Combination of Core Analysis and Dielectric Log Data to Derive Archie Exponents

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ABSTRACT

The determination of Archie exponents m and n is very critical to the proper calculation of oil-in-place. However in carbonate reservoirs, the standard assumption of water being the wetting phase may not be valid. The saturation exponent (n) is highly dependent upon the wetting phase and will often vary from the standard value of 2.0 that is normally used in calculations. Realizing this problem, the paper describes a method in which the cementation exponent (m) is determined using special core analysis. The saturation exponent (n) is then calculated using a procedure which minimizes the error in water saturation.

The calculations use lab derived values for m, then n is determined from an error minimizing technique. The technique uses a least squares summation of the difference in Archie water saturation and dielectric flushed zone saturations. The value for n in the Archie equation is varied until a minimum error is reached. The significance of this method is that the error minimized is the difference between a known water saturation and a calculated water saturation. The m and n values determined by the proposed method can then be used to calculate the Archie water saturation in the uninvaded zone.

The procedure is demonstrated in a case study of a Permian Glorietta-Clearfork Dolomite in the Monahans field. The calculations reveal a difference of over 8% in water saturations between standard Archie saturation calculation (n=m=2.0) and the proposed method. In the case study the proposed method accurately predicted a much lower oil-in-place than the standard Archie method.

INTRODUCTION

The Archie exponents m and n play an important role in the calculation of water saturations from log data. Even with the most advanced log packages, knowledge of these parameters is crucial to proper log analysis. The problem of finding values for the cementation exponent (m) and the saturation exponent (n) to use in Archie's equation is complex when one is dealing with a carbonate reservoir. This is due to the variations in porosity types and pore geometries found in carbonate reservoirs(1-2). Numerous authors have reported that the standard assumption of a water-wet media is not always the case when dealing with a carbonate reservoir(3). Also, it has been observed that the wettability of the reservoir has the greatest impact upon the saturation exponent(4-6). These variations result in wide fluctuations in the value of the Archie exponents adding greatly to the problem of accurate log analysis.

Reliable values for the cementation exponent(m) may be determined from core analysis; however, the determination of the saturation exponent from core analysis is more difficult and usually very expensive. The determination of the cementation exponent involves taking resistivity measurements at only one saturation ($S_w = 1.00$), while the measurement of the saturation exponent requires varying the saturation under steady-state conditions. The fact that proper determination of the saturation exponent requires steady-state conditions forces the procedure to be very time consuming and therefore expensive. Also, the questions of altered wettability of the sample and the fact that the fluid distributions are altered from the native conditions, further complicate the result of lab derived n values.

Maute et al. (1991) proposed a new method that compared core derived water saturations to water saturations calculated using Archie's equation(7). This method, called CAPE (Core Archie Parameter Estimation), statistically varies the values for m and n in Archie's equation until a minimum error is reached between S_w(core) and S_w(Archie). In this method the values for both m and n are allowed to vary until the minimum error is calculated using least squares summation as in equation 1.

$$\varepsilon = \sum \left[S_{W_{core\,i}} - \left(\frac{1}{\Phi_i^m} * \frac{R_w}{R_{t_i}} \right)^{1/n} \right]^2 \tag{1}$$

Where:

ε - Error
S_w- Water Resistivity of Uninvaded Zone
R_w - Resistivity of Formation Water
R_t - True Formation Resistivity
Φ - Porosity
m - Cementation Exponent
n - Saturation Exponent
i - Depth Increment

However a limitation of the CAPE method is the limited availability of core data and even when core data are available the reconstruction of in-situ water saturations is difficult to achieve. This inability to reconstruct original reservoir conditions in the lab causes significant problems in the determination of the saturation exponent as the laboratory procedure may easily alter the wettability of the rock.

PROCEDURE

The authors propose a new procedure in which the laboratory determination of the saturation exponent is not required. Water saturations calculated from dielectric logs will be substituted for the core water saturations and the error equation will be modified as in equation 2.

$$\varepsilon = \sum \left[S_{XO_{ept_i}} - \left(\frac{1}{\Phi_i^{m_i}} * \frac{R_{mf}}{R_{xo_i}}\right)^{1/n}\right]^2 \qquad (2)$$

Where:

ε - Error
S_{xo}- Water Resistivity of the Flushed Zone
R_{mf} - Resistivity of the Mud Filtrate
R_{xo} - Resistivity of the Flushed Zone
Φ - Porosity
m - Cementation Exponent
n - Saturation Exponent
i - Depth Increment

Saturations from dielectric logs may be substituted for core measured water saturations because dielectric water saturations are calculated independently of m and n values as in equation 3.

$$S_{XO_{ept}} = \frac{\Phi_{ept}}{\Phi_t} \qquad (3)$$

Where:

S_{xo}- Water Resistivity of the Flushed Zone
Φ - Porosity

The advantage of using dielectric water saturations is that these saturations are calculated from data measured in place and therefore the calculated water saturation is at reservoir conditions. One problem associated with the use of dielecric saturations is that the log is measuring the flushed zone water saturation and during invasion the wetting behavior of the rock may have been altered. However, it must be remembered that even native-state core data also represents flushed zone conditions.

