Journal of Petroleum Science and Engineering 134 (2015) 131–142

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Application of neural network and fuzzy mathematic theory in evaluating the adaptability of inflow control device in horizontal well

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ARTICLE INFO

Article history:
Received 14 November 2014
Received in revised form
23 May 2015
Accepted 20 July 2015
Available online 29 July 2015

Keywords:
Inflow control device
Adaptability
Fuzzy evaluation
Back Propagation network

ABSTRACT

Inflow control device (ICD) has gained popularity since its first introduction to oil industry. However, ICD completion isn't suitable for all reservoirs because the economic value of ICD technology depends on various factors. This paper first establishes a mechanism model and summarizes the influences of single factors (permeability variation coefficient, reservoir thickness, average permeability, K_v/K_h (the ratio of vertical permeability to horizontal permeability), horizontal section length, base pipe diameter, segment number and $\Delta P_{ICD}/\Delta P_{reservoir}$ (the ratio of pressure drop caused by ICD to the pressure drop of the reservoir)) on ICD completion adaptability by static evaluation method. Next, sensitivity analysis of the influencing factors is conducted by orthogonal experiment. Then, different subordinate functions of each influencing factor are established according to the variation tendency of water yield reduction and inflow profile variation coefficient difference (compared with conventional screen completion) resulting from mechanism model. After that, six cases of ICD completion are introduced, and the weight sets and evaluation sets of the cases are established, according to which fuzzy evaluation model of ICD completion adaptability is obtained. What's more, a neural network synthetic evaluation model with superior in self-learning ability and computing power is proposed by improving the fuzzy evaluation model. The results of case studies demonstrate that both fuzzy evaluation model and neural network synthetic evaluation model are practical and feasible.

1. Introduction

Intelligent well completion is a powerful monitoring and controlling system capable of collecting, transferring and analyzing production data (Chen et al., 2004). Application practice indicates that it is outstanding in controlling production rate of high-yielding formation, delaying bottom water coning, decreasing well work-over frequency and enhancing ultimate recovery (Brouwer and Jansen,2001).

Current research findings present that the inflow control device (ICD) adaptability mainly depends on the reservoir properties (porosity and permeability distribution), equipment characteristics as well as technological measures. Sharma et al. (2002) proposed a model to quantify the value of ICD by random method with the consideration of uncertainty. Visosky et al. (2004) made a comprehensive evaluation of the formation that is suitable for ICD completion. Abdullatif (2007) established an economic evaluation model by reservoir simulation to screen out reservoirs that are suitable for ICD completion. They mainly focused on economic value comparison between conventional well completion and ICD completion. Fernandes et al. (2009) presented a simple analytical method to determine the application conditions of ICD. Garcia et al. (2009) evaluated the water control ability and yield-increasing effect of ICD completion by reservoir simulation when ICD technologies were applied to reservoirs of various types, and they found that ICD completion showed a good adaptability. But mathematical methods were seldom used to evaluate ICD adaptability. Almeida et al. (2010) proposed an evolutionary algorithm-based decision support system capable of optimizing intelligent well control under technical and geological uncertainties. Miri Lavasani et al. (2011) used analytical hierarchy process to estimate the weight required for grouping non-commensurate risk sources in offshore wells. Birchenko et al. (2011) presented a mathematical model to weaken inflow imbalance resulting from heterogeneity, and the model addressed a key ICD application question – the trade-off between well productivity and inflow equilibrium. Ahmadi et al. (2013) put forward a new method for oil rate prediction

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http://dx.doi.org/10.1016/j.petrol.2015.07.020
0920-4105/

Nomenclature

Fuzzy evaluation method an effective multi-factor decision-making method to evaluate an object affected by various factors, neither to absolutely affirm nor to absolutely negate. According to the importance of each evaluation factor, initial qualitative evaluation will be transformed into quantitative evaluation. The result of fuzzy evaluation is represented in a form of set.

Neural network an information processing system aimed at simulating the structure of human brain and implementing pattern recognition. It's capable of processing problems with complex information, unclear background knowledge and undefined influence rule. Samples with major defect and distortion are allowed in neural network. It's characterized by superior fault tolerance and nonlinear approximation ability.

Permeability variance coefficient the ratio of permeability standard deviation to average permeability, representing the heterogeneity degree of the reservoir. It's calculated by Lorentz method (Zhu, 2009) in this paper.

