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A novel approach to sand production prediction using artificial intelligence

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ABSTRACT

Over the years, accurate and early prediction of oil or gas well sanding potential has been of great importance in order to design an effective sand control management strategy. Significant technical and economic benefits can be achieved if the correct and early design of sand control method is considered. In this study, critical total drawdown (CTD) as an index of sand production onset is aimed to be estimated through 4 proposed methods. A total of 23 field data sets collected from problematic wells of North Adriatic Sea were used to develop these models. First, simple regression analysis was performed to recognize the statistically important affecting parameters. Using these variables, multiple linear regression (MLR) and genetic algorithm evolved MLR (GA-MLR) were developed for estimation of CTD. Two artificial neural networks (ANN) with back propagation (BP) and particle swarm optimization (PSO) algorithms were constructed to correlate CTD to all affecting parameters extracted from the literature. The performance comparison showed that the artificial intelligent system could be employed successfully in sanding onset prediction and minimizing the uncertainties. More accurate results were obtained when PSO algorithm was applied to optimize the weights and thresholds of neural network.

1. Introduction

About 70% of the total world's hydrocarbons are located in poorly consolidated reservoirs (Nouri et al., 2003). As a result, many oil and gas reservoirs are susceptible to sand production. Field observations reported in the literature indicate volumetric concentration of sand in oil pipe systems varies from 1% to 40% (Almedeij and Algharaib, 2005; Talaghat et al., 2009). Production of sand along with reservoir fluids might lead to the erosion of downhole and surface production facilities, thus creating severe safety problems including loss of well control, blowouts, fires and production shut-in (Almedeij and Algharaib, 2005). In addition to the damages of sand production on production facilities another main problem is the instability of the production cavities and wellbore itself (Fattahpour et al., 2012). This results in productivity losses and in extreme cases, complete filling and obstruction of the borehole. Sand control methods cost the petroleum industry several hundred-million dollars each year Isehunwa and Olanrewaju (2010), Kanj and Roegiers (1999). However, the success of these sand control management strategies is highly dependent on the early prediction of the reservoir sanding potential.

Significant researches have been conducted on sand production prediction, in recent years. Sand prediction techniques based on field experiences rely on establishing a correlation between sand production well data and field and operational parameters. This method can be of three categories, namely, one parameter, two parameters and multi parameter correlations in which increasing the number of parameters will increase the accuracy and generality of sand prediction model (Veeken et al., 1991). The neural approach proposed by Kanj and Abousleiman (1999) to predict sanding onset can be a good example of the multi parameter correlations. However, developing such correlations needs collecting a comprehensive field data base.

There are also different numerical and analytical models based on tensile and shear failure criteria, a critical pressure gradient criterion, a criterion of critical plastic deformation and erosion based criteria (Nouri et al., 2006). Although numerical models are accurate, with the capability of dealing with different complex situations, they are computationally demanding and often needs input parameters which are not routinely measured. Therefore, in the cases when quick sand control decision is needed, analytical or semi-analytical models are more practicable (Yi et al., 2004). However, due to using simple sand failure criteria in these models, analytical approach can not be as accurate as the numerical ones.

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Nomenclature

ANN	artificial neural network
BP	back propagation
PSO	particle swarm optimization
MLR	multiple linear regression
MLR-GA	multiple linear regression evolved by genetic algorithm
CTD	critical total drawdown (MPa)
EOVS	effective overburden vertical stress (MPa)
TT	transit time (micro s/ft)
TVD	total vertical depth (m)
COH	cohesive strength (MPa)
APE	average percent relative error
AAPE	average absolute percent error
MSE	mean square error

In recent years, the use of artificial neural network (ANN) has been successfully employed for developing predictive models. ANN method brings together the accuracy of the numerical models and the simplicity of the analytical approach. ANN can simulate highly non-linear functions and can be trained to accurately generalize/forecast, if presented with new, the unseen data (Lu et al., 2003). Data driven based characteristic of this modeling approach gives it more flexibility for self-adjustment to adapt various ranges of data (Malallah and Sami Nashawi, 2005). Applying ANN to predict sand production has a prominent advantage in that it does not require any previous assumption about complex mechanical behavior of the rock and failure mechanisms to construct a reliable and accurate model. Despite the discussed advantages, traditional ANN has a significant shortcoming i.e. the possibility to trap in local extremums which leads to dissatisfactory predictions. Therefore, many improved algorithms have been proposed. One of the significant developments is PSO algorithm which is further discussed and used in this work.

