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Estimation of Archie parameters by a novel hybrid optimization algorithm

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ABSTRACT

Archie parameters play a critical role in accurately identifying water saturation for a given reservoir condition. Due to interdependence of these parameters, it is difficult to estimate them accurately. In order to achieve more accurate parameters, we model a non-convex optimization problem based on the core Archie parameters' estimate (CAPE). Then we present a new hybrid global optimization method to solve this non-convex problem. The hybrid technique has the features of both fast local convergence in interior point method and global convergence in Firefly algorithm (FA). Finally, our method was implemented to determine Archie parameters and some comparisons are done among two deterministic techniques and four population-based algorithms. Water saturation profiles were generated using the different Archie parameters determined by six techniques. These profiles have shown a significant difference in water saturation values between CAPE methods and population-based methods. These results highlight that our proposed algorithm performed better than conventional CAPE and three dimension (3D) method for reservoirs to calculate the water saturation values due to more accurate Archie parameters achieved by our method.

1. Introduction

An accurate identification of oil reserve, either in an undeveloped or a developed reservoir, is a significant task for petrophysicists and reservoir engineers. To calculate the hydrocarbon reserve in its formation, it is required to know the amount of water saturation. Inaccurate calculation of the amount of water saturation will lead to a large error in the estimation of the hydrocarbon reserve. Archie equation, which is the underlying foundation for analyzing water saturation in potential oil and gas zones, is commonly used in the calculation of the amount of the water saturation of a reservoir rock, and hence providing an estimate of the initial hydrocarbon reserve of the reservoir. The values of the input parameters of Archie water saturation model in a clean or shaly formation must be estimated as accurately as possible. From field experiments, it is observed that the values of the following three input parameters, the tortuosity factor a, the cementation exponent m and the saturation exponent n, depend critically on the petro-physical properties of a given rock. Thus, these parameters will take different values for different fields. Furthermore, the values of m, n and a in Archie formula are interdependent. Therefore, it is of critical importance that the estimations of the values of the parameters m, n and a are done accurately (Makar and Kamel, 2012; Riedel et al., 2013; Mabrouk et al., 2013).

There are several techniques available in the literature for estimating the values of Archie parameters m, n and a. In Maute et al. (1992), a data analysis approach is proposed to determine the Archie parameters m,n and a based on standard resistivity measurements on the core samples. In Hamada et al. (2002, 2013), Archie parameters are being estimated by an approach based on a three-dimensional (3D) regression plot involving water saturation, formation resistivity and porosity. The simplex method is applied in Chen et al. (1995) to identify the three parameters of Archie equation. A conventional technique is to determine n separately, independent of a and m. Some intelligent algorithms, such as Genetic Algorithm (GA) and Artificial Bee Colony (ABC) is applied for estimation of Archie parameters in Godarzi et al. (2012), Hamada (2013), and Liu et al. (2015). In Hamada (2013), three techniques were implemented to determine Archie parameters; conventional technique, core Archie's parameters' estimate (CAPE) technique and 3D technique. An application of local linear neuro-fuzzy (LLNF) model in estimating reservoir water saturation from well logs in a carbonate reservoir is studied in Mollajan (2014). Mollajan and Memarian (2013) applied Radial Basis Function

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Nomenclature

a	tortuosity factor
m	cementation factor
n	saturation exponent
S_w	water saturation
R_t	resistivity of rock, Ω m.
R_w	resistivity of brine, Ω m.
R_o	resistivity of rock Ω m. at S_w=1.0
I_R	resistivity index
F	formation resistivity factor
ϕ	formation porosity, fraction

Neural Network (RBFNN) modeling to estimate water saturation responses in a carbonate reservoir.

In reality, the parameters a, m and n in the Archie equation are known to be closely interdependent. In this paper, a new hybrid optimization technique is proposed to estimate these Archie parameters. Several sand reservoirs are chosen to carry out comparative experiments using the proposed hybrid optimization technique and other existing techniques.

