT

One of the most challenging aspects of well log analysis is the accurate estimation of permeability in complex carbonate reservoirs. Permeability is predicted from many models by using well log data. Many correlations are developed over the years to calculate permeability based on known petrophysical properties or empirically derived relationships. The complex formation under study is Mishrif carbonate formation that is one of the shallowest hydrocarbons bearing zone in the Nasiriya oilfield in the south of Iraq. The available scanned copies of well logs are digitalized by using Neurolog software. Schlumberger charts 2005 had been used for environmental corrections. These correction charts are supplied in the Interactive Petrophysics software. The Schlumberger K3 and Timur models have been used to estimate permeability of Mishrif carbonate formation. After making the environmental corrections, the porosity interpretation shows that the logging tools have a good quality of data reading. From Schlumberger and Timur models, the permeability of Mishrif formation is ranged from 6.25 to 25.21 and 5.95 to 26.81 respectively. This study is provided permeability for varies depth, that is very important in the evaluation of the studied formation.

1. INTRODUCTION

Permeability (K) is a petrophysical property, which refers to the ability of fluid flow through a porous medium. The behaviour of petrophysical properties of complex carbonate reservoirs is a highly nonlinear because these reservoirs are heterogeneous in nature. In complex carbonate petroleum reservoirs, many forms of heterogeneity in rock properties are present. Estimation of the volume of hydrocarbons and their flow patterns depend on porosity, permeability and fluid saturation that are the key variables for characterising a reservoir. Porosity can be determined by using different logging devices, such as; formation density log, sonic log or neutron log all, can determine the values of porosity (kadhim *et al*., 2015).

Fluid flow through heterogeneous carbonate reservoirs (limestone and dolomite) is a substantially different process from the flow through the homogeneous sandstone reservoir. This variation is largely caused by the fact that carbonate rocks tend to have a more complex pore system than sandstone (Mazzullo, 1986).

The density log is a continuous record of a formation's bulk density. It is used mainly for the determination of porosity, and the differentiation between liquids and gases (when used in combination with neutron log). When organic content is present, density is low. Variation of density indicates porosity changes. For example, low density indicates high porosity. The density tool responds to the electron density of the material in the formation. Formation bulk density (RHO_B) is a function of matrix density, porosity, and density of fluids in the pores (salt water, fresh water mud, or hydrocarbons). The formula for calculating density derived porosity is (Ellis and Singer, 2007):

$$PhiD=2.71-RHO_B/2.71-RHO_f \quad \text{…………………. (1)}$$

Where: RHO_B: is the bulk (matrix) density, [2.71 (gm/cc) for limestone, 2.87 (gm/cc) for dolomite and 2.65 (gm/cc) for sandstone]. RHO_f: is the fluid density (gm/cc) [fresh water mud = 1, for salt water mud 1.1].

Neutron logs are porosity logs that measure the hydrogen concentration in a formation. In clean formations (shale-free), where the pores are filled with water or oil, therefore, hydrogen is concentrated in the fluid-filled pores, energy loss can be related to the formation porosity. Whenever shale is part of the formation matrix, the reported neutron porosity is greater than the actual formation porosity (Asquith and Krygowski, 2006).

The sonic log is a porosity log that measures interval transit time (Δt) of a compressional sound wave traveling through the formation, the interval transit time depends on both lithology and porosity. Wyllie time-average equation may be written as follows (Etnyre, 1989):

$$PhiS=\Delta tl_{og}-\Delta t_m/\Delta t_f-\Delta t_m \text{ ……………………… (2)}$$

Where: Φs is sonic-derived porosity, fraction, Δtm: is the interval transit time in the matrix [Its value is 47.6µsec/ft for limestone and 43.5 µsec/ft, for dolomite], Δt_{log}: is the interval transit time in the formation, µsec/ft., Δt_f: is the interval transit time in the fluid within the formation [for fresh water mud = 189 (µsec/ft); for salt-water mud = 185(µsec/ft)].

Porosity, clay content and grain sorting are main parameters that influenced permeability. The evaluation of hydrocarbon reservoirs strongly depends on the permeability. Therefore, several models are derived to relate the permeability with the grain size. The Kozeny Carman model is one of the most commonly known (Dullien, 1991). Rodriguez and Pirson in1968 showed the advantages of the continuous dip-meter as a tool for studies in directional sedimentation and directional tectonics. They were also noted that the strongest grain orientation is parallel to the direction of maximum permeability in bedding planes. Mohaghegh *et al*., (1997) derived correlation to calculate the permeability by using well log parameters; gamma ray index, bulk density and deep induction. In 1997, Saner *et al*. estimated permeability from well logs using resistivity and water saturation data.

