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Analysis and Implications of the Archie-Haro Equation in Modeling Resistivity of the Rocks

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Abstract

The Archie-Haro equation (modified Archie's equation) theory and accompanying relationships have been proven in the literature (Haro, 2010) by use of the corner angle solution of the Laplace differential equation, which is applicable in electrostatic problems. This approach defines the streamlines that describe the current distribution within the porous system by honoring the tortuosity, topology and conductive-water spread within the rock. Indeed, the openings within the rock frame and conductive paths oblige the electric current to continuously meander and change direction. These changes are quantified by the magnitude of corner angles. The effectiveness of this procedure to calculate water saturation (Sw) has been verified using Archie's and Hamada's core datasets (Haro, 2010).

The Archie-Haro equation solves a problem that consists of obtaining resistivity equivalents at various scales, whilst a substitution of the rock-fluids content occurs (from 100% water to partial water saturation). The solution is built by converting a pore-scale problem to an equivalent cube model (Serra, 1989), and then to well-log scale. The macroscopic Ohm law (referred as simply Ohm's law throughout) can give the equivalents only when the conductive paths are straight. For this reason, calculations require straightening of the curved conductive paths with the Laplace equation first. Advantages of the proposed theory include:

• It opens the possibility of continuously measuring the tortuosity (m) and saturation (n) exponents with a dipole sonic log (Haro, 2010; Haro, 2006; Mavko, 1998; Mitchell, 1981; Kamel, 1992) and the dielectric-resistivity combination, respectively.
• The new relations establish a mathematical link with the geometry of the rocks.
• It enables us to obtain the solution of more complicated problems, like shaly sands and thin laminated sequences (Haro, 2008).
• The m exponent can be univocally defined at every depth using core data, and n can be expressed as a function of water saturation. Furthermore, there is no need to fix the tortuosity factor (a) equal to 1.
• The number of unknowns reduces from 3 (a, m, n) to only 2: tortuosity (δ) and divergence (ζ) angles.

The Archie equation has been the backbone of petrophysics for more than 70 years. With the proposed enhancements, the Archie equation is no longer empirical but has a sound basis in scientific theory. The Archie-Haro equation enables improved calculations of water saturations, with the concomitant gain in accuracy to estimate hydrocarbons in place.