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A Novel Model of Productivity Analysis and Forecasting for Oil-gas Well

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Abstract: The accuracy of dynamic prediction of productivity influences the reasonableness of the selected development program greatly. The characteristics and applicable conditions of oil-water composite method, fluid productivity index method and Petrobras method are analyzed in this study. Afterwards, we propose to combine three methods mentioned above to derive a novel productivity analysis model. We calculate the fluid productivity index firstly and then calculate the unknown set of test points based on the principle of Petrobras method, finally choose oil-water composite method to draw the IPR curve. In this study, after calculating reservoir pressure and saturation pressure, we exploit the proposed model to design a productivity analysis and forecasting system for single well. The results show that compared with the traditional methods, the proposed method improves the productivity forecasting accuracy.

Key words: Fluid production index, Maximum liquid production, flow efficiency, static pressure, saturation pressure

INTRODUCTION

Reservoir productivity evaluation and prediction is an important part of oil-gas development programs. It provides basic reference for the developing program (Whitson, 1983). For these problems, there exist many methods in reservoir engineering. Domestic research is relatively slow and mainly depends on foreign mature models to guide the production currently, including oil-water composite method, fluid productivity index method etc (Vogel and Shell, 1968; Wang and Ma, 2005). However, due to the differences in reality, some equatione aren't suitable for domestic applications. Therefore, aiming at the specific situation, we present a novel model and apply it to the oil-gas field.

The rest of the study is organized as follows. We analyze three kinds of models: the oil-water composite method, fluid productivity index method and Petrobras method in section 2. In section 3, a novel production model based on above models is proposed and we analyze the key factors. We design software to analyze the productivity in section 4. Finally, the study is concluded.

ANALYSIS OF PRODUCTION MODELS

Oil-water composite method: Oil-water composite method is the generalized IPR (Inflow Performance Relationship) curve of oil, gas, water in three-phase flowing. It reflects the ability of the reservoir to supply oil to the well, which is usually applied to analyze the dynamic production and determines the working way. It is the basis of dynamic analysis of oil wells, productivity prediction and lifting process design analysis (Wang and Ma, 2005). The key of this method is to obtain any flow pressure-productivity point and then we trace the points to curve. The conventional IPR curves are based on Darcy's law, whose productivity shows a linear relationship with pressure. For multiphase flow, IPR curve is non-linear and productivity index is defined as the negative reciprocal slope of IPR curve accurately. Since the slope of non-linear IPR curve is not constant, we should indicate corresponding flow pressure when utilizing the index.
Productivity equation is as follows:

$$q_o = J_o\,(\overline{P}_R - p_{wf}) \tag{1}$$

where, q_o is oil production; j_o is oil productivity index; $\overline{P}_R$ is the static pressure; p_{wf} is flowing bottom pressure.

Fluid productivity index method: Fluid productivity index reflects the relationship among the reservoir properties, fluid parameters etc. It is an important index to measure productivity. In application, it needs two quarters' flow pressure-production data. We calculate the index according to the law that liquid production index is equal

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to the negative reciprocal slope of the line and predict the next quarter's production. So it is more suitable for the application of optimization design in the machine (Li and Kong, 2000).

Petrobras method: This method is to compute the three-phase IPR curve. The essence is to calculate the weighted average according to the ratio of water content, which exploits pure oil IPR curve and pure water IPR curve. So the key is to get productivity index. This model can be classified into two methods, including production weighted average and flow pressure weighted average (Sun and Zhang, 1995).

ESTABLISHMENT OF A NOVEL PRODUCTION MODEL

Apparently, all of the three methods are limited in application. Oil-water composite method needs perfect data to draw IPR curve, which is difficult in the early stages of oil exploration. Fluid productivity index method requires two quarters' data but due to the two quarters may be in different stages, the values are volatile, so the deviation is large. Petrobras method is relatively perfect. However, its precondition is that the static pressure and saturation pressure data are known. Therefore, we present a novel model by a combination of the former methods: First, we impress on the method of using other data to get the key parameters: static pressure and saturation pressure. Then we use them to calculate fluid productivity index and use the Petrobras method to determine the unknown set of data. Finally, we draw the IPR curve according to the principles of oil-water composite method. The required information is listed in Table 1.

Analysis of the factors affecting the production of single well.

