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A Practical Method for Production Decline Analysis of the Single Well During Natural Depletion in Tight Reservoirs After Fracturing

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ABSTRACT

The development of tight oil reservoirs has made remarkable progress all over the world currently, but how to quickly and accurately forecast the production decline trend of the single well after fracturing is quite a huge challenge in practical terms. Based on the production characteristics of tight oil reservoirs after fracturing during natural depletion and the fractional flow equation, as well as combined with the material balance equation and the Arps exponential decline model, a novel and practical method for production decline analysis (PDA) of the single well during natural depletion in tight reservoirs after fracturing was proposed. Then, a production well (JX) from the tight oil block X in the Junggar basin of China was selected as the case well for application and the production decline curve of the JX well was calculated and forecasted. Compared with the Logistic model and actual production data from the field, the accuracy of the practical PDA method was verified, the economic recoverable reserves and the corresponding oil recovery factor of the JX well were further predicted. The novel PDA method is of great help for field engineers to evaluate the current production status of oil wells and predict their future production trends quickly and conveniently.

Keywords: practical method, production decline analysis (PDA), natural depletion, tight reservoirs, fracturing

NONMENCLATURE

a,b,c	characteristic constants, > 0
B_o	formation oil volume factor
B_w	formation water volume factor
D_I	initial nominal decline rate, min^{-1}
f_w	water cut
L_p	cumulative liquid production, 10^4m^3
$L_{p\max}$	maximum cumulative liquid production, 10^4m^3
M_{wi}	total injected water quality, 10^4t
M_{wp}	total produced water quality, 10^4t
N_p	cumulative oil production, 10^4m^3
Q_l	liquid production, m^3/mon
Q_{li}	initial liquid production, m^3/mon
Q_o	oil production, m^3/mon
S_{we}	water saturation at the outflow end
S_{wi}	initial water saturation
$\overline{S_w}$	average water saturation
t	producing time, mon
V_t	total reservoir volume, 10^4m^3
W_i	cumulative water injection, 10^4m^3
W_p	cumulative water production, 10^4m^3
Greek symbols	
ϕ	porosity
ϕ_i	initial porosity
μ_o	oil viscosity, mPa·s
μ_w	water viscosity, mPa·s
ρ_w	water density, t/m^3
ρ_{wi}	initial water density, t/m^3

1. INTRODUCTION

Nowadays tight oil resources have shown great development potentials and huge economic benefits all over the world. Despite the significant progress has been made in some tight oilfields, academic studies on fluid flow mechanisms and well production performance still lag behind actual demands and requirements in the field. How to quickly and accurately forecast the production decline trend of the single well after fracturing is a quite huge challenge in practical terms [1-2].

In general, production decline analysis (PDA) methods of unconventional resources proposed in the literature can be mainly classified into two principal categories: decline curve analysis (DCA) and rate transient analysis (RTA) [3-5]. Based on the production characteristics of tight oil reservoirs after fracturing during natural depletion and the fractional flow

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equation, as well as combined with the material balance equation and the Arps exponential decline model, a novel and practical method for production decline analysis of the single well during natural depletion in tight reservoirs after fracturing was proposed, which is of great help for field engineers to evaluate the current production status of oil wells and predict their future production trends quickly and conveniently.

2. METHODOLOGY

Assuming that all fluids in the matrix system flow into the wellbore through artificial fractures and the flow of oil and water obeys the Darcy's law in the fracture system, then the following expressions can be obtained by the fractional flow equation and the empirical model for the oil-water relative permeability ratio [6-7]:

$$\begin{cases} f_w = \dfrac{1}{1+(\mu_w/\mu_o)(B_w/B_o)a\mathrm{e}^{-bS_{we}}} = \dfrac{1}{1+A\mathrm{e}^{-BS_{we}}} \\ A=(a\mu_w B_w)/(\mu_o B_o) \quad A>0 \\ B=b \quad B>0 \end{cases} \tag{1}$$

