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Effect of Petrophysical Parameters on Water Saturation in Carbonate Formation

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ABSTRACT
Assessment of petrophysical parameters is very essential for reservoir engineers. Three techniques can be used to predict reservoir properties: well logging, well testing, and core analysis. Cementation factors and saturation exponents are crucial for calculation, and their values pose a pronounced effect on water saturation estimation. In this study, a sensitivity analysis was performed to investigate the influence of cementation factor and saturation exponent variation, as it applies to logs and core analysis, for use in water saturation estimates. Measurements of water saturation resulting from these variations showed a maximum spread difference of around fifteen percent.
Keywords - cementation factor, formation factor, porosity, saturation exponent, water saturation

I. INTRODUCTION

Reservoir rock properties can be predicted by several approaches. One of these basic approaches is geophysical well logging. Many wells drilled for petroleum exploration are “logged”, meaning that a tool containing various sensors is lowered into the borehole and then drawn back up, while the sensors measure various properties of the surrounding rock.

The measured properties generally include electrical, acoustic, and nuclear properties of the surrounding medium, which are the combined properties of both the rock matrix and the fluids in the pore space1. The resulting records of measured properties versus depth are variously referred to as wire line logs, well logs, geophysical logs, or just plain logs. These logs give indirect information regarding the distribution of the critical reservoir properties. Gamma Ray Logging "GR" is a recording of the natural radio activity of formation, indicative of the thorium and potassium present in the rock2. Spontaneous Potential Log is a log of potential difference between a movable electrode in the borehole and fixed surface electrode. The purpose of SP log is to differentiate the permeable from the non-permeable zones. Sonic log is a porosity log that measures interval transit time (Δt) of a compression sound wave traveling through the formation. The sonic log device consists of one or more sound transmitters, and two or more receivers. Neutron logs emits neutrons of high energy from a chemical source and allow it to interact with the nuclei of the formation in different stages. In this process, the concentration of hydrogen (hydrogen index) in the formation is measured. In porous clean sandstone or carbonate formations, neutron log reflects the amount of rock porosity. The formation density log is a porosity log that measures electron density of formation. Electrical resistivity methods involve the measurement of the apparent resistivity of soils and rock as a function of depth position3.

The other approach used to predict reservoir properties is a core analysis technique which involves coring of samples from the formation which has been used in the past to obtain some petrophysical properties of reservoirs in the laboratory. This approach, while being a direct method to recover quality data, satisfies the objective of prudent data-gathering, but coring activities are expensive and cannot be conducted throughout the entire length of the rocks penetrated, and is thus unable to provide a representative sample of the entire depth of the well. Another problem is the possibility of the mud filtrate invasion on the rock next to the wellbore while coring which may cause the fluid distribution in the cores to be different from that in the reservoir rock at in-situ conditions. Hence, relationship developed using the cores obtained in that condition may not correctly predict the reservoir rock parameters. It is desirable to obtain a sample of the rock as it exists at in-situ conditions. This, however, may be impossible since during the drilling process and the subsequent recovery to the surface, the core and its contained fluids are irretrievably altered. Three factors are responsible for this alteration: flushing of the rock ahead of the bit by the drilling fluid, pressure reduction and expansion of the fluid contained in the core, and temperature reduction, which along with pressure reduction, occurs while bringing the core to the surface. All the three factors are responsible for the saturation changes that occur within the core during recovery from the reservoir to surface conditions.

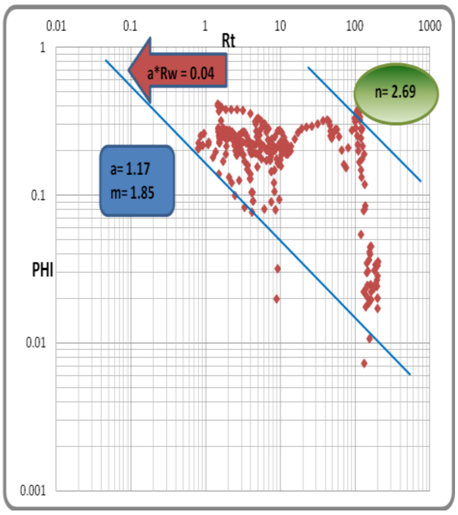
The purpose of this work is to increase awareness on more accurate data-gathering methods for water saturation estimation, while applying it to two methods, logs and core analysis, through application to different properties of carbonate formation.

