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Combining water flooding type-curves and Weibull prediction model for reservoir production performance analysis

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ABSTRACT

One particular study received increasing emphasis in recent years is water flooding type-curves, which plays an essential role in evaluating oil reserves and predicting future production. The main objective of this paper is to propose a combined method that is based on water flooding type-curves and Weibull prediction model to analyze the reservoir production performance such as predicting reservoir performance in future and estimating reserve's water cut. The method is developed based on four types of water flooding type-curves and Weibull prediction model. The study shows that the method is able to successfully produce solutions for oil production and water cut. Two case studies are conducted to demonstrate the applicability and accuracy of the combined method using the actual data from oil fields. The outcome of the study shows that the production performance and water cut can be accurately estimated from the calculation of the combined method, which takes into account water flooding type-curves and Weibull prediction model. The calculated results have a good agreement with the data came from the oil fields.

1. Introduction

As the oil and gas industry matures, ongoing reservoir targets move towards more challenging applications commonly exhibiting refining model to predict the future production performance and water cut for oil property evaluation. Some performance technique methods are under consideration for quite a long time since they appear in multiple applications, such as simulation studies, material-balance calculations, and decline curve analyses. When a reservoir is under a situation which belongs to water-drive reservoir, there will be an increasing water production after the water breakthrough. The oil recovery will be reduced owning to the water production, which means that the prediction of water cut plays a significant role in the production operations.

Estimating and predicting production in reservoirs has been a challenge for a long time (Khanamiri, 2010). Traditionally, water cut period can be classified as four categories (Joseph et al., 2011): low water cut (0–20% range), middle water cut (20–60% range), high water cut (60–90% range), and super high water cut (90–98% range). Most conventional studies on water cut measurement in oil industry can be divided into two classes i.e. on-line continuous monitoring and laboratory test methods. Current procedures rely on obtaining water cut measurements at the wellhead (Yang, 1990). For on-line continuous monitoring process, a capacitance probe is installed inside a pipe-line to measure the dielectric property of the fluid and obtain the oil water ratio. The water cut can be measured by nuclear logging (Castle and Roberts, 1974). Ye (2009) also proposed a method that improves Tong's chart and application in forecasting water cut of reservoir. Yu et al. (2011) analyzed the regulation of water cut variation during the low permeability oil reservoir CO_2 flooding process. There is a decrease on water cut as the CO_2 is injected. Overall, the on-line continuous testing process is complicated. The alternative choice is laboratory test. Laboratory methods have many favorable features, however a number of limitations still exist, particularly the challenge to respond quickly enough to the instantaneous see water situations that are representative for production well.

The mathematic method provides a computational technique for the prediction of reservoirs production performance, such as t model, Γ model (Zhao and Chen, 2004) and β model (Xie and Jia, 2005). In the present work, the combined model is formulated to arrive at an appropriate estimation of the production performance data. It is very simple and accurate to generate the coefficients of equations based on this method, instead of opting for ready-generated coefficients with uncertainty. One can easily compute the coefficients and hence obtain the solution for production performance in reservoirs. The main objective of this study is to develop a combined solution to estimate reserves objectively and predict future performance according to the production analysis.

Water drive curve is the inherent characteristic of the water flooding reservoirs production, which has been widely used and can predict the water flooding recoverable reserves (Muellera

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Nomenclature

a, b, c	Weibull model parameters, constants
a_1, b_1, a_2, b_2, a_3, b_3, a_4 and b_4	coefficients of water drive type-curves, constants
A, B	coefficients of linear regression, constants
f_w	water cut, %
f_{w1}, f_{w2}, f_{w3}, f_{w4}	corresponding prediction water cut of water flooding type-curves, %
L_p	cumulative fluid production, 10^4 t
N_p	cumulative oil production, 10^4 t
N_{pm}	corresponding cumulative oil production of highest annual production, 10^4 t
N_R	recoverable reserves, 10^4 t
Q_o	annual oil production, 10^4 t
Q_m	highest annual production, 10^4 t
t	oilfield development time, yr
t_m	highest annual production time, yr
W_p	cumulative water production, 10^4 t