This study aims to develop the empirical relationships for prediction of critical total drawdown as an index of sand production onset in oil and gas wells by using multiple linear regression (MLR), MLR in which coefficients are optimized using genetic algorithm (GA-MLR), back propagation neural network (BP-ANN) and particle swarm optimization neural network (PSO-ANN). The sand production data of 23 problematic wells of North Adriatic Sea was used to establish the predictive models. These data have been previously used by Kanj and Abousleiman (1999) to develop a BP-ANN model for prediction of sand production onset. Aforementioned intelligent approach is extended in the present paper by introduction of a comprehensive 3 stage statistical framework for analysing sand production in North Adriatic Sea. First the effect of all relevant parameters on sanding onset is investigated and discussed through simple regression analysis. In the next step, MLR and GA-MLR are employed to correlate CTD to the most affecting parameters recognized previously. These models are explicit, simple and easy to use. Finally, BP-ANN and PSO-ANN models are developed to simulate the complex relation between CTD and all technical parameters.

2. Data processing and analysis

2.1. Affecting parameters

Selection of input parameters is an important task in neural network modeling. So, great care must be taken in selection of input variables to construct an effective network. In gas and oil fields, sand production is caused by the fluid flow in the underground porous media. Therefore, sand production potential of the well is affected by many parameters.

The main factors affecting sand production are in-situ stresses, drawdown pressure, flow rate of different fluids from reservoir to the well, strength and mechanical properties of the reservoir rock, perforation density, fluid density and reservoir pressure (Veeken et al., 1991; Ghalambor and Asadi, 2002; Weissenburger et al., 1987). Furthermore, the reservoir permeability (Veeken et al., 1991; Morita et al., 1989), perforation depth (Veeken et al., 1991; Ghalambor and Asadi, 2002), reservoir thickness (Veeken et al., 1991; Han et al., 2011), wellbore inclination (Veeken et al., 1991; Weissenburger et al., 1987), shale volume and porosity (Ghalambor and Asadi, 2002) and type of well completion can also be important parameters in sand production prediction.

From the rock mechanical point of view, if the flow rate is sufficiently large, tensile net stresses can be induced in the surrounding formation and cause sand tensile failure (Nouri et al., 2006; Weingarten and Perkins, 1995). Furthermore, increase in in-situ stress and drawdown causes increase in shear stresses. If the shear stress increases to the point that the formation generally fails in shear (i.e. a function of the reservoir rock properties), weakly cemented rock may become disaggregated (Morrica et al., 1994; Weingarten and Perkins, 1995). However, the compaction effect of the net overburden stress should not be neglected (Morrica et al., 1994). It is also expected that the presence of large volume of low permeability shales in the bulk rock may increase rock strength and decrease flow rates which consequently lowers the probability of sand production in shaly sands (Ghalambor and Asadi, 2002).

In many unconsolidated formations, onset of sanding is often observed to be concomitant with water cut. Various mechanisms may be active in observing this occurrence. For instance, water inflow into a hydrocarbon bearing may cause changes in relative permeability or weakening the overall strength of the rock (Nouri et al., 2006). Chemical interactions may also occur between the water and the rock cementation and affect the sand production (Weingarten and Perkins, 1995). However, destruction of capillary induced cohesion between the grains due to increase of water saturation play a dominant role. This is because the capillary cohesion is the main source of rock cohesion and tensile strength against seepage induced drag forces in a rock whose natural cohesion has been eroded by shear failure (Nouri et al., 2006; Han and Dusseault, 2002).

It is valuable to note that the effect of flowrate and water cut on sanding onset should not be misinterpreted. Flowrate mainly affects the transport of the sand after the onset of sand production. Also, in a lot of cases, especially for silicon dominated cementing system, the water cut influence is very limited.

2.2. Data collection

The Northern and Central portions of the Adriatic Sea stretching from the gulf of Venice to Ancona make up a single geological unit, called the Northern Adriatic Basin (Morrica et al., 1994). The gas fields in this region are one of the main sources of gas supply for Italy's need (Morrica et al., 1994). AGIP performed an intensive survey on 31 wells belong to 9 gas fields. This survey includes the field measurements and experimental studies on core samples. A brief geological description of these gas fields is as follows:

- The vertical profile is an alteration of sand and shale interbeds. The thickness of these shale interbeds may sometimes be of a few centimeters only.