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Full Length Article

# Saturation exponent determination by using genetic algorithm in carbonate reservoirs: A case study in Sarvak Formation

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ABSTRACT

Well logging analysis has been recognized as the best way to characterize reservoir properties, especially water saturation. Archie equation is known as the best method to estimate water saturation from well logging data. Determination of Archie parameters is an incessant challenge in advanced reservoir engineering because of its complex intrinsic. Measurement of Archie parameters in core laboratory has a high sensitive, expensive and time consuming procedure, that causes the excluding of core analysis to be impossible for the entire depth of reservoir zone. Although some empirical and mathematical models have been introduced to measure cementation factor, without the need of coring, there is not exist a reliable method to estimate saturation exponent in similar way.

Genetic algorithm is excelled than other meta-heuristic global search methods, which could be used in solving engineering problems. In this study, a genetic algorithm based strategy has been developed to develop a model to estimate saturation exponent from a core of drilled well in Sarvak Formation at Marun Oil Field in Iran. This model has been validated with laboratory measurements of saturation exponent with the accuracy ($R^2$) of 0.91 and the miscalculation (MSE) of 0.23.



## 1. Introduction

Based on Archie model [1], the ratio of a sandstone sample resistance saturated partially with brine, $R_t$, to saturated completely, $R_o$, has a logical relation to $S_w$ as follows:

$$S_w^{-n} = \frac{R_t}{R_o} = IR \tag{1}$$

The ratio of $R_t/R_o$ is famed as resistance index ($IR$) that is mainly influenced by formation water salinity [2], and $n$ is known as saturation exponent. Although $IR$ is primarily considered to be unit on $S_w$ of 100%, many researchers [2–4] approved experimentally that this value is not unit, and the Archie formula (Eq. (1)) had been revised as follows:

$$S_w = \frac{b}{IR^n} \tag{2}$$

where $b$ is a drift coefficient and its behavior appertains to the wettability of reservoir rock, temperature, pore size distribution, existence of micro- and macro fractures, and uncertainty caused by core analysis [2]. The value of $n$ can be obtained from the slope of the best straight line on the semi-log plot of $IR$ vs. $S_w$ for several brine saturated level of core sample. In many studies regarding the prediction of water saturation, the researchers assumed the value of $n$ to be 2 [5]. This assumption is not absolutely incorrect, and is attributable only for samples with macro-scale porous space and high $S_w$ value [6]. Many researchers have studied the dependency of $n$ to some reservoir rock and fluid properties such as saturation history [4], wettability ([7,8]), capillary pressure [9], salinity of brine [10], and the geometry of pore space [11]. By surviving in the widely studies have been done on the relationship between the $n$ and other petrophysical parameters, apparently wettability has the greatest impact on $n$ value [8]. Wettability between rock and fluid systems can be highly varied from highly water-wet rock to highly oil-wet [7]. $IR$ value of water-wet rock is more than oil-wet rock [4]. Although, saturation exponent of water-wet rock is approximately equal to 2, it can be changed abruptly from 1.5 to 3 in carbonate rock [12]. Donaldson measured it more than 8 in oil-wet rock [13]. On the other hand, wettability can also change with the saturation history [8], consequently it could be concluded that $n$ always changes when $S_w$ changes in the carbonate rock [14].

Data mining is a set of intelligent tools and machine learning techniques that can explore the hidden patterns behind the existing data sets, and extract a quantity formula between the

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dependent and independent-variables. Failure of empirical relationships to characterize reservoir rock properties, especially in carbonate reservoirs, is the most important justification for the use of intelligent systems in parameter estimation.

The genetic algorithm (GA) has been introduced as a method for evolutionary optimization John Holland in 1970 [15]. GA is an intelligent machine inspired from the theory of Darwinian evolution in searching the solution of a problem. Darwin believed that survival of creatives depends on their compatibility with the environment. He supposed that the chance of the survival increases by increasing degree of consistency with the environment. In GA, individuals in each population included a set of solution candidates to resolve the problem that have been evaluated. The first population is created randomly by a probability distribution function. In next generations, the parents will be selected to reproduce next population form the superior individuals based on their compatibility degree (fitness). The generated offspring in the new population is merged with the origin population, and evaluated based on objective function. After that, by using a selection algorithm, the superior individuals are selected to create next generation. This process continues until one of the predefined criteria in the algorithm are satisfied. Cross-over and mutation are the processes of GA occurs between the selected individuals. The purpose of cross validation and mutation in each generation is attaining to a better solution. Pc and Pm which are respectively cross-over and mutation probability, define how many individuals must have been used to cross-over and mutation process. Fig. 1 shows the implementation process of optimization by using GA.