et al., 1981; Towler and Bansala, 1993; Chen and Hu, 1995; Ridha, 2003; Khaled Abdel Fattah, 2006; Li and Guan, 2012). Although there are rich literature and publications on describing using water drive curves to predict cumulative water production and cumulative oil production, it seems there remains a problem that could not predict the relationship between production performance and time. At the same time, the production model is an important method for the oil reservoir engineering, which is statically based on the history matching with the specific oil and gas reservoir mathematical model and the predicted future production. Weibull prediction model has better adaptability comparing with other models. It can be used for predicting oil and gas production changes during development period and forecasting oil and gas recovery, the highest annual output and occurrence time. However, it fails in predicting the water cut and other development index. In this paper, a combined solution is proposed for oil production and water cut prediction, which comprises the majority of water drive type-curves and Weibull model and can not only keep the two methods original prediction function, but also overcome their limitations.

2. Theory foundation

2.1. Weibull prediction model

Proposed by Chen and Hu (1995), it is now widely believed that Weibull distribution can be converted to a prediction model. The model can be used to predict reservoir production, cumulative production and recoverable reserves. The basic equations are as follows:

$$Q_o = at^b \exp\left(-\frac{t^{b+1}}{c}\right) \tag{1}$$

$$N_p = \frac{ac}{b+1}\left[1-\exp\left(-\frac{t^{b+1}}{c}\right)\right] \tag{2}$$

$$N_R = \frac{ac}{b+1} \tag{3}$$

Take the first derivative to Eq. (1), when $dQ_o/dt=0$, the highest production time is obtainable, which is given by

$$t_m = \left(\frac{bc}{b+1}\right)^{(1/(b+1))} \tag{4}$$

Substituting Eq. (4) into Eq. (1) gives the highest annual production Q_m.

$$Q_m = a\left(\frac{bc}{b+1}\right)^{(b/(b+1))} \exp\left(-\frac{b}{b+1}\right) \tag{5}$$

Substituting Eq. (4) into Eq. (2) obtains the cumulative production N_{pm} at the highest Q_m.

$$N_{pm} = \frac{ac}{b+1}\left[1-\exp\left(-\frac{b}{b+1}\right)\right] \tag{6}$$

2.2. Water flooding type-curves

The technique of water flooding type-curves has no fundamental theoretical foundation but the simplicity and the success of its forecasts have gained its reputation and general acceptance. There are four water flooding type-curves. The basic relationships are classified as follows.

2.2.1. Type I water drive curve

Type I water drive curve was first proposed by Masi Khomov in 1978. It is the semi-log linear relationship between cumulative water production and cumulative oil production (Chen, 2001). Eq. (7) is the basic equation.

$$\log W_p = a_1 + b_1 N_p \tag{7}$$

Taking the derivative to time t gives:

$$\frac{1}{2.303 W_p}\frac{dW_p}{dt} = b_1 \frac{dN_p}{dt} \tag{8}$$

where $(dW_p/dt) = Q_w$ and $(dN_p/dt) = Q_o$.

Therefore, the ratio R_{wo} of water to oil can be expressed as

$$R_{wo} = \frac{Q_w}{Q_o} = 2.303 b_1 W_p \tag{9}$$

Taking the logarithm on both sides of Eq. (9) gives

$$\log R_{wo} = \log 2.303 b_1 + \log W_p \tag{10}$$

Substituting Eq. (7) into Eq. (10) produces the following relationship:

$$\log R_{wo} = \log 2.303 b_1 + a_1 + b_1 N_p \tag{11}$$

where

$$R_{wo} = \frac{f_w}{1-f_w} \tag{12}$$

Substituting Eq. (12) into Eq. (11) is the water cut equation.

$$f_{w1} = 1 - \frac{1}{1+2.303 b_1 \times 10^{a_1+b_1 N_p}} \tag{13}$$

2.2.2. Type II water drive curve

Type II water drive curve describes the relationship between cumulative liquid production and cumulative oil production. The basic equation is (Chen, 2001)

$$\log L_p = a_2 + b_2 N_p \tag{14}$$