Generally, the total water volume involved in the whole production process after fracturing can be classified into four distinct parts: (1) the total water volume in the original formation; (2) the total injected water volume; (3) the total produced water volume; (4) the total water volume stored in the formation. Thus, the material balance equation of the water phase is:

$$S_{wi}\phi_i V_t \rho_{wi} + M_{wi} = M_{wp} + \overline{S}_w \phi V_t \rho_w \tag{2}$$

Accordingly:

$$\overline{S}_w = \frac{S_{wi} + \left[(M_{wi}-M_{wp})/\phi_i V_t \rho_{wi}\right]}{(\phi/\phi_i)(\rho_w/\rho_{wi})} \tag{3}$$

In fact, the total water volume in the original formation and the total injected water volume can be regarded as constants. If the compressibility of both water and rock are ignored, then:

$$\begin{cases} \overline{S}_w = S_{wi} + (W_i - W_p)/(\phi_i V_t) = C - DW_p \\ C = S_{wi} + W_i/(\phi_i V_t) \quad C>0 \\ D = 1/(\phi_i V_t) \quad D>0 \end{cases} \tag{4}$$

During the process of natural depletion, assuming that $\mathrm{d}S_{we}/\mathrm{d}t \approx \mathrm{d}\overline{S_w}/\mathrm{d}t$, the following Eq. (5) can be obtained by substituting Eq. (4) into Eq. (1):

$$\begin{cases} f_w = \dfrac{1}{1+A\mathrm{e}^{-B\cdot K(C-DW_p)}} = \dfrac{1}{1+A\mathrm{e}^{-E+FW_p}} \\ E = B\cdot K\cdot C \quad E>0 \\ F = B\cdot K\cdot D \quad F>0 \end{cases} \tag{5}$$

According to Eq. (5), it can be apparently seen that the water cut is a function of the cumulative water production, in which the three parameters A, E, F can be obtained by curve fitting with the actual production data from the field.

Furthermore, due to the poor connectivity of tight oil wells, the limited depletion process of liquid production can be ideally regarded as a two-phase flow process of oil and water under the closed elastic-drive. Thus, the total liquid production can be calculated by the Arps exponential decline model [8]. Accordingly, the oil production can be expressed as:

$$Q_o = Q_l(1-f_w) = Q_{li}\mathrm{e}^{-D_l\cdot t}\left(1-\frac{1}{1+A\mathrm{e}^{-E+F\cdot W_p}}\right) \tag{6}$$

Eq. (6) is the practical comprehensive model for oil production calculation, which is also the theoretical basis for PDA of the single well during natural depletion in tight reservoirs after fracturing.

3. CASE STUDY

A production well (JX) from the tight oil block X in the Lucaogou formation, Jimsar sag, Junggar basin of China is selected as the case well to analyze production decline performance by employing the proposed novel PDA method for application.

3.1 Overview of the case well

The JX well was put into production after the staged fracturing operations on May 24, 2014. According to the production records, the monthly liquid production had reached a maximum of 2632m^3 in July and the monthly oil production had reached a maximum of 806m^3 in September, then the well entered production decline stage. The well was shut in from October to December of 2014 and subsequently reopened for natural flowing production. As of August 2017, cumulative liquid and oil production of the JX well are 1.7542×10^{4}m^3 and 1.7777×10^{4}m^3, respectively. The production and water cut performance curves of the JX well are shown as Fig. 1 and Fig. 2.

