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A comparative Study to Estimate Cementation Exponent (m) and Tortuosity Factor (a) with the Presence of Shale at Asmari Reservoir as a Case Study at an Iraqi Oil Field

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Abstract— Knowledge of Archie parameters is a very sensitive topic for developing an accurate reservoir description. The presence of shale will effect on the calculation of these parameters. A comparison between Pickett Plot and X-Y Cross Plot is done to clarify this effect and how the values of water saturation as a result are affected by them. This study will focus on the evaluation of Cementation exponent (m) and Tortuosity factor (a) for Asmari reservoir in an Iraqi oil field, depending on the data from four wells. Asmari is a carbonate reservoir formation and contains significant amounts of shales. The results of Cementation exponent (m) and Tortuosity factor (a) estimation from both methods Pickett and X-Y plots show a clear difference between them and the role of shale presence is revealed where X-Y plot depends on Indonesian water saturation model which includes the shale effect in the calculations. A comparison between the water saturation calculations based on the extracted values of cementation exponent (m) and Tortuosity factor (a) from Pickett and X-Y plots methods exhibit a significant percentage of variance between them and this is very sensitive in the calculations of hydrocarbon volumes.

***Keywords*—**comparative study, Pickett plot, X-Y cross plot, Asmari reservoir

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I. INTRODUCTION

Water saturation is one of the most important petrophysical properties where the volume determination of hydrocarbons depends on it. In 1942 Archie [1] introduced his famous formula to calculate water saturation which relates the latter (Sw, fraction) to true formation resistivity (R_t, Ohm.m), formation water resistivity (R_w, Ohm.m), and formation porosity (φ, fraction), the equation is presented as below;

$$Sw^n = \frac{aR_w}{\varphi^m R_t} \qquad (1)$$

Three parameters are appeared in the equation, (a) tortuosity factor, (m) cementation factor, and (n) saturation exponent. Traditionally the values of these factors were taken as (1, 2, 2) respectively, but after many researches it was found that the variation in the reservoir formation nature has a major effect on the estimation of these three parameters.

The existence of clay in the formation has a significant effect on the determination of Archie parameters, and as a result effect on the saturations calculation. The volume and resistivity of the clays should be included in the water saturation formula. Poupon and Leveaux (1971) [2] introduced the following model to calculate the water saturation at shaly formations;

$$\frac{1}{R_t^{1/2}} = \left[\frac{V_{cl}^{(1-0.5V_{cl})}}{R_{cl}^{1/2}} + \frac{\varphi^{m/2}}{(aR_w)^{1/2}}\right] Sw^{n/2} \qquad (2)$$

This formula is known as Indonesian Model, and (V_{cl}, fraction) is the clay volume, and (R_{cl}, Ohm.m) is the formation resistivity at clayey formation.

II. ARCHIE PARAMETERS AND PHYSICAL ROCK PROPERTIES

There is a direct relationship between Archie parameters and number of physical rock properties. Rock formation factor has a relationship with cementation exponent (m) and tortuosity exponent (a) through this formula [3];

$$F = \frac{a}{\varphi^m} \qquad (3)$$

The values of (m) is varies from (1.3-4), for (a) value which varies from (0.6-3), this variation is according to the formation characterization.

Water saturation can be expressed as a function of resistivity index and related to (n) value as follows [4];

$$1/Sw^n = \frac{R_t}{R_o} = I \qquad (4)$$

Where I is the resistivity index and R_o is the formation resistivity at a zone with 100% water saturation. The values of the saturation exponent (n) varies from (1.8-4) according to formation characteristics.

III. AIM AND THE AREA OF STUDY

The aim of the study is to determine the cementation exponent (m) and tortuosity factor (a) at Asmari Reservoir using two different methods; Pickett Plot and X-Y Cross Plot and make a comparison between them to reveal the effect of shale presence on the determination accuracy.

Asmari Formation is founded in Abughirab oil field in southern part of Iraq. It belongs to tertiary period and it is regarded as a carbonate reservoir with shales. Four wells are used in this study for estimation (m) and (a) parameters.

The available data from each well are formation porosity (φ), formation true resistivity (R_t), formation water resistivity (R_w), clay volume (V_{cl}), formation resistivity at clayey formation (R_{cl}), and saturation exponent (n).

A. Pickett Plot Method

Pickett, 1966 [5] introduced his famous method to calculate Archie parameters. The procedure of this method is illustrated as follows:

First, recalling Archie equation

$$Sw^n = \frac{aR_w}{\varphi^m R_t}$$

Second, taking the logarithm with base 10 for both sides of the equation and rearranging yields,

$$logR_t = -nlogS_w - mlog\varphi + logaR_w \qquad (5)$$

At Water bearing zone S_w=100%, so applying (5) again with this case yields,

$$logR_t = logaR_w - mlog\varphi \qquad (6)$$

This formula is a linear equation and it can be plotted on a log-log scale, where y-axis is $logR_t$ and x-axis is $log\varphi$ with slope ($-m$) and $logaR_w$ is the interception point@ φ=1. Figures (1-4) illustrates the Pickett plots for the four wells at Asmari reservoir and the red line represents Sw 100% line. The results of cementation factor (m) and tortuosity factor (a) from this method are tabulated in table (I).