II. RESULTS AND DISCUSSIONS

The porosity of a zone can be estimated either from a single "porosity log" (sonic, density or neutron) or a combination of porosity logs, in order to correct variable lithology effects in complex reservoirs.¬ The total average porosity values determined in this study are 20.95%, 19.39% for wells 1, and 2 respectively.

Logs and Core Analysis of Wells

The cementation factor "m" depends greatly upon characteristics of the rock, and it is a function of the degree of cementation, shape, sorting and packing of the grains, type of pore systems, presence of conductive solids, compaction due to overburden pressure and thermal expansion. Cementation factor is an essential parameter in Archie formula to determine water saturation, and it can be obtained from special core analysis available, and/or using the relationship between (Rt) and (ØN-E). In this study, Pickett cross-plot was constructed by plotting porosity (ØN-E) values versus true resistivity (Rt) values of two wells on log-log paper. A line of wet resistivity @ 100% Sw was drawn through the most south-west data points and the slope of this line, represent the "m" value. The relationship between (Rt) and (ØN-E) for the wells (1, 2) is shown in figure (1).



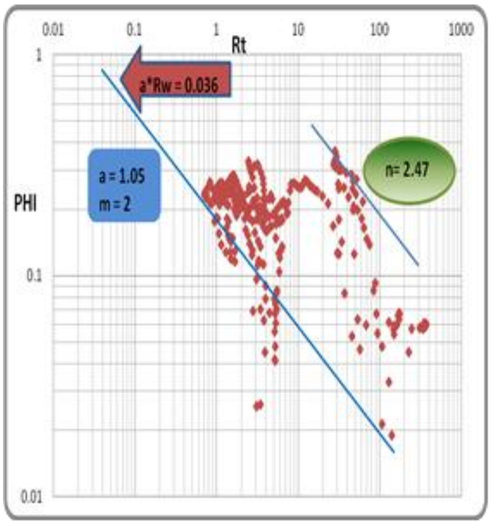


Fig (1) log-log plot of Rt against Ø for wells 1, 2.

The cementation factor can be determined also using the plotting porosity (Ø) versus resistivity formation factor (F) values of two wells on log-log paper, and fit the calculated values to a straight line, figure (2):

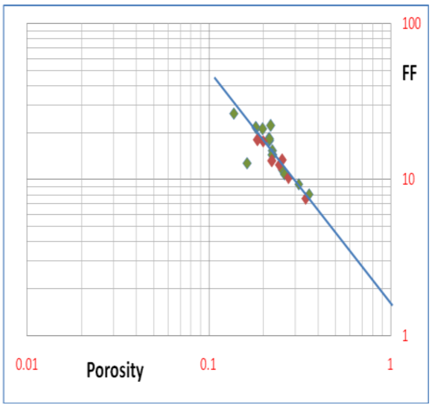


Fig (2) log-log plot of FF against Ø for wells 1, 2.

The saturation exponential (n) was calculated using the Archie equation, and it was obtained too from special core analysis data, using the relationship between (RI) and (Sw), figure (3).

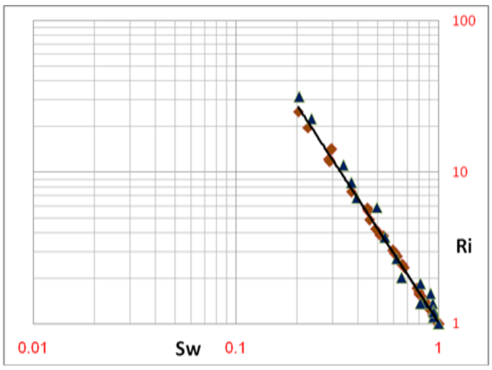


Fig (3) log-log plot of RI against Sw for wells 1, 2

Table 1 summaries the values of cement factor, saturation exponent, and tortuosity factor applying two methods:

Table (1) the saturation exponent, average cementation and average tortuosity factors.

