ACCURACY ANALYSIS OF ARCHIE PARAMETERS AND RELEVANT EFFECT ON WATER SATURATION VALUES

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ABSTRACT
Early in the life of reservoirs, it is required to estimate accurately hydrocarbon volumes in place. Modified Archie formula ($S_w = (a\,R_w / \phi^m\,R_t)^{1/n}$) is the basic equation to calculate water saturation. The exactness of water saturation value for given reservoir conditions depends on the accuracy of Archie parameters a, m and n. The terms of Archie relationship have been subjected to many laboratory investigations and even more speculation. There are many factors affect porosity exponent, m, saturation exponent, n and tortousity factor, a. Therefore, it is very difficult to fix Archie parameters regardless of reservoir characteristics; rock wettability, formation water salinity, permeability, porosity and fluids distribution. This paper presents a new technique to determine Archie parameters a, m and n. The developed technique is based on the concept of three-dimensional regression (3D) plot of water saturation, formation resistivity and porosity. 3D method provides simultaneous values of Archie parameters. Also, 3D method overcomes the uncertainty problems due to the separate use of formation resistivity factor- porosity and water saturation equations to get a, m and n parameters.

INTRODUCTION
Classic petrophysics holds that Archie's parameters a,m and n are constants for a given sample of a reservoir rock. In effect, this presumed constancy formulates the basis for the determination of hydrocarbon saturation from resistivity measurements for a particular lithology. An increasing number of cases are being encountered where the saturation exponent , n, has been observed to vary from the common value of 2. Field experience has also shown that the cementation factor, m, and the tortousity factor,a, depend on the petrophysical properties of a given rock.

Petroleum literature contains many reports of the results determining Archie's parameters and related water saturation. In quantitative log interpretation, an accurate water saturation requires good values of Archie's parameters (Archie, 1942; Sweeney and Jenning, 1960; Ranson, 1984; Hamada et al, 1996).

In this paper, the authors propose a new technique to determine Archie's parameters, three-dimensional regression (3D) technique. This technique is based on the analytical expression of 3D plot of Rt/Rw vs. Sw and,ϕ. Water saturation profiles were calculated using common values, conventional, CAPE and 3D methods for clean sand formations.

ARCHIE PARAMETERS DETERMINATION TECHNIQUES
Conventional technique

Conventional Determination of a **and m** The conventional determination of a and m is based on modified Archie equation ($F = a/\phi^m$) and is rewritten as:

$$\log F = \log a - m \log \phi \qquad\qquad (1)$$

Logarithmic plot F vs. ϕ is used to determine a and m for the core samples

Conventional Determination of n The classical process to determine saturation exponent, n, is based on Archie's water saturation equation ($Sw^n = aRw/\phi^m Rt = 1/ Ir$). This equation is rewritten as:

$$\log Ir = - n \log Sw \qquad\qquad (2)$$

Logaritmic plot of Ir vs. Sw gives a straight line with negative slope n

Core archie-parameter estimation (cape) technique

Maute et al (1992) have presented a data analysis approach to determine Archie's parameters m and n and optionally a from standard resistivity measurements on core samples. The analysis method, Core Archie- Parameters Estimation (CAPE) determines m and n and optionally a by minimizing the error between computed water and measured water saturations. The mean square saturation error ε, is given by

$$\varepsilon = \sum_j \sum_i [s_{wij} - (aR_{wij}/\phi_i{}^m R_{t\ ij})^{1/n}]^2 \qquad\qquad (3)$$

Where s_{wij} is core sample water saturation for number of measurments (i) and on number of core samples (j), $(aRwij/\phi_i{}^m Rt\ ij)^{1/n}$ is water saturation derived from field logging data for certain values of a,,m and n and

3d technique

Methodology The basis of the 3D method is to view S_w in Archie's formula ($S_w{}^n = aR_w/\phi^m R_t$) as a variable in three dimensional regression plot of Sw, Rw/Rt and ϕ. The 3D method determines Archie's parameters a,m and n by solving three simultaneous equations of Sw , Rw/Rt and ϕ. Archie's saturation Eq. is rearranged by taking the logarithm of both sides.

$$\log Rw / Rt = - \log a + m \log \phi + n \log Sw \qquad\qquad (4)$$

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For a given set of data for a core sample, we can obtain an equivalent set of variables X (log ϕ, Y (log S_w) , Z (log R_w/R_t) and A (log a). Eq. 4 will take the following form for i measurement points:

$$Zi = - A + m Xi + n Yi \qquad\qquad (5)$$

After normalizing Eq. 5 for n reading, we can have the following three simultaneous equations

$$\sum Zi \quad = - NA + m \sum Yi + n \sum Yi \qquad (6)$$
$$\sum Zi\, Xi = -A \sum Xi + m \sum Xi^2 + n \sum Yi\, Xi \qquad (7)$$
$$\sum ZiYi = -A \sum Yi + m \sum XiYi + n \sum Yi^2 \qquad (8)$$

Solution of Eqs. 6-8 provides the values of Archie's parameters a,m and n for one core sample. For j core samples, running the same analysis for j core samples produces an average value of Archie's parameters. Fig. 1 shows the flow chart of a computer program for 3D method determining a,m and n for j core samples. Also, this program calculates the standard deviation $\sigma(Sw)$ between the computed and measured water saturations.

