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Prediction breakthrough time of water coning in the fractured reservoirs by implementing low parameter support vector machine approach

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HIGHLIGHTS

- A first-break approach to monitor breakthrough time of water-coning was illustrated.
- Low parameters approach has been explicated.
- Handling massive coning dataset with LS-SVM approach.
- Implementation of fuzzy approach to tackle the water coning issue was presented.
- Optimization of fuzzy rules by utilizing hybrid of genetic algorithm and Kalman filter.

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ABSTRACT

Owing to water coning, water flows into the production wellbore from below the perforated channels and normally causes several technical issues in wellbore and surface production facilities such as separators. Knowledge about the time that water coning happens could help us greatly to plan the production scheme and overcome the addressed hurdles. Due to this fact, this research goes to great lengths of a low parameter approach development to figure out smartly the breakthrough time of water coning in fracture reservoirs (FRs). To reach the goal of this work, least square support vector machine (LSSVM), artificial neural network (ANN) and hybrid of fuzzy logic, Kalman filter and genetic algorithm (HFKGA) were utilized to predict breakthrough time of water coning in FRs. To scrutinize the proposed approaches of estimating the breakthrough time of water coning, a numerous number of real data from the northern Persian Gulf oil fields was implemented. Outputs of LSSVM approach draw parallel with the corresponding experimental values and results of HFKGA and ANN models depicting the giant potential implication of the proposed approach to predict the breakthrough time of water coning in FRs. Moreover, advantages of statistical parameters like the average absolute relative deviation (AARD%) was gained to quantify robustness and accuracy of the proposed model. Thanks to implementation of this cutting edge research, knowing timely the breakthrough time of water coning in oil wells provides this opportunity to plan more accurately and operate responsibly further.

1. Introduction

Coning refers to upward movement of water and/or downward movement of gas in the vicinity of the perforated zone belonging to a production well [1]. The mentioned phenomenon is regarded as the major reason for the noticeable increment of the production cost, very much reduction of production efficiency, dramatic growth of equipment corrosion and finally encountering with stop of production processes [1]. Coning is considered as a consequence of fluid motion in direction of less resistance which is balanced with the gravity force [2]. Coning is a strong function of gravity, viscous forces and capillary. In more details, increment of viscous forces In comparison with gravity forces play the most leading role in the taking place of coning while capillary forces are usually taken as negligible parameters and can be ignored [1]. Increasing the production rate gives rise to growth of cone height (up to a certain production rate). There is always a threshold in production rate known as the critical rate that crossing this ceiling turning the stable statements of the water or gas cones into unstable modes which is followed by occurring of breakthrough [3,4]. To put it another way, to prevent cone breakthrough it is necessary to set the production rate below this allowable limitation [4]. The critical

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production rate acquired from engineering and technical calculations is normally very low and based on economic constraints is not capable of being regarded and in most of cases it is observed that production wells are ordered to be flowed with the rate above the restricted rate. Therefore, happening of water and/or gas breakthrough seems to be inevitable after a while. This elapsed time is called time to breakthrough [t_{BT}] [1]. Knowing roughly about this vital parameter has its own importance because adjusting the production mode of a well makes the occurring of coning and breakthrough with delay and as a rule causes extending the life expectancy and general efficiency of production operation. Continues increment of water or/and gas to oil ratio by regarding the past time after happening of breakthrough is the major reason for some problematic issues in terms of separating these fluids from each other and it might even shut down the production in worse assumptions [5].

Great efforts have been put forward to characterize coning procedure by Predicting its related factors such as the critical production rate or breakthrough time, the specified topic of this research. Proposing a correlation to estimate the breakthrough time in vertical wells based on the laboratorial data and modeling results was done by Sobocinski and Cornelius [6]. Concluding that horizontal barriers delayed the breakthrough time while it was not capable of providing an absolute remedy to water coning problems was also made by Prison and Mehta [7]. In 1971 Bournazel and Jeanson [8] through applying the same dimensionless groups of Sobocinski and Cornelius [6], presented a new relationship for t_{BT} in horizontal wells. Modeling theoretically the breakthrough time in horizontal wells gaining from dimensionless groups was submitted by Ozkan and Raghavan [9] in 1988. A semi-analytical solution by Papatzacos and coworkers [10] in 1989 was suggested to depict t_{BT} in an anisotropic, infinite reservoir with a horizontal well placed in the oil zone [10]. In 2010 [11] a model designed by Omeke and coworkers to calculate breakthrough time and it was compared with numerical simulation study. Xinzhi and Sengju proposed a model in 2010 to estimate the breakthrough time in oil wells in low permeability bottom water reservoirs with barrier. These were not all but a few numbers of brilliant studies undertaken to describe connected issues of coning phenomenon, the concern of other researchers whose attentions were fully drawn towards coning relevant matters and put them on their agenda [12–25].