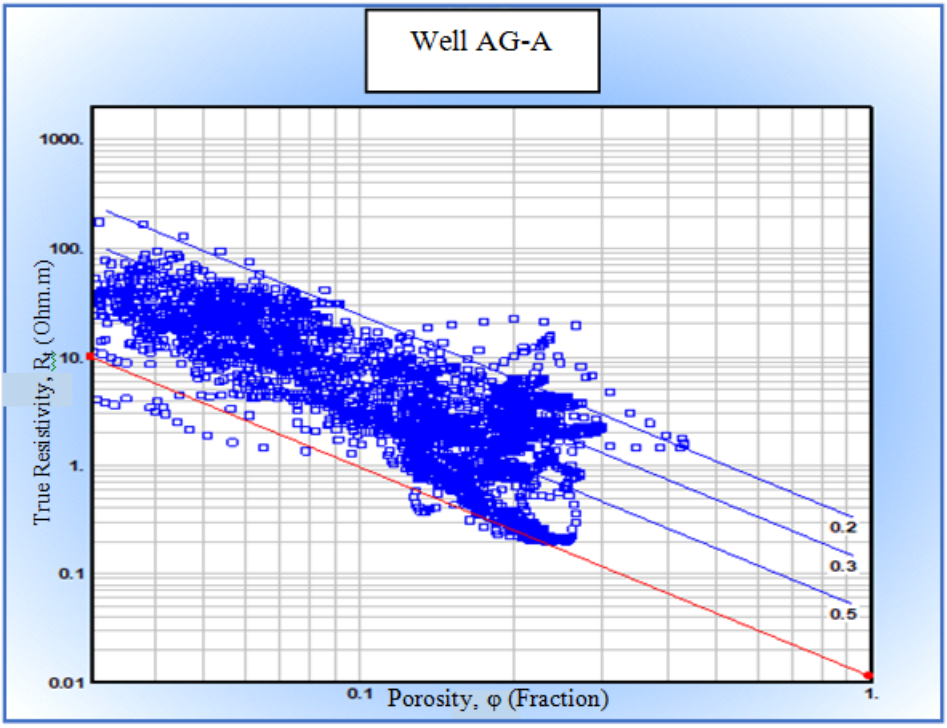

Fig.1 Pickett Plot of Well AG-A

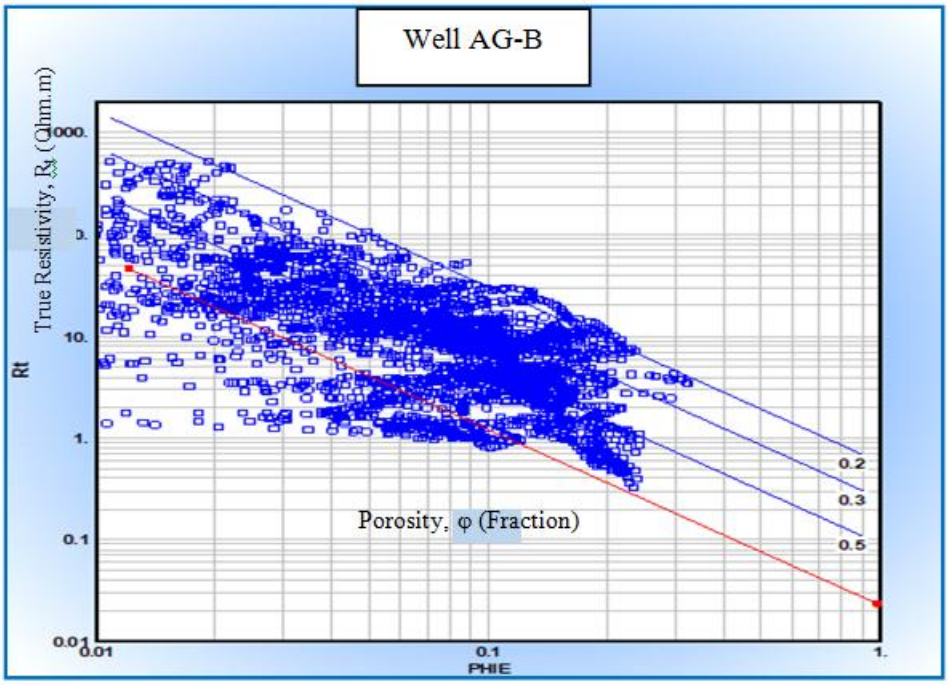

Fig. 2. Pickett Plot of Well AG-B

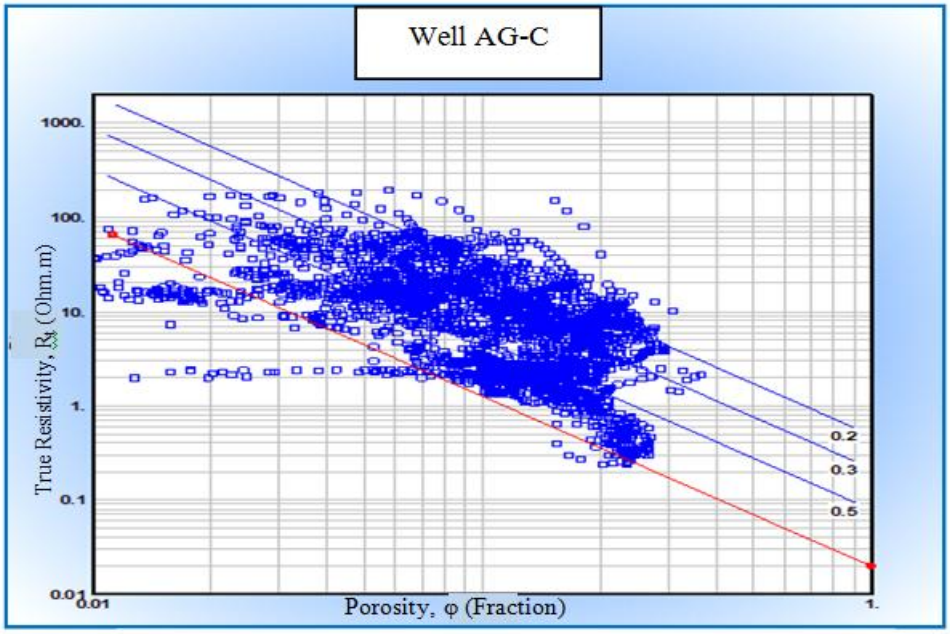

Fig. 3. Pickett Plot of Well AG-C

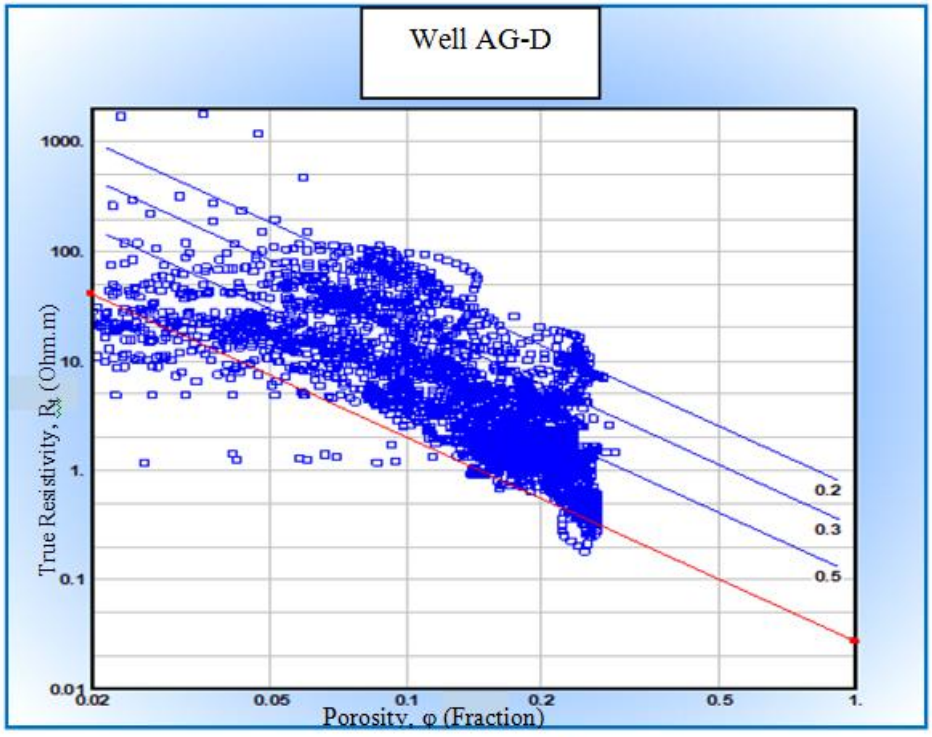

Fig. 4. Pickett Plot of Well AG-D

Table I. Pickett Plot Results

Calculated Archie Parameters (a and m) for Asmari Reservoir					
Well	R_w	aR_w	*a*	*m*	*n*
AG-A	0.022	0.0120	0.60	1.94	2.20
AG-B	0.022	0.0232	1.06	1.73	2.03
AG-C	0.033	0.0188	0.60	1.81	1.95
AG-D	0.032	0.0272	0.84	1.87	2.10

B. X-Y Cross Plot Method [6]

As mentioned previously the existence of clay has a great effect on the determination of the formation petrophysical properties, especially the water saturation. Thus the effect of clay will be included in the saturation equation through using the Indonesian model. By recalling equation (2);

$$\frac{1}{R_t^{1/2}} = \left[\frac{V_{cl}^{(1-0.5V_{cl})}}{R_{cl}^{1/2}} + \frac{\varphi^{m/2}}{(aR_w)^{1/2}}\right] Sw^{n/2}$$

