Determination of Archie Parameters m and n by Combining Core Analysis with Dielectric Logs

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ABSTRACT

The determination of the Archie exponents m and n is critical to the proper calculation of oil in place. Due to variations in pore geometry in carbonate reservoirs, it is critical to determine cementation exponents (m) at all depths in the reservoir. Because carbonate reservoirs are not universally water wet saturation exponents (n) in carbonate reservoirs often differ from the standard value of 2.0. Therefore, to determine accurate water saturations, a combination of core analysis data together with dielectric log data was used to determine the Archie Parameters m and n.

Using core data and dielectric log data from the Permian Glorietta-Clearfork Dolomite in the Monahans field in Ward County, Texas, m and n were determined by the following procedure. First, 60 core-measured porosity and m values were cross plotted and curve-fit to derive a porosity versus m transform. Next, flushed zone water saturations (S_{xo}) were determined from the dielectric log data. Then n was determined by calculating the value of n giving the minimum error between S_{xo} obtained from a dielectric log and S_{xo} determined by the Archie equation using the least squares technique over all depths in the reservoir. When calculating the minimum error, m is calculated at each depth using the core-derived porosity versus m transform and n is varied to obtain the minimum saturation error. It is important to remember that the n value determined by least squares summation is the n value that results in the minimum error in the calculation of water saturation. The n value

determined by the above procedure using the Monahans field data is 2.45, thus indicating that the reservoir is predominately water wet.

The m and n values determined by the core-derived porosity versus m transform and least squares summation based on dielectric log data can then be used to calculate the Archie water saturations of the uninvaded zone (S_w). Archie water saturations calculated using m = 2.0 and n = 2.0 averaged 30.1 percent. However, Archie water saturations calculated using the core derived porosity versus m transform and n = 2.45 averaged 38.7 percent. Thus, the importance of using core data integrated with log data in formation evaluation is demonstrated.

INTRODUCTION

Carbonate reservoirs are characterized by a variety of pore types that include intercrystalline, intergranular, vuggy, moldic, fracture, and intragranular porosity(Asquith, 1984). In addition, carbonate pore types often vary in a single carbonate reservoir. As a result of the variations in carbonate pore types and the concomitant variations in pore geometry, cementation exponents(m) can often vary throughout a carbonate reservoir (Focke and Munn,1987). Further complicating the log analysis of carbonate reservoirs, oil has greater affinity (wettability) for calcite and dolomite than for quartz. Therefore, carbonate reservoirs may not always be water wet. Keller (1953), Morgan and Pirson. (1964), Ransom (1984), Rasmus (1987), and Donaldson and Siddiqui (1987) have reported that wettability of oil relative to the reservoir rock has the greatest effect on the saturation exponent (n). Therefore, in carbonate reservoirs the value of the saturation exponent (n) may differ greatly from the standard value of 2.0 assumed for water-wet rock. Reliable values for cementation exponents (m) can be obtained from both core analysis and from the log data. However, the determination of the saturation exponent (n) from core analysis is much more difficult than obtaining m from core analysis. The problem encountered in determining the saturation exponent (n) from cores is the inability often encountered in reconstructing original reservoir conditions in the laboratory. When non-native state cores are taken and the core is treated in the laboratory, the original wettabilities are often changed. Unfortunately, native state cores are rarely available for analysis.

A new method is proposed to determine cementation and saturation exponents. The new method uses core-derived porosity versus m transforms to determine the cementation exponent (m). The saturation exponent (n) is then determined by using the saturations near the wellbore (S_{xo}) from dielectric logs and determining the value of n that minimizes the error between the log values and S_{xo} calculated by Archie's Equation.

Maute, et al. (1991) proposed a new method that compared core-derived water saturations to water saturations calculated using Archie's equation. 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 the least squares technique as shown in Eq. 1.

$$\varepsilon = \sum \left[S_{W_{core_i}} - \left(\frac{1}{\phi_i^m} * \frac{R_w}{R_{t_i}} \right)^{1/n} \right]^2 \qquad (1)$$

Where:

ε - Error
S_w- Water Saturation 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

PROCEDURE

A new procedure is proposed 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 shown in Eq 2, which follows:

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

Where:

ε - Error
S_{xo}- Water Saturation 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 shown in the equation below :

$$S_{XO_{ept}} = \frac{\phi_{ept}}{\phi_t} \tag{3}$$

Where:

S_{xo}- Water Saturation of the Flushed Zone
Φ_t - Porosity from Porosity Logs
Φ_{ept} - Water-filled Porosity from Dielectric Log Data

The advantage of using water saturations from dielectric logs is that these saturations are calculated from data measured in place and therefore, the calculated water saturation is at reservoir pressure and temperature. One problem associated with the use of dielectric 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 laboratory values for porosity and cementation exponent (m) are plotted (Fig. 1). A curve fit is performed 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 Fig. 2. The 30 cementation exponent values (m) are then used in in Eq. 2 to calculate the saturation exponent values (n) 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. This indicates that the standard assumption of n=2.0 and m=2.0 would lead to erroneous values for oil-in-place. A cross plot of the values for S_w calculated using the m=2.0 and n=2.0 versus variable m and n=2.45 (new method) is shown in Fig. 3. It can be seen that all thirty of the points show a higher water saturation than those using m=2 and n=2. This results in a significant difference in water saturations. They are 30.1 percent for n=2, m=2 and 38.7 percent for the new method. Fig. 3 also shows a 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 below:

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.