Flow Efficiency (FE) is the ratio of the actual fluid productivity index and the theoretical one. It reflects the level of actual output reaches theoretical productivity (Zhao *et al*., 2006). And the introduction of flow efficiency will greatly improve the accuracy of prediction results. Petrobras' derivation is three-phase inflow performance relationship of perfect wells but the scene in operations would often produces a certain harm to the oil wells, so the actual productivity will be less (Standing, 1970). So we introduce the quadratic two-phase flow (Wu and Shang, 2010). That is:

$$FE = \frac{(1+0.8p'_{wf}/p_b)(1-p'_{wf}/p_b)}{(1+0.8p_{wf}/p_b)(1-p_{wf}/p_b)} \tag{2}$$

where, p_b is saturation pressure.

In productivity analysis, maximum oil production must be analyzed, because the index reflects the ability of the fluid supplies to the well. And then we can also further determine the production condition. The maximum oil production equation is as follows:

$$\begin{aligned} q_{omax} &= q'_b + (q'_{omax} - q'_b) \\ &[1-0.025(\sqrt{81-80FE}-1) \\ &-0.0125(\sqrt{81-80FE}-1)^2] \end{aligned} \tag{3}$$

where, q_b is the production when p_{wf} is equal to p_b; q_{omax} is the maximum oil production.

The traditional method to calculate static pressure is based on two operated points and it is obtained as follows:

$$\overline{P_R} = \frac{B \pm \sqrt{B^2+4AC}}{2A} \tag{4}$$

Where:

$$A = \frac{q_1}{q_2} - 1 \tag{5}$$

$$B = 0.2(\frac{q_1}{q_2}p_{wf2} - p_{wf1}) \tag{6}$$

$$C = 0.8(\frac{q_1}{q_2}p^2_{wf2} - p^2_{wf1}) \tag{7}$$

This method uses only two quarters' test points, so the accuracy is not high. Since the static pressure is related to the half of reservoir depth, dynamic liquid level, fluid density, moisture content, liquid production index and other factors, it is possible to use the relations between the parameters to calculate the static pressure. (Xing and Yang, 2003). Specific steps are as follows: Mixed liquid density and moisture content, crude oil density:

Table 1: Required information comparison of each productivity analysis models

Productivity analysis method	Required information
Oil-water composite method	Flowing pressure-fluid production points, the static pressure, the saturation pressure, moisture, flow efficiency, fluid production index, etc
Fluid productivity index	Two quarters' flow pressure-liquid method production data, moisture, etc
Petrobras method	Liquid production, the static pressure, the saturation pressure, moisture, fluid production index, etc
Proposed Novel model	Flowing pressure-fluid production, moisture, the density of crude oil, half of reservoir depth, dynamic liquid level, etc

When r_o>0.91:

$$r_L = (3.2r_o-2.17)(1-f_w)+0.95 f_w \quad (8)$$

When r_o≤0.91:

$$r_L = (0.8r_o+0.01)(1-f_w)+0.95 fw \quad (9)$$

where, r_o is crude oil density; r_L is mixed liquid density; f_w is moisture content.

Liquid production index:

$$J_L = \frac{26.23}{1-f_w}(0.994 - 0.3608f_w - 0.3728f_w^2 - 0.2521f_w^3) \quad (10)$$

Flow pressure:

$$P_{wf} = \frac{r_L(H_z - H_D)}{100} \quad (11)$$

where, H_Z is half of the reservoir depth; H_D is dynamic liquid level.

Production pressure differential:

$$\Delta p = q_L/J_L \quad (12)$$

where, Δp is production pressure differential; q_l is liquid production; J_l is fluid productivity index.

The static pressure:

$$\overline{P}_R = P_{wf}+\Delta P \quad (13)$$

For a local area, it is easy to get the above parameters, so the static pressure can be easily calculated. This approach is not only feasible but also reliable, fully meeting the need of well performance analysis.

Seen from the above equations, it is crucial to determine the saturation pressure in terms of analyzing the reasonability of oil well production dynamically. Therefore, we utilize the following equation (Guo *et al*., 1999):

$$P_b = x \pm \sqrt{x^2 - \frac{q_{o2}p_{wf1}^2 - q_{o1}p_{wf2}^2}{q_{o2} - q_{o1}}} \quad (14)$$

Where:

$$x = [2\overline{P_R}(q_{o2}p_{wf1} - q_{o1}p_{wf2}) + q_{o2}(\overline{P_R} - p_{wf1})^2 - q_{o1}(\overline{P_R} - p_{wf2})^2] / [2\overline{P_R}(q_{o2} - q_{o1})] \quad (15)$$

So when liquid production index is unknown, we can also calculate saturation pressure only by two sets of data. The deviation between calculation and measurement is small, which was demonstrated in practical application.