By multiplying both sides with the quantity $((aRw)^{1/2}/\varphi^{m/2})$ and rearranging yields;

$$\frac{(aR_w)^{1/2}}{\varphi^{m/2}R_t^{1/2}} = \left[Sw^{n/2}\frac{(aR_w)^{1/2}V_{cl}^{(1-0.5V_{cl})}}{\varphi^{m/2}R_{cl}^{1/2}} + Sw^{n/2}\right] \qquad (7)$$

Equation (7) can be converted to a linear equation as follows;

$$Y = BX + C \qquad (8)$$

Where;

$$Y = \frac{(aR_w)^{1/2}}{\varphi^{m/2}R_t^{1/2}} \quad and \quad X = \frac{(aR_w)^{1/2}V_{cl}^{(1-0.5V_{cl})}}{\varphi^{m/2}R_{cl}^{1/2}} \qquad (9)$$

And,

$B = C = Sw^{n/2}$

The water saturation isograms can be derived on log-log scale by utilizing equation (8). Since the values of (n) are known previously, then we can apply this equation easily. Starting with constructing the Sw = 100% line as follows;

B = C = 1, then Y = X + 1

X	*(X+1)*	*Y*
0.01	0.01+1	1.01
0.10	0.10+1	1.10
1.0	1.0+1.0	2.0
10	10+1.0	11
100	100+1.0	101

Same procedure to construct the other water saturation isograms for Sw (50%, 30%, 20%).

After constructing the water saturation isograms the values of X and Y are calculated through equations (9), since the values of (a) and (m) are unknown then a trial and error process will be done by assuming the values of the both previous parameters till the values of X versus Y on the cross plot matches with the Sw line (100%).

Figures (5-8) illustrates the X-Y cross plots and the water saturation isograms are mentioned on it for the Asmari reservoir at Abughirab field from the four selected wells. The red curve represents Sw 100% line.
This method shows that the estimated values of (a) are ranging from (0.71-0.76), while the values of (m) are varies from (1.62-1.81) with a quick look on the extracted results from Pickett plot method and X-Y cross plot method the effect of clay presence is significant. See table (II).

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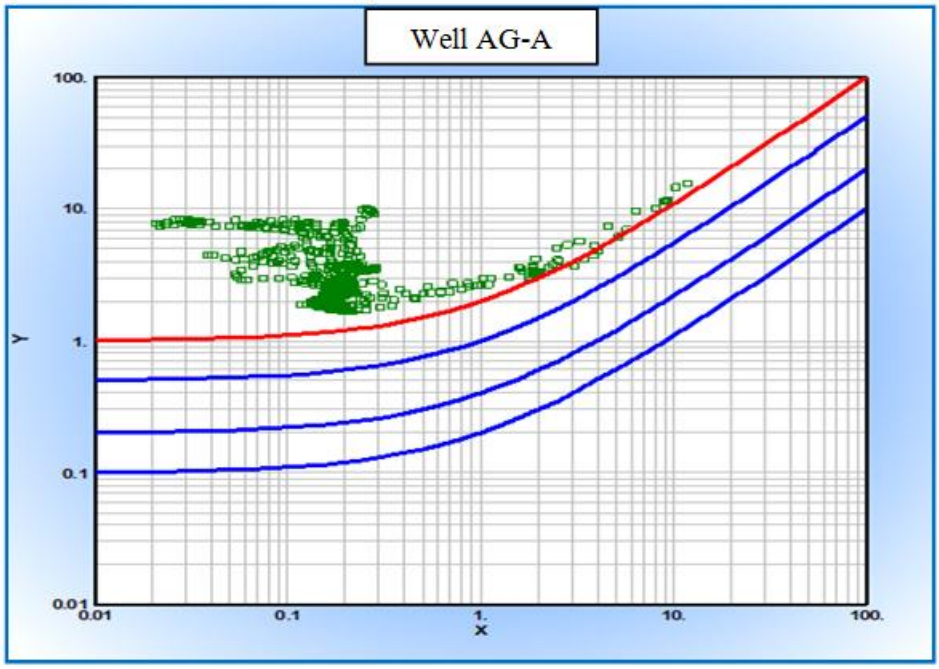