This application may be simplified further by obtaining a computer program to perform 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.

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 water saturations in the flushed zone. The Archie exponents are obtained from the porosity versus m relationship and the n value,which is varied until the least error in flushed zone saturations is obtained using the two methods and 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, Focke and Munn (1987), and the low n value (2.45) indicates that the reservoir is dominantly water-wet, Morgan and Pirson (1964). 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 barrels of oil (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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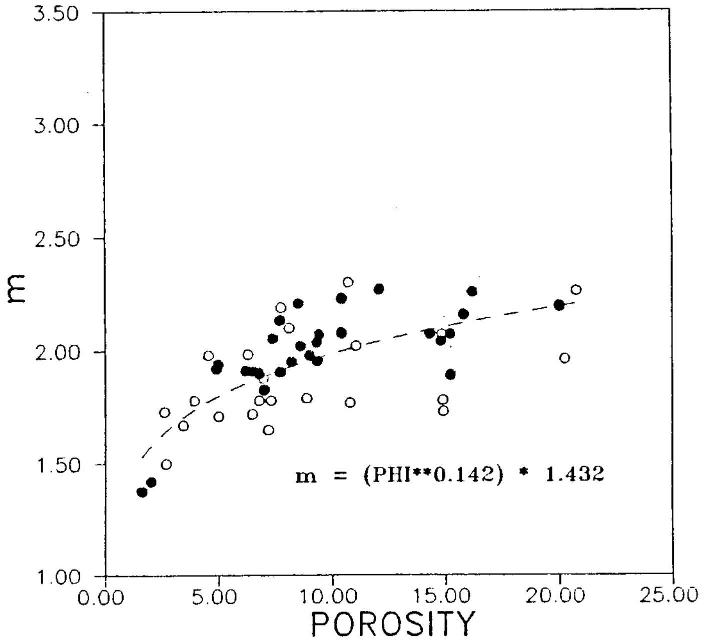

Figure 1.

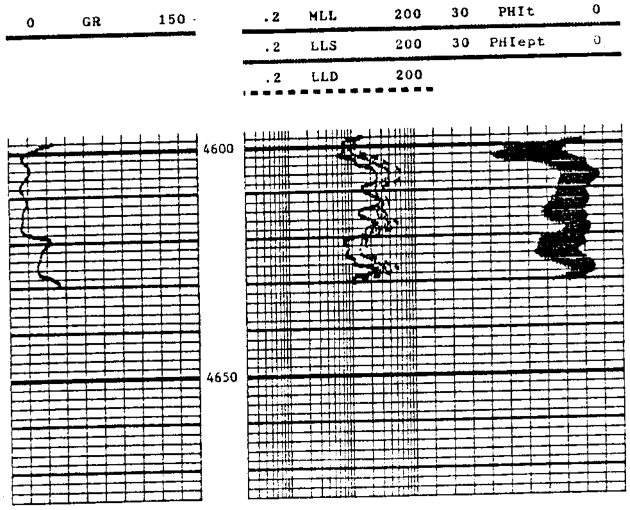

Figure 2.

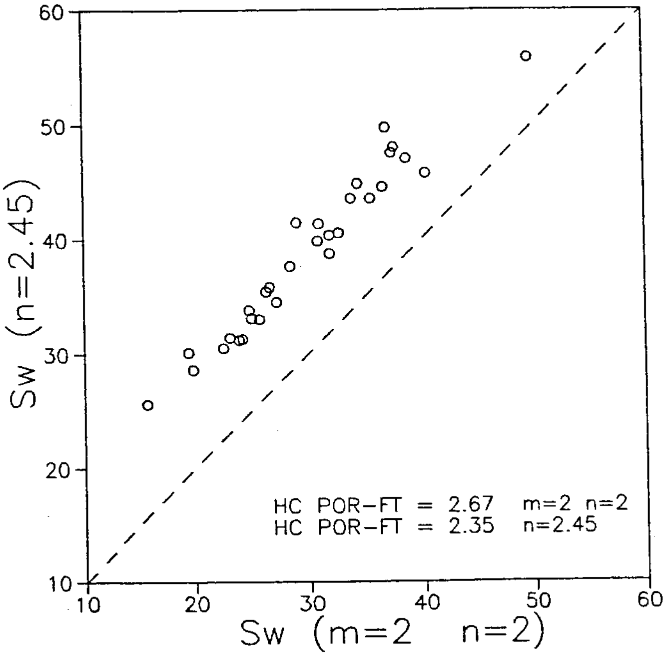

Figure 3.