The conventional method is used to correlate core permeability and porosity measurements and to use the resulting porosity-permeability transform to calculate the permeability from porosity logs. Schlumberger chart (K3) is used to calculate the permeability from porosity logs (Φ) and irreducible water saturation (S_{wi}) (Schlumberger, 2008).

$$K=10000\Phi^{4.5}/Sw_i^2 \text{ …………………………….. (3)}$$

Timur in 1968 investigated the relationships between permeability, porosity and residual water saturation in three different oil fields. He tested several relations for *k*, Φ and S_{wi}, by statistical technique to find the standard error of estimate and correlation coefficient for each field, and then for all fields. He found the best estimation of permeability through the following empirical equation (Schlumberger, 2008):

$$K=8581\Phi^{4.4}/Sw_i^2 \text{ …………………………….. (4)}$$

In this study, Permeability of Mishrif carbonate formation is determined using corrected well log data and compared with core data that obtained from five wells of NS oil field. The accurate determination of the permeability values with depth should provide information to evaluate this reservoir.

2.0 METHODOLOGY

The field under study is located in the north of Arabian platform in the Middle East between latitudes (34°80`- 34°60` N) and longitudes (57°50`- 60°10` E). It is anticline structure with northwest- southeast general trend. Three reservoir units contain most of the oil within the reservoir; the Mishrif, Nahr Umr, and Yamamma formations that consist mainly of limestone. Mishrif formation is one of the shallowest and important reservoir units due to rudist deposits (Amnah, 2009).

Cross-plot techniques are employed in the analysis of well log data. A set of log data from five wells in the Nasiriya oil field was used as the base data for the research reported in this paper. Neura-Log software (V5, 2008) was used to digitize the scanned copies of logs in which the results as LAS files were loaded into the Interactive Petrophysics software (IP, V3.5, 2008) where the reading measurements were taken as one reading per 0.1524 meters. The log curves are checked to be in depth with each other.

Environmental corrections were made using the current Schlumberger charts (SLB, 2005), which are supplied to (IP) as the environmental correction module. Actual mud properties, calliper log, hydrostatic pressure and temperature gradient were provided for accurate corrections. Depending on well log data the Interactive Petrophysics software had been used to calculate the porosities and determine the lithology cross-plots.

3. RESULTS AND DISCUSSION

Using IP software, corrections were achieved per 0.1524 m of depth to avoid erroneous results in logs interpretations. The correction charts (SLB, 2005) were supplied by the software as the environmental correction module. The density and sonic porosities are calculated from equations (1) and (2) which are supplied with the IP software. The porosity interpretation from porosity logging tools after making the environmental corrections is shown in Figure 1. These results are in agreement with the core porosity by (INOC, 2007) as shown in Table 1

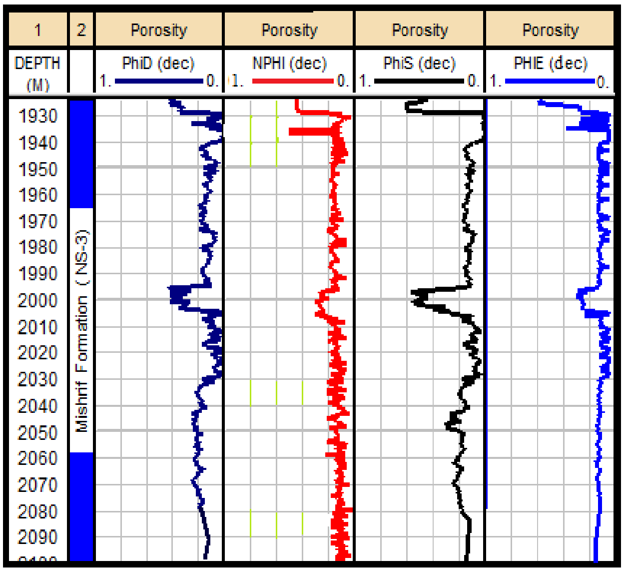

Figure 1 porosity results from well logs

Table 1 illustrates porosity values from core samples (Φ_{CORE}) and computer processed interpretation (Φ_{CPI}) as well as their changes with depth interval. The average values of Φ_{CORE} and Φ_{CPI} are ranged from 0.18 to 0.20 and from 0.13 to 0.15 respectively. The computer processed interpretation (CPI) is predicted effective porosity (Φ_{CPI}) from log data. The absolute percentage error (APE) between Φ_{CPI} (predicted) and calculated core porosity(Φ_{CORE}) by INOC (2007) for the studied formations are ranged from 16% to 35% as shown in Table 1.The relationships between Φ_{CORE} and average Φ_{CPI} for Mishrif formation is shown in Figure 2. From this relationship, the correlation coefficient (R^2) and standard errors are quite good. Therefore corrected equations for porosity are produced from statistical analysis in Figure 2 as follows:

$\Phi_{CPI} = -0.00173+\Phi_{CORE}$………………… (5)

Table 1 Comparison results of Φ_{CORE} and Φ_{CPI}

Well	Depth interval(m)	Φ_{CORE}, INOC(2007)	Φ_{CPI}	APE
NS-1	2012-2109	0.19	0.13	31
NS-2	1989-2089	0.19	0.14	26
NS-3	1924-2100	0.18	0.15	16
NS-4	1999-2106	0.20	0.15	25
NS-5	1996-2100	0.20	0.13	35

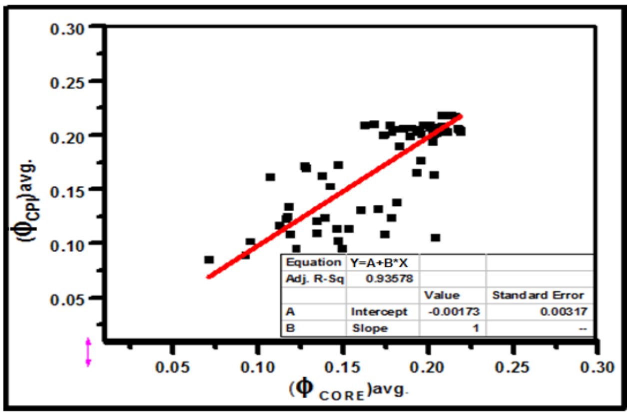

Figure 2 average (Φ_{CPI}) and average (Φ_{CORE}) relationship

The main reason that leads to differences between the porosity value from core and log is the varying between properties of formation water and the mud filtrate (Amin *et al.*, 1987; Kadhim *et al.*, 2015). The Ferro Chrome Lignite - Chrome Lignite (FCL-CL) used as drilling mud in the studied wells. The (FCL-CL) mud contains barite as a weighting agent and characterized by a high ratio of free phase (water), which lead to a high diameter of invasion zone (more than 50 in), that mean the investigation zone for logging tools was invaded by barite (Kadhim *et al.*, 2015).

Schlumberger model and Timur equations (3) and (4) respectively are already supplied with the IP software and used to calculate the permeability as shown in Figures 3. Permeability values of the core (K_{CORE}) and well test ($K_{W.T}$) that provided from INOC (2007) as well as the computer processed interpretations (K_{CPI}) are listed in Table 2. This table shows the results of K_{COR} and K_{CPI} are closed in NS-1 and NS-2 wells while the values of $K_{W.T}$ and K_{CPI} are closed in NS-3. The variation of permeability results between these methods is caused by many reasons such as; human error in measured of core samples as well as the mistake of slope extrapolation in well testing and finally the type of drilling mud that increase the invasion zone and effect to the porosity log reading. The absolute percentage error of results between the Permeability of Timur model (K_{TIMUR}) and Schlumberger model (K_{SLB}) are quite acceptable because its range from 1% to 10% as listed in Table 2. The relationships between average calculated core permeability (K_{CORE}) and average K_{CPI} (predicted) for Mishrif formation is shown in Figures 4. From this relation, the correlation coefficient (R^2) and standard error in the studied formations are quite good. Therefore, corrected equation for permeability is produced from statistical analysis in Figure 4 as shown in equations (6)

$K_{CPI}= -0.18567+0.9986K_{CORE}$………………..… (6)

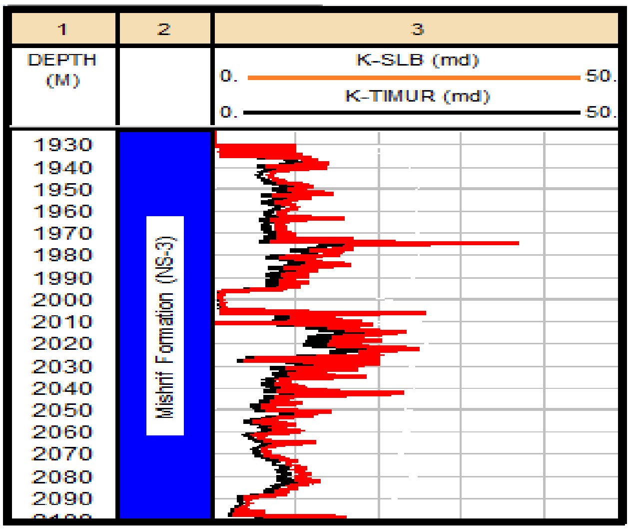

Figure 3 permeability results of SLB and Timur models

Table 2 Comparison of average permeability results from Timur model and Schlumberger model