Using data taken from the Permian Glorietta-Clearfork dolomite in the Monahans Field,located in Ward county, Texas, core lab values for porosity and cementation exponent are plotted(Fig. 1). A curve fit is preformed on the data to obtain a mathematical relationship between porosity and m. This relationship is then used to calculate m values at 1 foot intervals for the 30 foot porosity zone, illustrated in figure (2). The 30 cementation(m) values are then used in equation 2 to calculate the saturation exponent(n) values that result in the minimum error between $S_{xo(ept)}$ and $S_{xo(Archie)}$. The result of the application of the method results in an n value for the zone of 2.45. Thus indicating that the standard assumption of n=2.00 would lead to erroneous values for oil-in-place. A cross plot of the values for S_W calculated using the different values for saturation exponent is shown in figure(3), it can be seen that all thirty of the points show a higher water saturation than those using n=2. This results in a significant difference in water saturations of 30.1% for n=2, m=2 and a water saturation of 38.7% for the new method. The figure also shows the difference in hydrocarbon pore-feet of 0.3. These differences in oil-in-place indicate the importance of combining core analysis with log data to accurately calculate water saturations in carbonate reservoirs.

APPLICATION OF THE METHOD

The application of this technique may be easily accomplished by the procedure outlined in Table 1. This application may be simplified further by obtaining a computer program to preform the statistical error minimizing calculations. Such a program (MN), written in PASCAL for IBM or compatible personal computers, is available free of charge from the authors(8).

Table 1 Application Procedure

1) Subdivide the reservoir into correlatable zones.

2) Use the available core data to create a porosity versus m transform (curve fit).

3) Use available Dielectric Logs to determine n for each zone by least squares summation (Program MN).

4) In the remaining wells generate m by applying the porosity versus m transform in each zone.

5) Then use the n value calculated to obtain water saturations for each zone.

It is important to remember that in some carbonate reservoirs different zones may result in different porosity verses m relationships, therefore be sure to use the correct relationship when calculating the cementation exponents in each zone.

SUMMARY

By combining core analysis with dielectric log data the saturation exponent (n) can be calculated. These n values are those that result in the minimum error between the flushed zone water saturations determined from dielectric logs and the flushed zone water saturations calculated by Archie's equation.

The procedure is to first determine the values for porosity and cementation exponent from core analysis. The results of the core analysis are plotted and curve fit to obtain a relationship between the porosity and the cementation exponent for a particular zone. Next dielectric water saturations are compared to Archie saturations in the flushed zone. The Archie exponents are obtained from the porosity versus m relationship and the n value that results in the least error in flushed zone saturations between the two methods using least squares summation. The m and n values obtained from this procedure are then used to calculate the water saturation in the uninvaded zone of the reservoir.

Data from a 30 foot porosity zone in the Permian Glorietta-Clearfork dolomite in the Monahans Field,located in Ward County, Texas resulted in m values that ranged from 1.96 to 2.20 and an n value of 2.45. The low m values (<2.30) indicate that the reservoir porosity type is predominantly intercrystalline(3) and the low n value (2.45) indicates that the reservoir is dominantly water-wet(9). In the example, based on a 40 acre spacing, standard values for Archie exponents (n=2,m=2) results in the calculation of 828,554 BO in place. While the new method results in the calculation of 735,458 BO in place. This difference in calculation of reserves shows the significance of the new method.