The rest of the paper is organized as follows. In Section 2, the model of Archie equation is described. Three critical parameters, which are required to be estimated accurately, are clearly indicated. In Section 3, a new hybrid optimization method is developed. In Section 4, six methods are applied to estimate the values of Archie parameters and calculate the water saturate. Furthermore, the effectiveness and stability of the proposed technique are demonstrated by numerical results. Finally, some concluding remarks are drawn in Section 5.

Table 1
Correlation coefficients for different algorithms.

Method	CAPE1	CAPE2	DE	PSO	FA	HFA
Corrcoef.	0.6411	0.5830	0.6576	0.6590	0.6590	0.6590

2. Model for estimations of Archie parameters

2.1. Archie equation

The Archie equation characterizes the relation of the resistivity of the formation to the porosity, water saturation and formation water resistivity. It is expressed as

$$S_w = \left(\frac{F \cdot R_w}{R_t}\right)^{1/n} \tag{1}$$

where S_w is the amount of the water saturation (fraction or percentage), n is the saturation exponent, R_w is the formation water resistivity (Ω m), R_t is the true formation resistivity (Ω m), and F is the formation resistivity factor (dimensionless). It is known that the formation resistivity factor F is closely related to the porosity

Table 2
Archie parameters calculated by different algorithms.

Method	a	m	n
CAPE1	1.0700	1.2000	1.5000
CAPE2	23.2698	−0.5619	0.6522
DE	1.5957	0.5013	2.2625
PSO	1.3724	0.5000	2.4643
FA	0.9373	0.7387	2.5369
HFA	0.9344	0.7396	2.5404

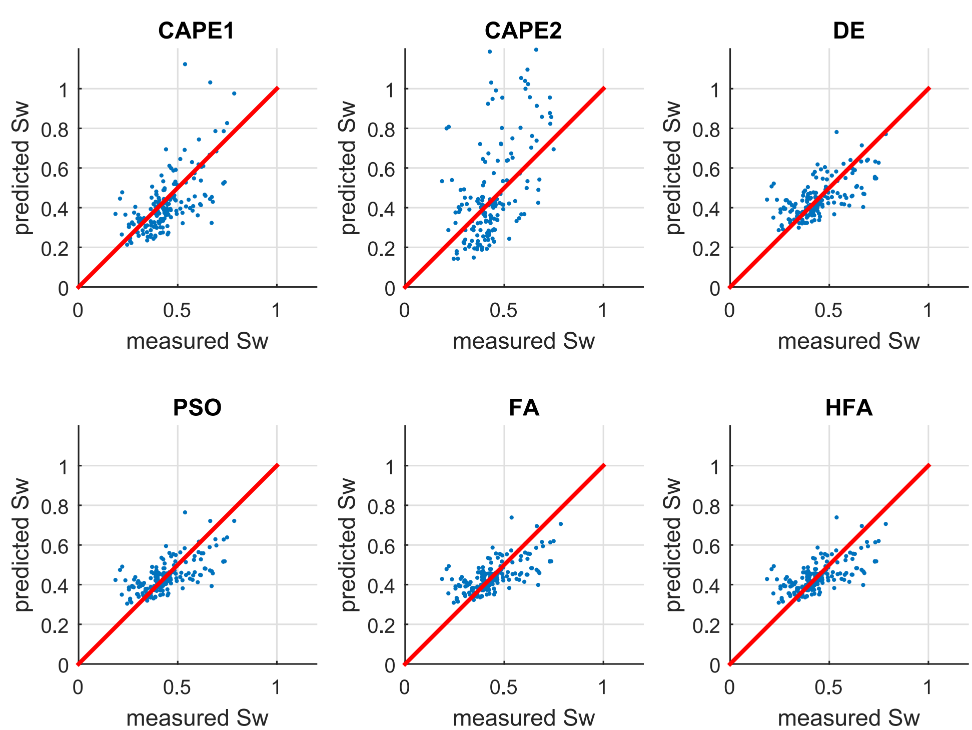

Fig. 1. Crossplot of the water saturation calculated and the measured ones. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)