Well	**K_{CORE} (md)**	**$K_{W.T}$ (md)**	**K_{CPI}**		**APE**
			K_{SBL} (md)	**K_{TIMUR} (md)**	
	INOC (2007)				
NS-1	4.240	9.05	6.25	5.95	5 .0
NS-2	12.59	9.95	12.43	12.10	3.0
NS-3	3.780	16.81	8.967	10.05	10
NS-4	74.50	16.50	11.33	11.18	1.0
NS-5	38.44	10.47	25.21	26.81	3.0

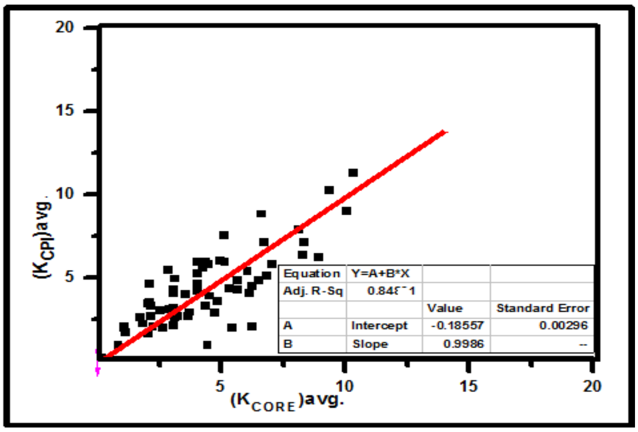

Figure 4 average K_{CPI} and average K_{CORE} relationship

CONCLUSION

The accurate determination of permeability results gives reliable of formation evaluation studies. The environmental correction for sonic, density and neutron logs gives accurate values of porosity, and the average effective porosity for Mishrif formation is almost between 0.13-0.2.The Schlumberger model gives permeability results that are more consistent than Timur model and closet to the core values. The average permeability value of this model for studied formation is located between 6.25 and 25.21

REFERENCES

Amin, A. T. Watfa, M., and Awad, M. A. (1987).Accurate Estimation of Water Saturation in Complex Carbonate Reservoir, *Middle East Oil Show*, 7-10 March, Bahrain, SPE-15714-MS

Amnah, M. H. (2009).Prediction of Reservoir Permeability from Well Logs Data Using Artificial Neural Networks, *Iraqi Journal of Science*, 50 (1), 67 – 74

Asquith, G., and Krygowski, D.(2006). Basic Well Log Analysis, *AAPG Methods in Exploration*, Series No.16, June 30

Dullien, F. A. L. (1991). *One and Two-Phase Flow in Porous Media and Pore Structure*, (pp. 173-214), New York, Science Publishers Inc

Ellis, D. V., and Singer, J. M. (2007). *Well Logging for Earth Scientists*, (pp. 629-634), the Netherland, 2nd Edition, Springer

Entyre, L. M. (1989), *Finding Oil and Gas from Well Logs*, (pp.91-145), New York, Van Nostrand Reinhold

Iraqi National Oil Company, INOC (2007). *Nasiriya Oil Field- Integrated Reservoir Study Updating*, Unpublished report

Kadhim, F.S, Samsuri, A., Kamal, A., Alwan, H. and Hashim, M. (2015), Investigation of petrophysical properties for Yamamma carbonate formation, *Modern Applied Science*, 9 (6), 36-47

Mazzullo, S. J. (1986). Stratigraphic Approach of Hydrocarbon Exploration and Exploitation, *Geological Journal*, 21(3), Pp 265-28

Mohaghagh, S., Balan, B., and Amer, S. (1997). *Permeability Determination from Well Log Data, SPE Formation Evaluation*, 12(03), 170-174, SPE-30978-PA

Rodriguez, A. R. and Pirson, S. J. (1965).The Continuous Dip-meter as a Tool for Studies in Directional Sedimentation and Directional Tectonics, *SPWLA 9th Annual Logging Symposium*, 23-26 June, New Orleans, Louisiana, SPWLA-1968-G

Saner, S., Kissami, M., and Al-Nufaili, S. (1997).Estimation of Permeability from Well Logs Using Resistivity and Saturation Data, *SPE Formation Evaluation*, 12 (1) SPE-26277-PA

Schlumberger, (2008).*IP- Interactive Petrophysics* V-3.5, Manual

Timur, A. (1968). An Investigation Permeability and Porosity, and Residual Water Saturation Relationships, *SPWLA 9th Annual Logging Symposium*, 23-26 June, New Orleans, Louisiana, SPWLA-1968-J