Fig. 5. X-Y Cross Plot of Well AG-A

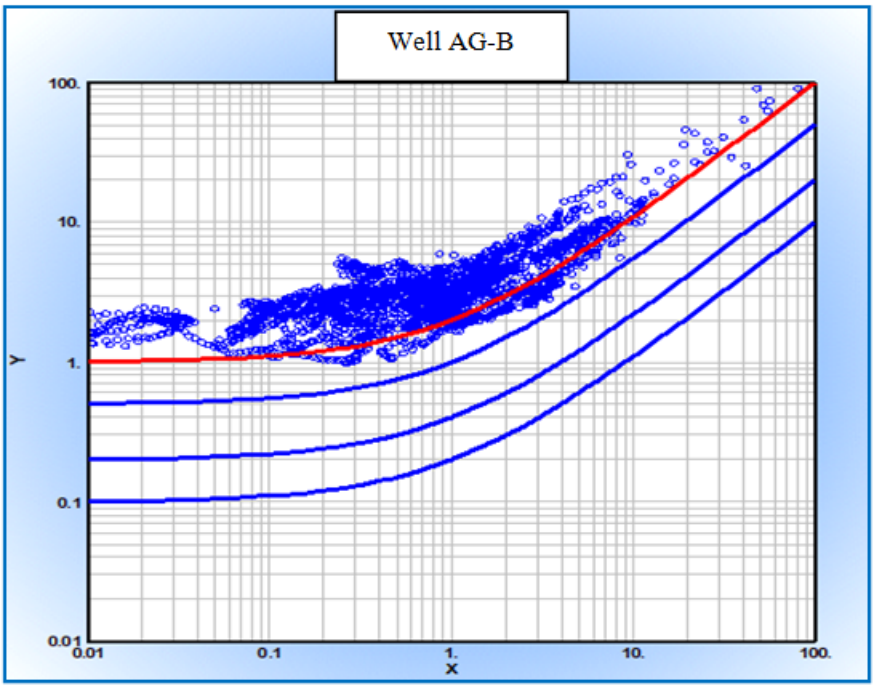

Fig. 6. X-Y Cross Plot of Well AG-B

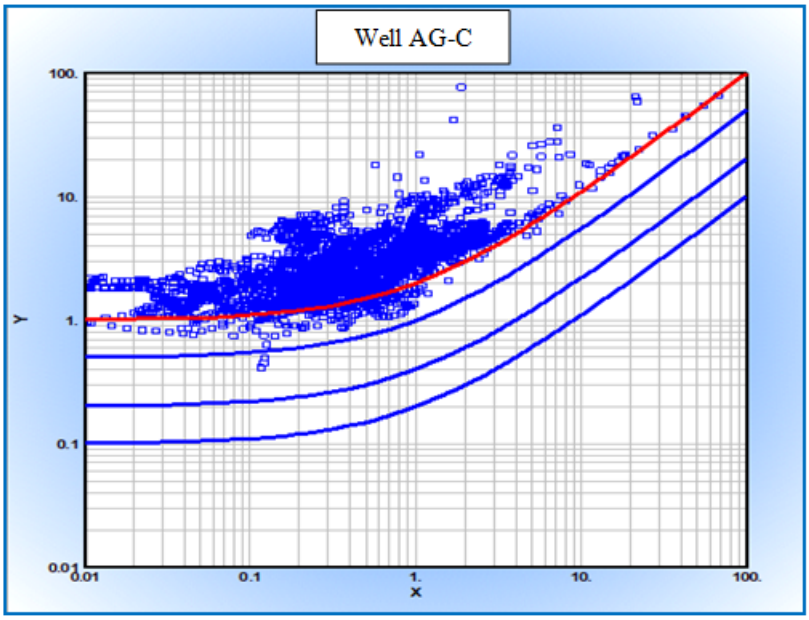

Fig. 7. X-Y Cross Plot of Well AG-C

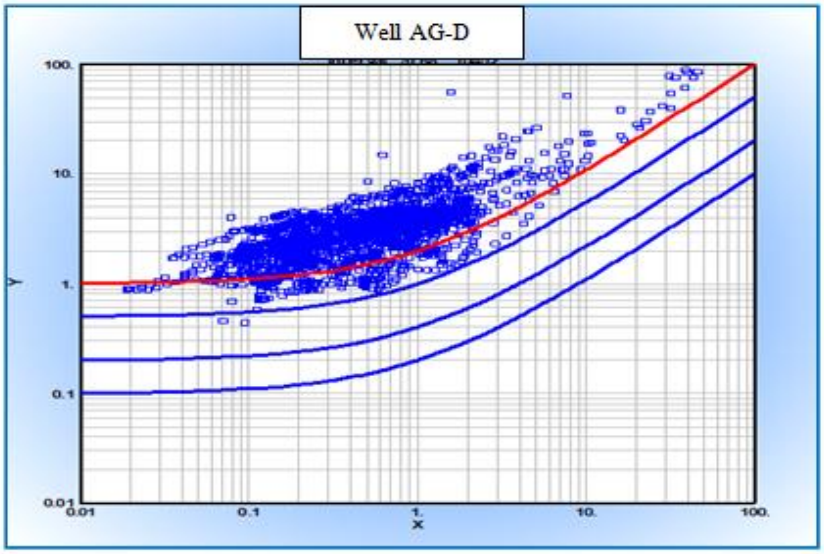

Fig. 8. X-Y Cross Plot of Well AG-D

Table II. X-Y Method Cross Plot Results

Calculated Archie Parameters (a and m) for Asmari Reservoir					
Well	R_w	R_{cl}	*a*	*m*	*n*
AG-A	0.022	3.50	0.71	1.81	2.20
AG-B	0.022	1.30	0.77	1.62	2.03
AG-C	0.033	1.92	0.75	1.73	1.95
AG-D	0.032	1.16	0.76	1.78	2.10

By calculating the water saturation values from equation (2) by using the results of (a) and (m) from both methods it will be obvious how the values of water saturation will be affected by these changes. Figures (9-12) shows the differences between water saturation that obtained from Pickett plot (Swpickett) and water saturation that obtained from X-Y cross plot (SwXY). The percentage of variance of water saturation can be obtained through the following equation;

$$Sw_{variance} = \frac{(SwXY - Swpickett)}{SwXY} \times 100\% \qquad (10)$$

The results show that the changes percentage varies from (0-45) % and this is related to variance of the petrophysical properties as well as the presence of shale. Figures (13-16) illustrate that for the four wells at Asmari reservoir.