Derivation of a novel model: Based on the above parameters, we can draw IPR curves. The main equatione are as follows:

- Vogel equation (Vogel and Shell, 1968):

$$\frac{q_o}{q_{omax}} = 1 - 0.2(\frac{p_{wf}}{\overline{P}_R}) - 0.8(\frac{p_{wf}}{\overline{P}_R})^2 \quad (16)$$

- Fetkovich equation (Fetkovich and Phillips, 1973):

$$\frac{q_o}{q_{omax}} = [1 - (p_{wf})^2]^n \quad (17)$$

- Bendakhlia combined the two equations above and got the following equation:

$$\frac{q_o}{q_{omax}} = [(1-V)\frac{p_{wf}}{\overline{P}_R} - (1-V)(\frac{p_{wf}}{\overline{P}_R})^2]^n \quad (18)$$

where, V is variable parameter in Vogel's equation. The curve can be simply considered according to the well flow equation, Eq. 1. In fact, when the productivity is very high, non Darcy percolation will appear near the bottom. In this case, the conventional method will be no longer suitable.

According to the three-phase inflow performance curve (Fig. 1), we can get a more reasonable method: A is the IPR curve whose moisture content is equal to 100%,

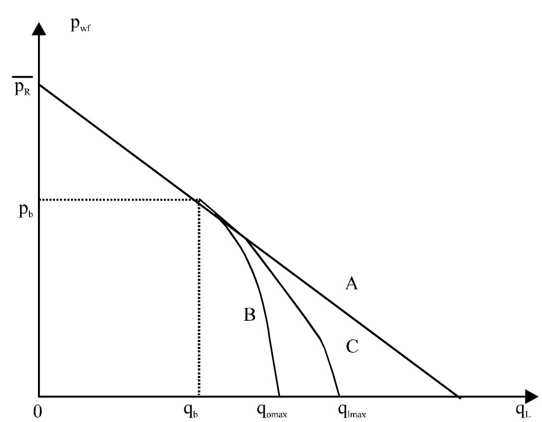

Fig. 1: Oil-gas-water three-phase inflow performance of oil wells

and B is the IPR curve whose moisture content is equal to 0%, and C is the IPR curve for the three-phase flow (Ji and Zhao, 2000).

Calculation of productivity index: When $P_{wf} \geq P_b$:

$$J_1 = \frac{q_t}{\overline{P_R} - P_{wf}} \tag{19}$$

When $P_{wf} < P_b$:

$$J_1 = q_t / [(1 - f_w)(\overline{P_R} - P_b + \frac{P_b}{1.8} A) + f_w(\overline{P_R} - P_{wf})] \tag{20}$$

Where:

$$q_t = (1 - f_w)q_o + f_w(q_l - q_o) \tag{21}$$

$$q_o = q_b + (q_{omax} - q_b)\{1 - 0.2[\frac{p_{wf}}{p_b}] - 0.8(\frac{p_{wf}}{p_b})^2\} \tag{22}$$

$$(q_l - q_o) = J_1(\overline{P}_R - p_{wf}) \tag{23}$$

$$q_b = J_1(\overline{P}_R - p_b) \tag{24}$$

$$A = 1 - 0.2(\frac{p_{wf}}{p_b}) - 0.8(\frac{p_{wf}}{p_b})^2 \tag{25}$$

The calculation of flowing bottom pressure: When $0 < q_t \leq q_b$:

$$P_{wf} = \overline{P}_R - q_t / J_1 \tag{26}$$

When $q_b < q_t < q_{omax}$:

$$P_{wf} = (1 - f_w)\, p_{wf(o)} + f_w p_{wf(w)} \tag{27}$$

Thus, using a combined IPR curve to calculate $p_{wf(o)}$:

$$p_{wf(o)} = 0.125 p_b[-1 + \sqrt{81 - 80(\frac{q_t - q_b}{q_{omax} - q_b})}] \tag{28}$$

Using the constant production index to calculate $p_{wf(w)}$:

$$p_{wf(o)} = \overline{P}_R - q_t / J_1 \tag{29}$$

Then:

$$p_{wf} = f_w(\overline{P_R} - q_t / J_1) + 0.125(1 - f_w) p_b[-1 + \sqrt{81 - 80(\frac{q_t - q_b}{q_{omax} - q_b})}] \tag{30}$$

Table 2: Deviation comparison of the productivity analysis models

Model	Maximum liquid production	Deviation
Oil-water composite method	27.17(m^3/d)	14.07(%)
Productivity index method	36.20(m^3/d)	14.48(%)
The Petrobras method	30.30(m^3/d)	4.17(%)
The novel model	30.60(m^3/d)	3.2(%)

