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Original article

Determination of oil well production performance using artificial neural network (ANN) linked to the particle swarm optimization (PSO) tool

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ABSTRACT

Greater complexity is involved in the transient pressure analysis of horizontal oil wells in contrast to vertical wells, as the horizontal wells are considered entirely horizontal and parallel with the top and underneath boundaries of the oil reserve. Therefore, there is an essential need to estimate productivity of horizontal wells accurately to examine the effectiveness of a horizontal well in terms of technical and economic prospects.

In this work, novel and rigorous methods based on two different types of intelligent approaches including the artificial neural network (ANN) linked to the particle swarm optimization (PSO) tool are developed to precisely forecast the productivity of horizontal wells under pseudo-steady-state conditions. It was found that there is very good match between the modeling output and the real data taken from the literature, so that a very low average absolute error percentage is attained (e.g., <0.82%). The developed techniques can be also incorporated in the numerical reservoir simulation packages for the purpose of accuracy improvement as well as better parametric sensitivity analysis.

1. Introduction

Petroleum engineers are always interested in finding appropriate and reliable tools to predict the productivity of horizontal well as accurate predictions seem very important to conduct technical and economical feasible studies before drilling the wells which is very costly. It is a very important factor to decide on the economical feasibility of drilling horizontal wells [1–7].

According to the experimental investigation conducted by Yasar et al. [8]; applied load and torque for both specific energy and penetration rate in drilling operations have great importance. Based on their results, penetration rate decreases dramatically with raising Unconfined Compressive Strength (UCS) of the cement grout being drilled, proposing that rock characters will intensely effect advance in the drilling operation, and determined specific energy decreases dramatically with both raising applied load and raising penetration rate in the drilling operation [8]. Moreover, Wasantha et al. [9] studied the effect of strain rate on the mechanical behavior of sandstones with various grain sizes. They concluded that size of constituent grains is an essential factor which requires to be encompassed in

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thoughts of the mechanical behavior of sandstones under various strain rates [9].

The pseudo-steady state occurs when the fluid production manifests its impact in the boundaries far from the production well where the oil is approaching from the drainage boundary on the way to the depletion area around the well [10,11].

It indicates that the reservoir has reached a condition where the pressure at all reservoir boundaries and also the average reservoir pressure will reduce over time as more fluid is extracted from the reservoir [12,13].

A suitable technique to estimate the pressure transient response of producing horizontal wells was developed by Clonts and Ramey [14]; where the source functions are combined with the Newman product approach. Recently, an analytical approach was also introduced by Hagoort [15] to calculate the productivity of a horizontal well with infinite conductivity placed in a reservoir which is considered as a closed rectangular system.

The resultant of the source functions was utilized by Daviau et al. [16] for oil reservoirs with particular characteristics. A reliable solution was presented by Ozkan et al. [17] and Joshi [18] to estimate pressure response for the anisotropic and infinite reservoirs which experience either uniform influx or include a horizontal well with infinite-conductivity.

Several researchers performed a variety of works to use the source function scheme to obtain profile or/and magnitudes of pressure in surrounded reservoirs [16,4,5,19,20,7,21].

The horizontal well-bore was considered as a strip source by Goode and Thambynayagam [22]. In their work a uniform distribution of flow rate in the well length is maintained. The pressure response was found for the horizontal producing well through combination of the finite Fourier cosine and Laplace transforms.

Depletion mode, especially in linear flow patterns depends on well productivity in non-circular flow configurations. Helmy and Wattenbarger [23] noticed that this observation matches well with the analytical long-time solutions for the analogous linear heat flow problems.

In general, the horizontal wells are not fully drilled in horizontal direction such that a significant change in vertical elevation happens during the drilling, leading to huge effects on outlet pressure of the horizontal well. In addition, the computation usually is difficult due to negative skin factor of horizontal wells. On the other hand, accurate calculation of the length of horizontal production well is not simple in many cases [2].

Production at a constant well rate plays a major role in current analytical approaches to study the productivity of horizontal wells in closed reservoirs [24,25].

Helmy and Wattenbarger [26] presented simple productivity correlations using several number of reservoir simulations to calculate the productivity of horizontal wells. The reservoir model contained a homogeneous, isotropic, closed reservoir with the shape of a rectangular box and an open hole horizontal well parallel to one of the sides of the box.

A semi-analytical model to determine of the productivity of wells in Darcy flow systems was presented by Hagoort [27].

Finally, summary of the productivity models in steady state and pseudo-steady state conditions is demonstrated in Table 1. It should be noted that, each of equations should only use in the specific circumstances. In other words, various assumptions should be met to use each correlations (for instance, steady state flow regime, homogeneous porous media and etc) and this is a big disadvantage for petroleum engineers to employ the aforementioned correlations. Moreover, most of the correlations developed are depending on the size of the system because they are not dimensionless and this is another drawback for using these formulas.

An attempt was made by Mutalik et al. [28] to compile different data sets of shape factors and the corresponding skin factors (S_{CAh}), where different horizontal wells are considered at various locations of the drainage area in the reservoir [2]. The presence of an enclosed reservoir and an infinite-conductivity well are the main assumptions in their methodology. The horizontal well productivity is determined by an equation as given below [2]:

$$J_h = \frac{q_o}{P_R - P_{wf}} = \frac{kh}{141.2\beta_o\mu_o}\left(\frac{1}{\ln\left(\frac{r'_e}{r_w}\right) - A' + S_f + S_m + S_{CAh} - C' + Dq_o}\right) \quad (1)$$

where

$$r'_e = \sqrt{\frac{A}{\pi}} \quad (2)$$

$$S_f = -\ln\left[\frac{L}{4r_w}\right] \quad (3)$$

Bahadori et al. [29] introduced a predictive tool buy means of Vandermonde matrix concepts, for estimating pseudo skin factor of horizontal wells through rectangular drainage area. They noticed that the calculation of productivity of a horizontal oil well depends on the pseudo-skin factor for centrally located wells within different drainage areas.

Given the above matters, developing a proper and straightforward correlation seems necessary. Compared to available approaches, the developed equation is expected to be less complicated, and more accurate for predicting the pseudo-skin factor as a function of dimensionless length (L_D) and the ratio of horizontal well length over drainage area side ($L/2X_e$) for square and rectangular shapes with ratios of sides 1, 2, and 5.

$$L_D = \frac{L}{2h}\sqrt{\frac{K_v}{K_h}} \quad (4)$$

In this article, an intelligent method utilizing a new type of network modeling which called "Least Square Support Vector Machine (LSSVM)" is developed to serve as a rapid and inexpensive predictive model for monitoring well productivity of horizontal wells in box shape drainage area. The proposed LSSVM model is developed implementing extensive actual well productivity data.

To depict the robustness, integrity and accuracy of the suggested LSSVM model, the obtained outcomes from the introduced approach are contrasted with the relevant actual productivity data. Outputs from this research reveal that the evolved approach can monitor the horizontal well productivity with high accuracy. The introduced predictive model can be utilized as a reliable way for quick and cheap but efficient prediction of well productivity of horizontal well parameter in absence of appropriate experimental or/and real data, specifically through the initial stages of evolvement of horizontal well drilling.