In this communication a huge amount of attempts have been made to evolve and demonstrate artificial intelligence based approaches to predict breakthrough time of water coning in fractured reservoirs like as carbonate reservoirs. Due to this fact, a new kind of smart method properly named least square support vector machine (LSSVM) has been implemented to estimate the breakthrough time of water coning in fractured reservoirs. Besides, another robust approach root in fuzzy logic tuned by a hybrid of Kalman filter and Genetic Algorithm (GA) was conducted to figure out the addressed target of this research. To assess the capability and flexibility of introduced methods an extensive experimental data implemented to develop the addressed approaches. Complete explanation of the methodology, model development and discussion in further details will be demonstrated in the next sections.

2. Methodology

2.1. Support vector machine (SVM)

Enormous efforts have been made throughout this step to facilitate nonlinear correlation between breakthrough time of water coning and four addressed input variables: flow rate (q), height (h), viscosity (μ) and fracture number (FN). To deal with this issue, a network-based mathematical model has been implemented.

As much as which can clearly be seen from previous literature, the artificial neural network (ANN)-based approaches result mostly in high precision in various aspects of engineering and scientific issues [26,27]. Despite the predecessor fact that the random initialization of the neural networks, alternative of the stopping criteria throughout optimization of the addressed approach parameters, and large numbers of the network parameters may demoralize their implement for external estimation [27–31].

Due to the inherent nature of the support vector machine, it is an effective mathematical approach evolved from the machine-learning community [27,28,32–34]. The addressed SVM model analyzes a group of data, recognizes their patterns and then implemented for regression ends. In addition, it should be noted that the SVM is a nonprobabilistic binary linear classifier [27,28,32–34]. The substantial merits of the SVM-based approaches over the other conventional approaches based on the ANNs have been already negotiated [27,28]. Also, it is worth to bear in mind that both linear and nonlinear regressions can be persisted to set the relevant issues to implement the SVM algorithm [27,28,32–34].

As a result of over-fitting issues in implementation of the neural network, significant amendment to the original support vector machine (SVM) has been developed by Suykens and Vandewalle [32,33] with the end of simplifying the rout of nonlinear expressions set in the original algorithm of SVM. The new least square support vector machine (LSSVM) approach carries about an easier-to-use calculation approaches and faster rout-searches while drawing parallel with the conventional SVM approach [27,28,32–34].

2.2. Mathematical background of LSSVM

Following expression was implemented as a cost function of the least square support vector machine (LSSVM) in calculation steps [27,28,32–34]:

$$Q_{LSSVM} = \frac{1}{2} w^T w + \gamma \sum_{k=1}^{N} e_k^2 \tag{1}$$

Relate to the following restriction [27,28,32–34]:

$$y_k = w^T \varphi(x_k) + b + e_k \quad k = 1, 2, \ldots, N \tag{2}$$

where γ stands for the regularization parameter and e_k represents the error variable for x_k [26–29].

To obtain the solution of the optimization issues given in Eq. (1), the restricted problem is turned into an unrestricted problem and the Lagrange multipliers α_i to determine the objective function is denoted as follow [32–34]:

$$L(w, b, e, \alpha) = J(w, e) - \sum_{k=1}^{m} \alpha_i \{ w^T \o(x_k) + b + e_k - Y_k \} \tag{3}$$

Based on the Karush–Kuhn–Tucker (KKT), the optimal situations may be determined by performing the partial derivatives of Eq. (3) with respect to w, b, e and α, correspondingly as below [32–34]:

$$\left\{ \begin{array}{l} w = \sum_{k=1}^{m} \alpha_i \o(x_i) \\ \sum_{k=1}^{m} \alpha_i = 0 \\ \alpha_i = \gamma e_i \\ w^T \o(x_i) + b + e_i - Y_i = 0 \end{array} \right\} \tag{4}$$

Therefore, the linear equations are fallen into place as the following [32–34]:

$$\begin{bmatrix} 0 & -1^T \\ 1 & \Omega + \frac{1}{\gamma} I_N \end{bmatrix} \begin{bmatrix} b \\ a \end{bmatrix} = \begin{bmatrix} 0 \\ y \end{bmatrix} \tag{5}$$