After introducing flow efficiency, Eq. 30 can be changed to:

$$p_{wf} = fw(\overline{P_R} - q_l / (J_1 FE)) + 0.125 p_b (1 - f_w)(\sqrt{81 - 80\frac{q_l - q_b}{q_{omax} - q_b}} - 1) \tag{31}$$

When $q_{omax} \leq q_t < q_{lmax}$, the slope of the comprehensive IPR curve can be approximated a constant. So flowing bottom pressure at the maximum oil production point is:

$$p_{wf} = f_w(\overline{P_R} - q_{omax} / J_1) + (q_t - q_{omax})(8f_w + 9) / J_1 \tag{32}$$

where, q_t is liquid production. We calculate the parameters according to the above equations and draw the IPR curve according to the principles of oil-water composite method. It will be more in line with the actual situation.

DEVELOPMENT OF PRODUCTIVITY ANALYSIS AND FORECASTING SYSTEM FOR SINGLE WELL

We design the productivity analysis and forecasting system. And we can calculate the key parameters respectively. Furthermore, the system provides functions including saving IPR curves, zooming, printing, outputting to word etc., which is convenient for statistical analysis of the experimental results to equationte a better solution. To achieve the function of drawing the IPR curves, we choose GDI+graphics device interface provided by. NET platform, which provides a rich variety of graphics and image processing functions. We accomplish the basic drawing in the paint event of picture Box and create a bitmap in the specific operation of the image, which improves the speed and efficiency of the system significantly.

Parts of the operation interfaces are shown as follows (Fig. 2, 3, 4). According to the results of the interfaces, the comparison of deviations for the maximum liquid production is listed in the Table 2. We can choose the most suitable model according to the actual situation in the system. The results show that different models will have different IPR curves. And the values of