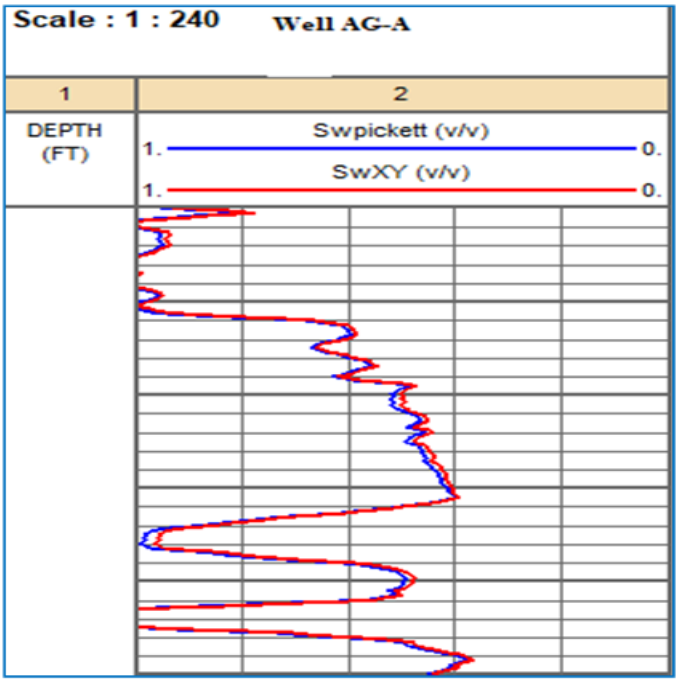

Fig 9. Water Saturation Results From Pickett and X-Y Plot Methods of Well AG-A

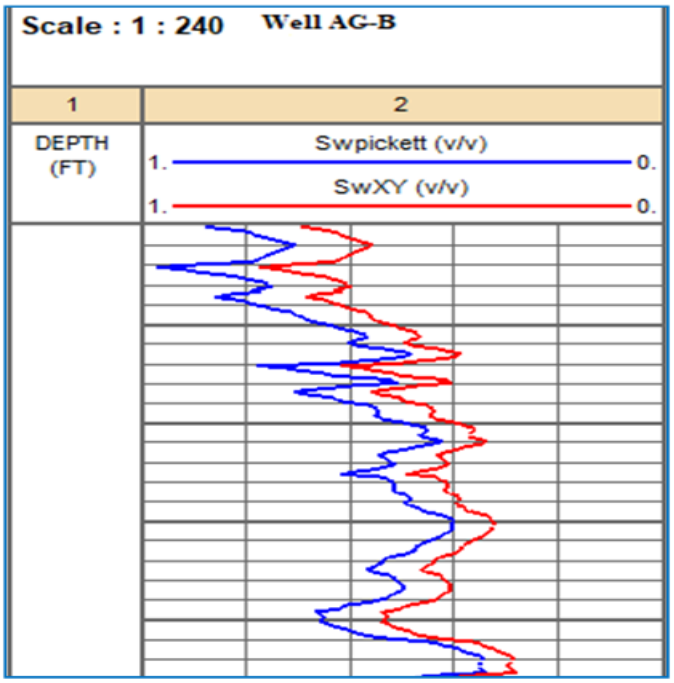

Fig 10. Water Saturation Results From Pickett and X-Y Plot Methods of Well AG-B

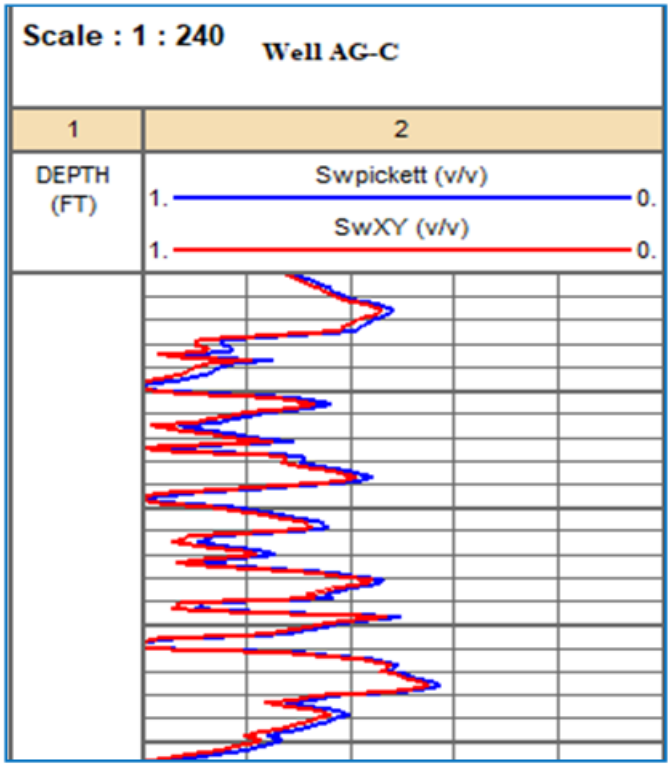