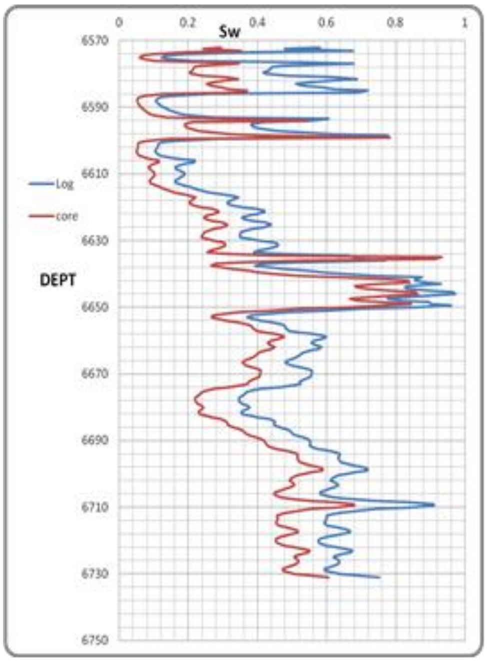
Well No.	Saturation Number (n)		Cementation Factor (m)		Tortuosity Factor (a)	
1	2.69	2.04	1.85	1.47	1.17	1.7
2	2.47	2.15	2	1.40	1.05	1.5

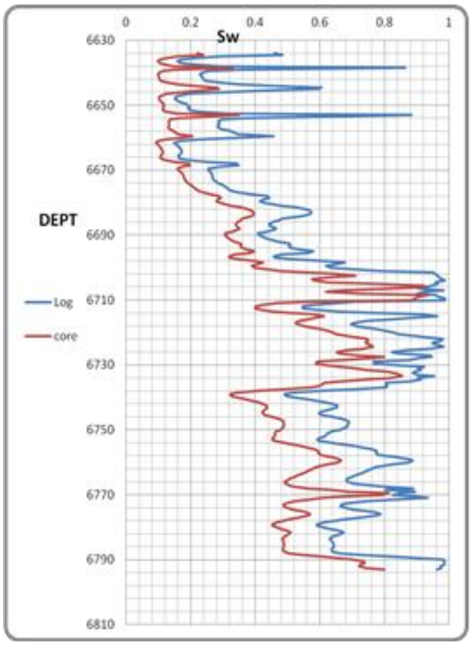
All available measurements performed on reservoir samples and in wells, such as core analysis and well logs, are extensively used in evaluating water saturation (Sw) figure (4), table (2). Combining the two original Archie equations together and rearranging4 to solve for water saturation, Sw Eq 1:

$$Sw = \left[\frac{axRw}{\phi^{m}xRt}\right]^{\frac{1}{n}} \quad \text{(Eq1)}$$

Table (2) average water saturation (Sw%)

Well No	Sw(avg) % from core analysis	Sw(avg) % from logging
1	0.358	0.493
2	0.431	0.600





Fig(4) Sw vs depth from logging & core analysis for wells 1, and 2.

III. INDENTATIONS AND EQUATIONS

The first paragraph under each heading or subheading should be flush left, and subsequent paragraphs should have a five-space indentation. A colon is inserted before an equation is presented, but there is no punctuation following the equation. All equations are numbered and referred to in the text solely by a number enclosed in a round bracket (i.e., (3) reads as "equation 3"). Ensure that any miscellaneous numbering system you use in your paper cannot be confused with a reference [4] or an equation (3) designation.

IV. FIGURES AND TABLES

To ensure a high-quality product, diagrams and lettering MUST be either computer-drafted or drawn using India ink.

Figure captions appear below the figure, are flush left, and are in lower case letters. When referring to a figure in the body of the text, the abbreviation "Fig." is used. Figures should be numbered in the order they appear in the text.

Table captions appear centered above the table in upper and lower case letters. When referring to a table in the text, no abbreviation is used and "Table" is capitalized.

V. CONCLUSION

This study is concerned with water saturation determination in carbonate formation with varying rock properties, through application of well logging and core analysis methods using experimental data to derive tortuosity factor, cementation factor, and saturation exponent, in order to obtain more accurate estimates. Cementation factor determined is 1.93 and 1.44, from logs and cores, respectively. Tortuosity factor equals 1.11, and saturation exponent is 2.58 using logs, while the tortuosity factor equals 1.60, and saturation exponent is 2.095 from core analysis. The average water saturation (sw) for wells from logs and from special core analysis is equal 0.54%, 0.39% respectively.

ACKNOWLEDGEMENTS

An acknowledgement section may be presented after the conclusion, if desired.

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