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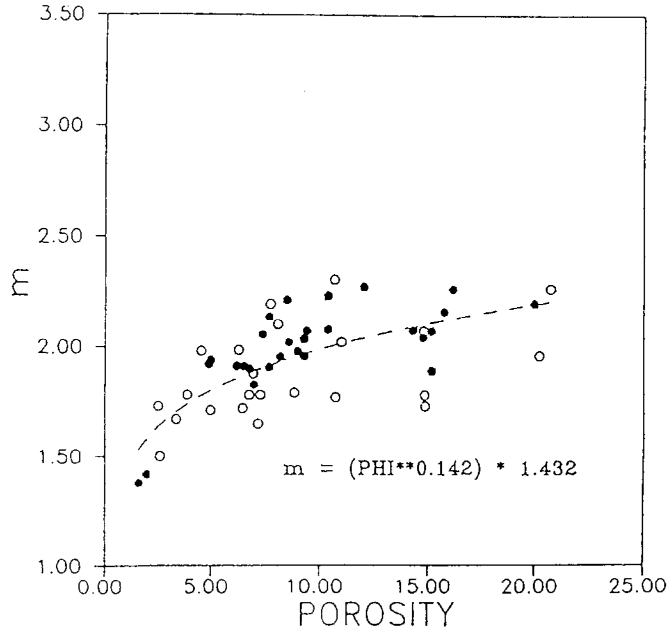

Figure 1 - Core-derived porosity vs. m plot

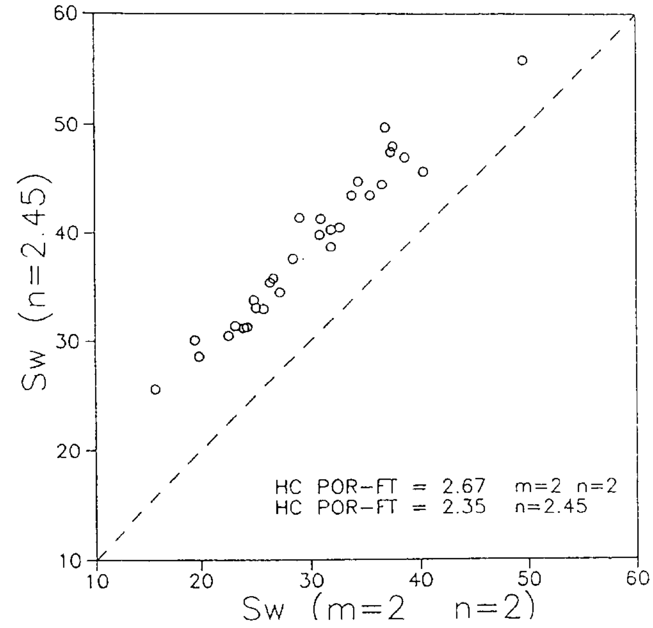

Figure 3 - Crossplot of water saturation calculated using m=n=2.0 vs. water saturation using variable m and n=2.45 for the Glorietta porosity zone illustrated in Figure 2

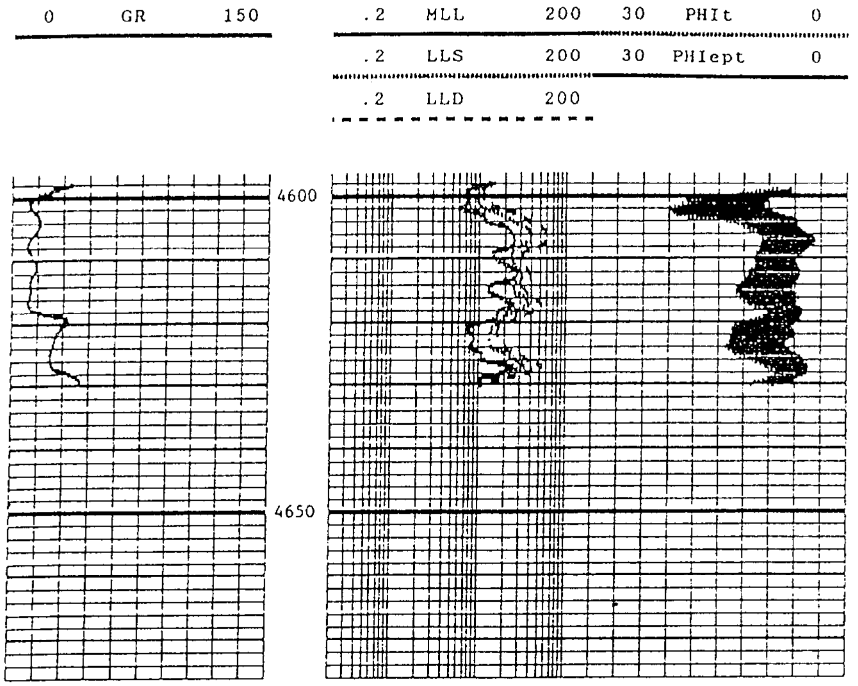

Figure 2 - Gamma ray and dual laterolog - MLL with total porosity (PHI_t) for the example well. (Note: Dark area in track 3 is due to presence of hydrocarbons.)