APPLICATION
Now, we develop the 3D method by considering field examples of effectively clean sandstone. Table 1 shows typical results from the conventional method, the CAPE method, the 3D method,and the common values (0.65, 2.15,2). In addition to m,n and a values, the average error $\sigma(Sw)$ between measured and calculated water saturations is given.

Also, note that the saturation error $\sigma(Sw)$ decreases as we go from the case where (1) common values are used to the cases where the following methods are used: conventional method with, CAPE method and 3D method. This behavior was expected and it could be attributed to the fact that conventional method tries to optimize the two functions F vs ϕ. and Rt vs. Sw rather than water saturation, while either CAPE or 3D optimizes water saturation. But 3D method is more credited than CAPE by less computer time consuming and by its optimiziation technique which is more physically concerned with water saturation and related factors than CAPE method. Therefore it is recommended to use the 3D method which provides us directily the values of Archie's parameters a,m and n and with an accepted water saturation error. Fig. 2 depicts water saturation profiles calculated by the four options against selected interval for well A. The examination of water saturation profiles has shown that (1) the use of common values yields water saturation values greater than the correct ones, and that (2) Unlike the case of common values the water saturation profiles calculated by conventional, CAPE and 3D methods have shown certain departure from each other. For application where highest possible accuracy in water saturation is desired, it is not recommended to rely on the conventional method and use the CAPE or the 3D method. Moreover, the 3D method is more preferred than the CAPE method because of its more physically representation of the data and because it overcomes the dilemma of whether, a, is to be: Conventional method optimizes the two functions F vs ϕ and Rt vs. Sw rather than water saturation values.

CONCLUSIONS

CAPE method confirms that the quantity one should optimize is not the two functions but rather the water saturation.

3D method provides simultaneously the values of Archie's parameters from standard resistivity measurements on core samples.

3D method answer the controversial question of whether tortousity factor a should fixed at unity or not. It gives directily a, m and n , and thereby, it is recommended to consider the case of the three variables a,m and n

REFERENCES

Archie, G.E., 1942" Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics," Trans., AIME, v. 146, p. 54-62.

Hamada, G.M., Assal, A.M. and Ali, M.A.1996, Improved technique to determine Archie's parameters and   consequent impact on the exactness of hydrocarbon saturation values: SCA # 9623 presented at Intl. Symposium of SCA, Sept. 8-10, Montpellier, France.

Maute, R.E., Lyle, W.D. and Sprunt Eve,1992, Improved Data- Analysis Method Determines Archie Parameters From Core Data," JPT, January 1992, p. 103-107.

Ransom, R. C, 1984, A Contribution Toward a Better Understanding of The Modified Archie Formation Resisivity Factor Relationship," The Log Analyst, no.2 , p. 7-12.

Sweeney, S.A. and Jenning, H.Y, 1960, The Electrical Resistivity of Preferentially Water-Wet and Preferentially Oil-Wet Carbonate Rock,, Schlumberger Publ., v. 24, p. 29-32.

Table 1 Archie Parameters and Calculated water saturations using Different Techniques for Well A

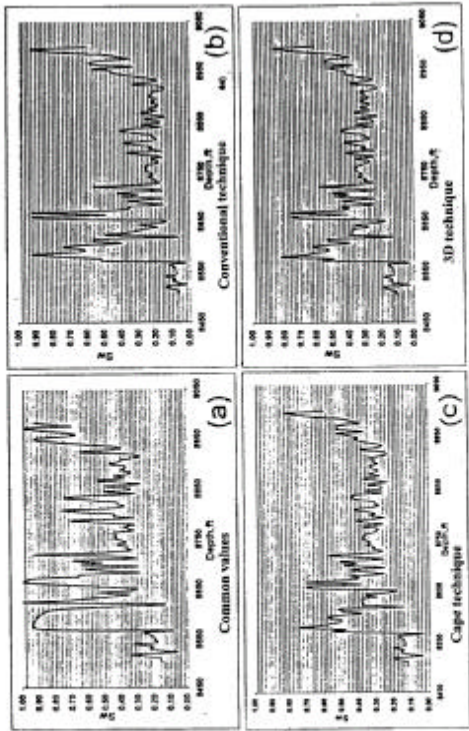| Technique	a	n	m	S_w	σ_{sw}
Common	2.15	2.15	2	0.381	0.14
Conventional	2.3	2.3	1.98	0.311	0.098
Cape	2.887	2.887	1.76	0.297	0.0717
3-D	2.537	2.537	1.87	0.289	0.0686

Fig. 2 Saturation profiles for different Archie's parameters
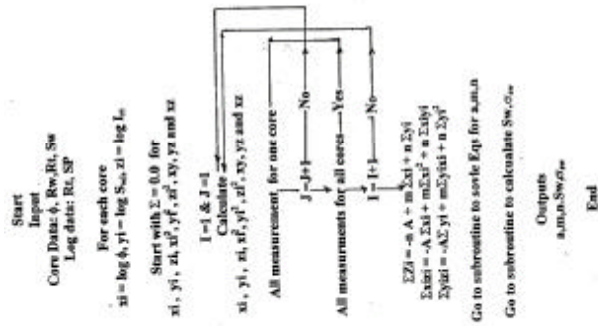
Fig.1 Flow chart to calculate Archie Parameters
by 3D Technique and Sw