Fig 11. Water Saturation Results From Pickett and X-Y Plot Methods of Well AG-C

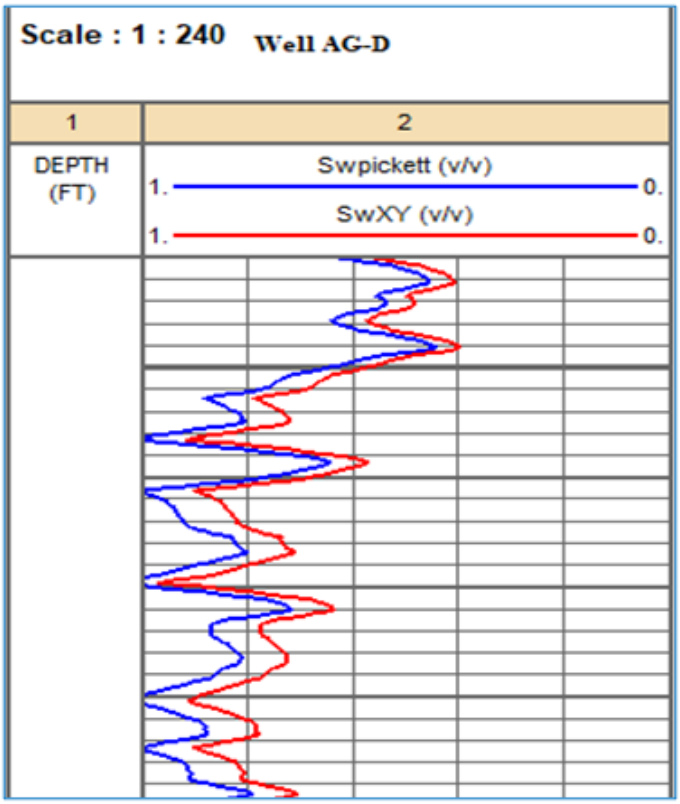

Fig 12. Water Saturation Results From Pickett and X-Y Plot Methods of Well AG-D

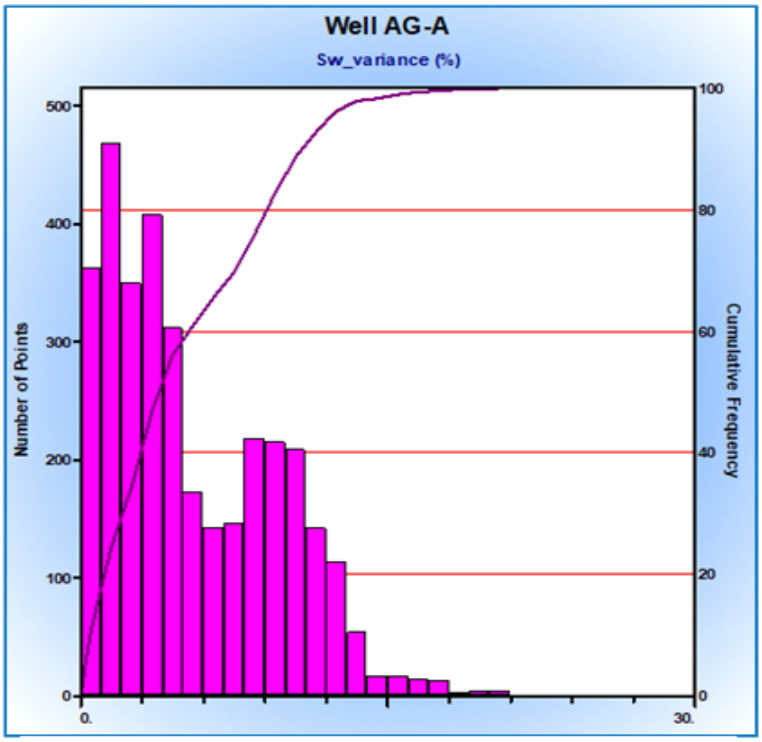

Fig 13. Water Saturation Percent of Variance Frequency Calculated From Pickett and X-Y Plot Methods of Well AG-A