Inflow profile variance coefficient the ratio of flow rate standard deviation of each test point to average flow rate.

Permeability variance coefficient difference the difference between permeability variance coefficient in ICD completion and that in conventional screen completion.

Inflow profile coefficient difference the difference between inflow profile variance coefficient in ICD completion and that in conventional screen completion.

Water yield reduction the difference between water yield in ICD completion and that in conventional screen completion.

Segment number the number of segmented reservoir along horizontal wellbore.

K_v/K_h the ratio of vertical permeability to horizontal permeability of the reservoir.

$\Delta P_{ICD}/\Delta P_{reservoir}$ the ratio of pressure drop caused by ICD to the pressure drop of the reservoir.

Attribute value represents the quality or quantity of an object.

Degree of freedom the number of independent variables in statistics.

F ratio the ratio of average square error between data sets to average square error within the data set, representing the possibility of random event.

of single well based on fuzzy logic, artificial neural networks and imperialist competitive algorithm. However, there has been little research on sensitivity and influencing factor analysis of ICD completion adaptability so far.

Fuzzy mathematics is widely used in various fields. The mathematization of contemporary science and technology prompts people to look for a mathematical method to study and deal with fuzzy concept. Subordination relations between the elements and the set could be neither absolutely "yes" nor absolutely "no", but expressed by real number ranging from 0 to 1 (Zadeh, 1965). Subordinate function describes the transition between preciseness and fuzziness with a quantifiable approach. Fuzzy mathematics is to study and deal with fuzzy phenomena with mathematical method (Xie, 2000). It extends the application range of mathematics from precise phenomena to fuzzy phenomena. It's a promotion and development for classical mathematics as well as an improvement of general set theory in classical mathematics.

Based on typical mechanism model, this paper categorizes the influencing factors of ICD adaptability into reservoir factors and technological factors. Orthogonal experiment is applied to analyze the influences of sensitivity factors on ICD adaptability. Subordinate functions of each factor are established according to static simulation results derived from the mechanism model, and fuzzy evaluation model is built by utilizing weight sets and evaluation sets of each factors. Besides, a neural network synthetic evaluation model with superior in self-learning ability is obtained by improving fuzzy evaluation model.

2. Static simulation method

The main functions of ICD indicate that the abilities of balancing inflow profile and controlling water yield are the key criterions to assess the effect of ICD. Thus, the factors that influence inflow profile and water yield will affect the adaptability of ICD technology. Research findings illustrate that the influencing factors stem from three sections: (1) inflow part, which is relevant to geology features; (2) outflow part, which involves the process design and the equipment; (3) inflow control device part, which contains the stability and the type of ICD. This paper categorizes the discussible factors into reservoir ones (heterogeneity degree, permeability, reservoir thickness, K_v/K_h (the ratio of vertical permeability to horizontal permeability)) and technological ones (base pipe size, segment number, horizontal section length, $\Delta P_{ICD}/\Delta P_{reservoir}$ (the ratio of pressure drop caused by ICD to the pressure drop of the reservoir)) (Fig. 1).

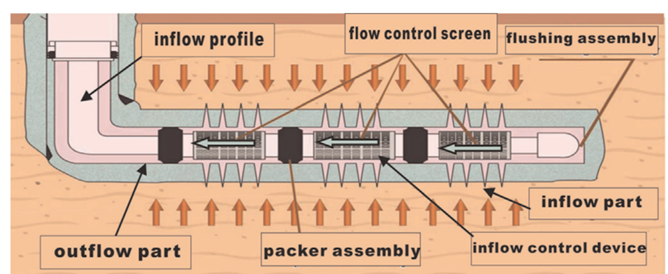

Fig. 1. Influencing factor sketch of ICD adaptability.

2.1. Single factor analysis of influencing factors

When building mechanism model, we mainly consider the displacement mechanism, phase number and phase behavior of the fluid et al. The heterogeniety of the reservoir mainly reflects in the permeability distribution along the horizontal segment. Basic reservoir parameters are listed in Table 1. Fig. 2 is the relative permeability curve to be used for modeling.

Table 1
Basic reservoir parameters.

Item	Value
Porosity	0.2
Rock compressibility	$5.0E–5$ MPa^{-1}
Original formation pressure of horizontal segment	30 MPa
Reservoir thickness	40 m
Radius of horizontal segment	0.108 m
Horizontal length	400 m
Flowing bottomhole pressure	28 MPa