## 2. Methodology

In this study, a multi-stage strategy has been introduced to create a model of saturation exponent estimation based on the available core analysis and logging data in Sarvak Formation in Marun Oil-Field. Marun Oil-Field is located in south east of Iran, in Zagros basin, and is one of the main oil fields in the world. The saturation exponent measuring is a time-consuming and costly affair in core analysis laboratory. Therefore, the number of core samples that have a measurement of $n$ is usually very low to create a valid model. Only 17 core samples are available in Sarvak Formation which has a measurement $n$ for the Marun Oil Field. To overcome this challenge, a database of core laboratory data including water saturation and porosity, and well log data including deep lateral resistivity log, neutron porosity, density, sonic, gamma rays have been used in this study. Integration of core and logs data is a sensitive part of petrophysical analysis, particularly when both kind of data is required. Core porosity and porosity calculated from neutron, density and sonic logs have been implemented for depth shifting between log and core data. Due to lack of information about saturation exponent, a data set consisting of porosity ($\varphi$), formation resistivity ($R_t$), brine resistivity ($R_w$), water saturation ($S_w$) and geology description has been used. For this purpose, a numerical method has been implemented for minimizing the objective function introduced by the meaning of least squares (LS) estimator and Archie water saturation equation as follow.

$$ObjFun = \left(S_w - \left(\frac{a \cdot b \cdot R_w}{\varphi^m \cdot R_t}\right)^{\frac{1}{n}}\right)^2 \quad (3)$$

where $m$ and $a$ are respectively cementation factor and tortuosity factor. In this problem, $a$ and $b$ parameters are known proportionality as the coefficient of lithology [15], therefore, can be considered together as a variable. The goal of solving the objective function is to find the adequate unknown variables $n$, m and $a.b$. To obtain the unknown variables, Newton-Raphson method has been implemented to minimize *objFun* numerically. This method gets help from the gradient of objective function to find the minimum point. In optimization based gradient method, it is assumed finally the optimum solution received in a point with zero gradient or near zero gradient. Therefore, it can be supposed that finding minimum value of objective function, *f(x)*, is equivalent to find somewhere with zero value of the gradient function, *g(x)*. By using Taylor series, a function with dependent variables can be expanded as follow:

$$f(X) \cong f(X_k) + \nabla f(X)^T|_{X_k}[X - X_k] + \frac{1}{2}[X - X_k]^T \nabla^2 f(X)^T|_{X_k}[X - X_k] \quad (4)$$

that $x_k$ is the vector of independent variables, $[n_k, m_k, ab_k]$, $\nabla f(X)$ is the gradient of the objective function, and $\nabla^2 f(x)$ is the Hessian matrix of objective function.

$$f(X) \cong f(X_k) + g_k^T[X - X_k] + \frac{1}{2}[X - X_k]^T H_k [X - X_k] \quad (5)$$

*g(x)* and *H(x)* represent respectively the gradient and Hessian matrix of objective function.

$$g_k + H_k[x - x_k] = 0 \quad (6)$$

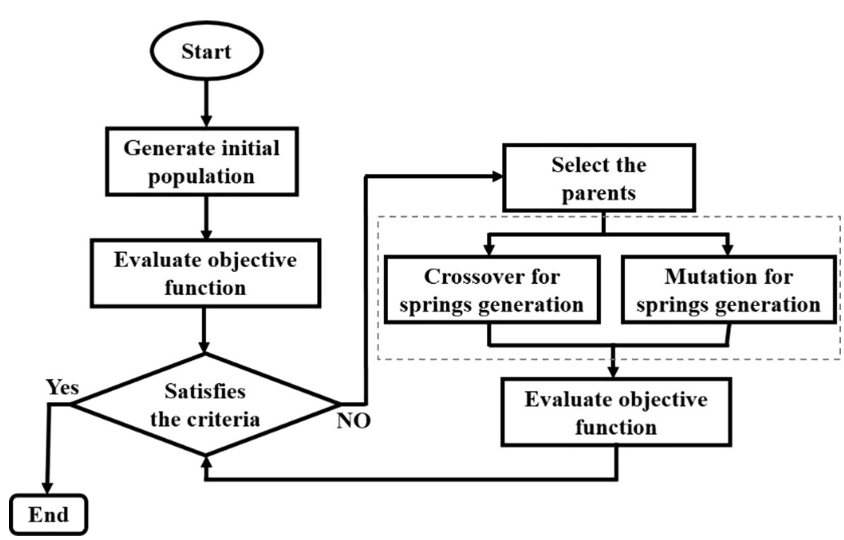


**Fig. 1.** Flowchart of Genetic Algorithm.

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