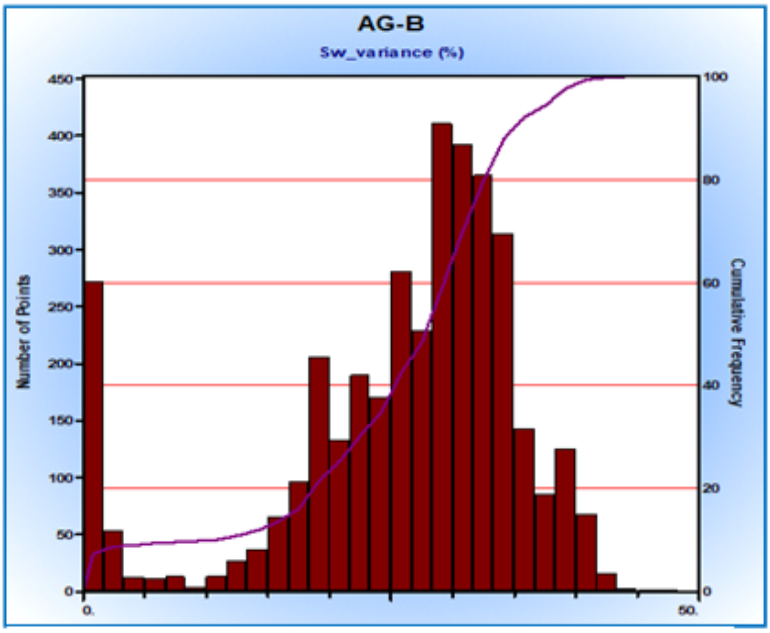

Fig 14. Water Saturation Percent of Variance Frequency Calculated From Pickett and X-Y Plot Methods of Well AG-B

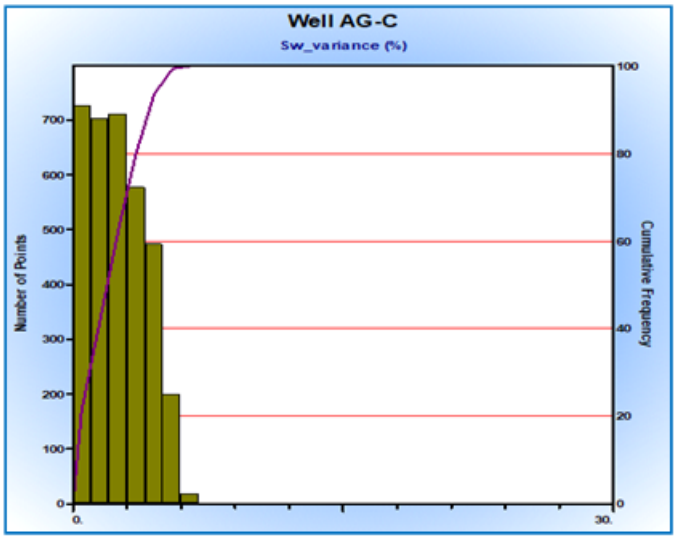

Fig 15. Water Saturation Percent of Variance Frequency Calculated From Pickett and X-Y Plot Methods of Well AG-C

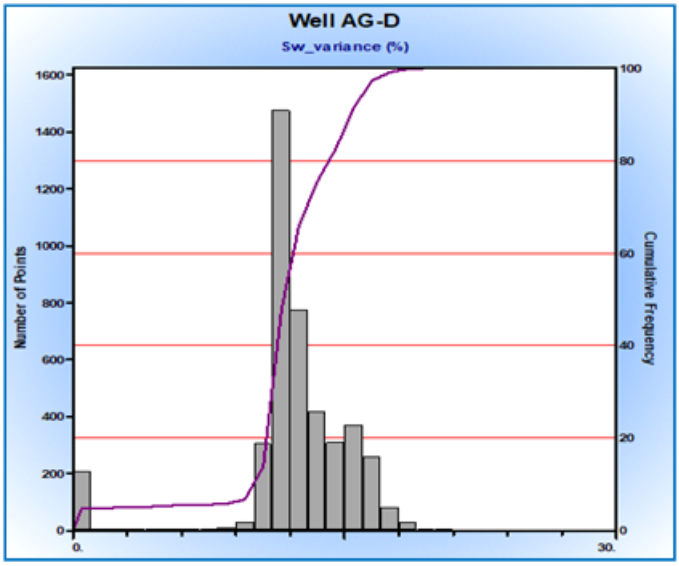

Fig 16. Water Saturation Percent of Variance Frequency Calculated From Pickett and X-Y Plot Methods of Well AG-D

IV. CONCLUSIONS

- Pickett plot method is useful in clean formations to extract Archie parameter, but with the existence of clay a modified method should be used to include that effect where at Asmari formation that contains significant amounts of shales, the X-Y cross plot has been used and there was a significant difference between the extracted values of (a and m) parameters.
- The values of cementation exponent (m) at Asmari formation based on X-Y cross plot method varies from (1.62-1.81) and this give an indication of low to moderate cementation between the rock grains and the presence of clay as well as the fractures. Same thing for tortuosity factor (a), that varies as (0.71-0.76).
- Archie parameters (a, m, and n) has a major and sensitive effect on the reservoir water saturations calculation especially with presence of shales. This is obvious through the comparison between the calculated water saturation based on the results of (a and m) from Pickett plot and X-Y cross plots. The results of water saturation calculated from the data of four wells penetrated Asmari formation show a significant change and the percentage of variance in the different zones in the four wells varies as (0-45) % and this is very sensitive in the calculations of hydrocarbon volumes.

ACKNOWLEDGMENT

My faithful wife Mrs. A. M. Hassan, thanks for your kind support.

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