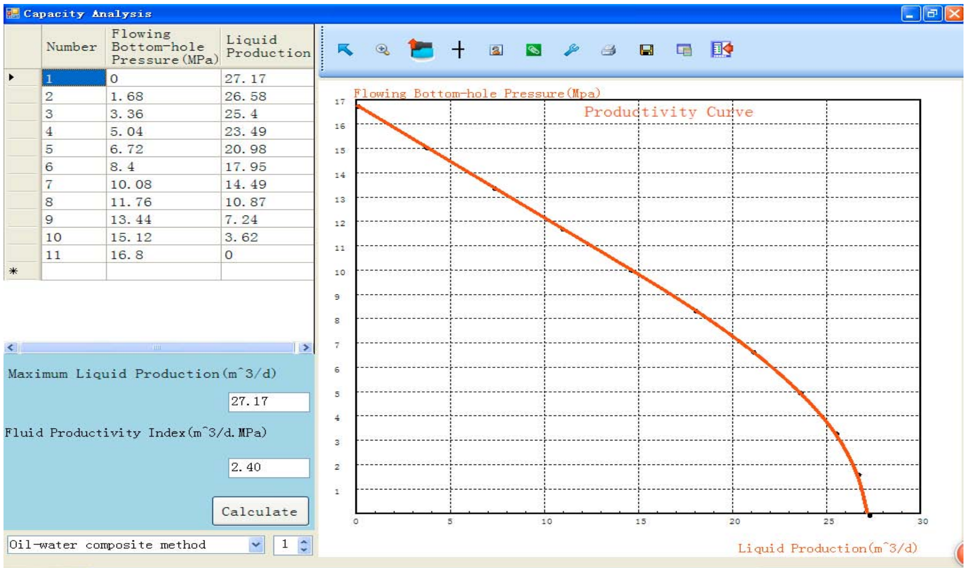

Fig. 2: Operation interface of oil-water composite method

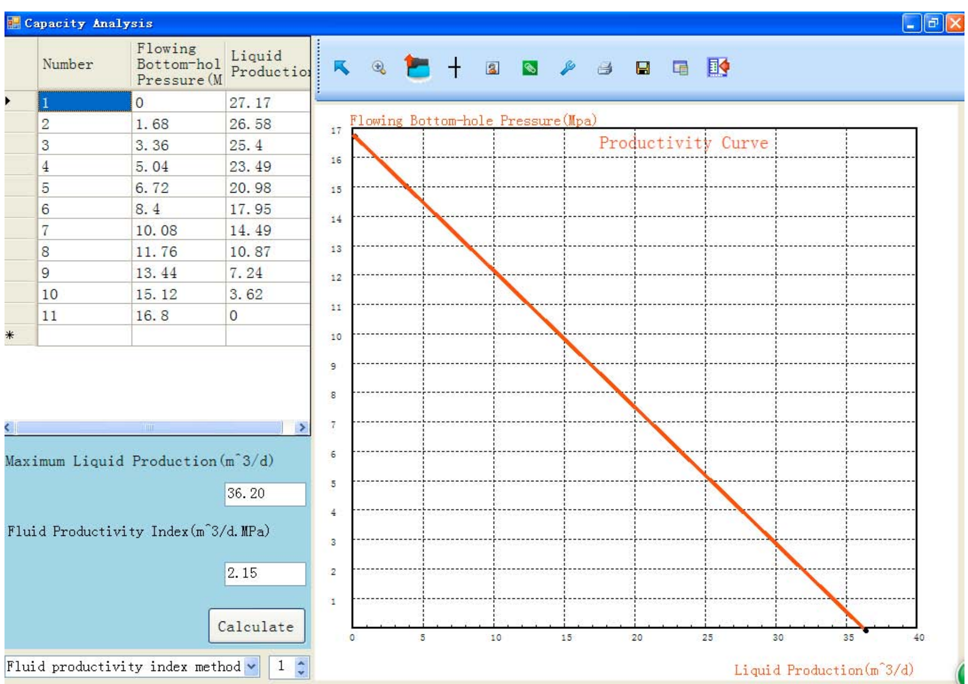

Fig. 3: Operation interface of fluid productivity index method

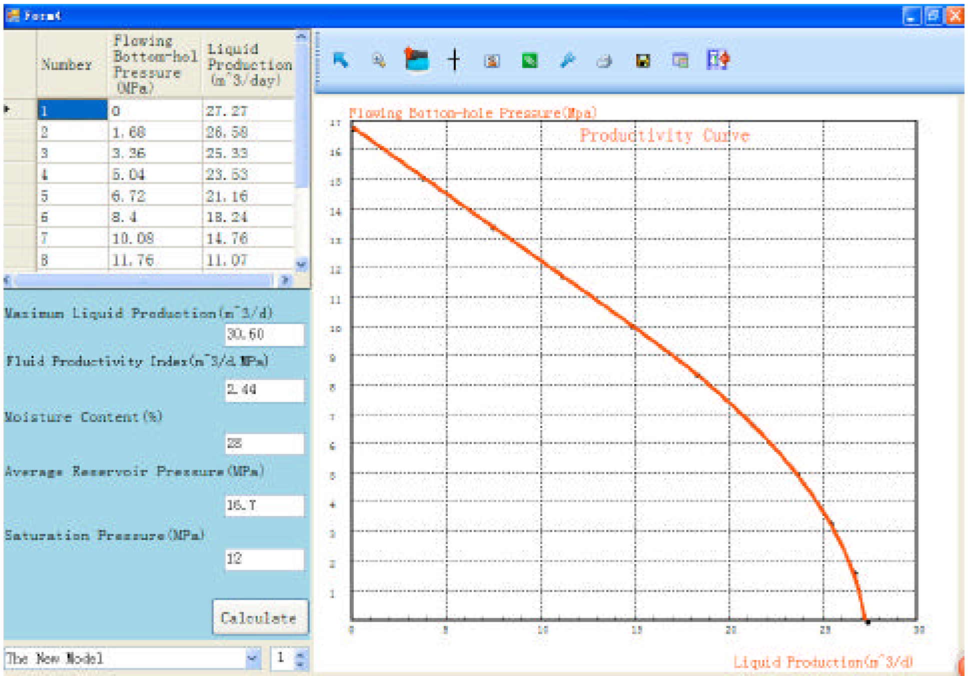

Fig. 4: Operation interface of the novel model

the parameters are also different. The novel model has higher accuracy and its deviation is the minimum, the scene data also confirmed this conclusion.

CONCLUSIONS

We present a novel productivity analysis and forecasting model, and develop a software platform for single well. We can use the proposed scheme to calculate key parameters combined with the oil reservoir and production data. It is more appropriate for the future production forecasting according to the IPR curves and provides basic reference data for making development plan. The main contributions are: (1) We apply three traditional methods to analyze production of single well; (2) We derive a novel productivity analysis model. The applicability and accuracy of the novel one is improved through comparative analysis; (3) We develop a software platform, which provides operations such as saving, zooming, sending etc., which facilitate further processing and analyzing results.

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