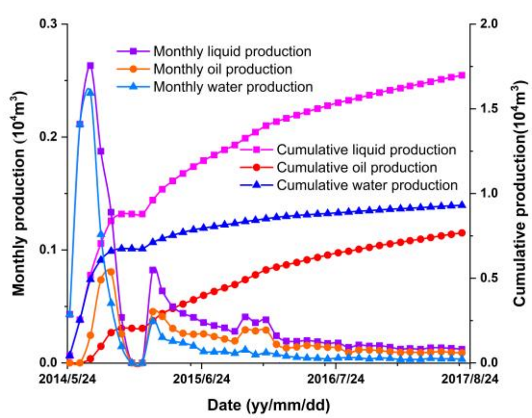

Fig. 1. Production performance curves of the JX well

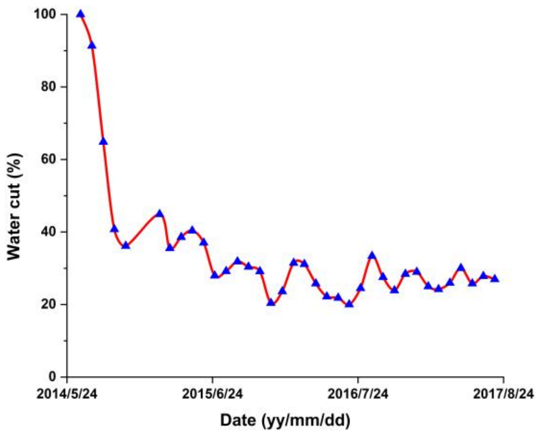

Fig. 2. Water cut performance curve of the JX well

3.2 Liquid production decline for the JX well

Firstly, the liquid production data from March, 2015 to May, 2016 are selected and it is found that there is a quite good linear relationship between monthly liquid production and producing time in the semi-logarithmic coordinate system, as shown in Fig. 3.

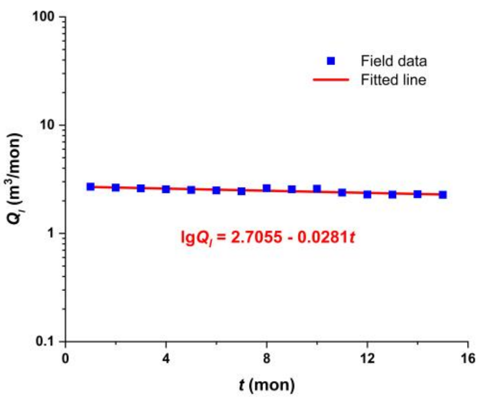

Fig. 3. Relationship curve between liquid production and producing time of the JX well

According to the fitted equation in Fig. 3 and the Arps exponential decline model, the liquid production model can be expressed as:

$$Q_l = 508e^{-0.0647t} \quad (7)$$

Then it can be predicted that the maximum cumulative liquid production is 1.8513×10^{4}m^3.

To further verify the forecasted result, the Logistic model is employed to predict the maximum cumulative liquid production of the JX well for mutual verification [9]. The deduced expression can be written as follows:

$$\frac{Q_l}{L_p} = c - \frac{c}{L_{p\max}} L_p \quad (8)$$

Based on the field data, the maximum cumulative liquid production of the JX well can be calculated directly by curve fitting with Eq. (8), which is 1.8157×10^{4}m^3.

It is calculated that the relative error of two results forecasted by the Arps exponential decline model and the Logistic model is only 1.95%, which further demonstrates that liquid production decline during natural depletion in tight reservoirs after fracturing conforms to the Arps exponential decline model.

3.3 Oil production decline for the JX well

According to Eq. (5), the fitted curve between water cut and cumulative water production of the JX well is shown as Fig. 4. It can be seen that the fitted curve based on the fitting relationship established in this study is quite in good agreement with the field data.

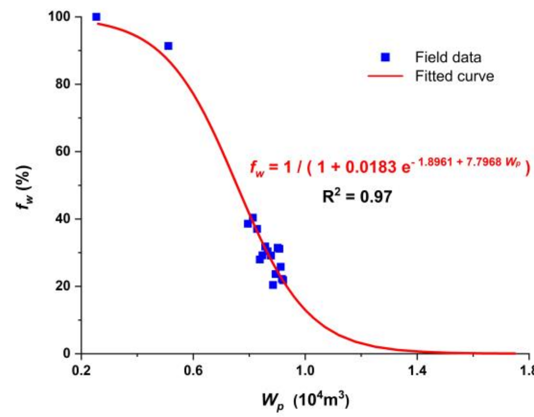

Fig. 4 Curve fitting on f_w and W_p of the JX Well

Meanwhile, by analyzing production records of many wells in the X block, it is found that the well performance curves between cumulative water production and producing time have shown quite good linear characteristics in the later stage of production. Accordingly, the field data from August 2015 to May 2016 are selected for linear fitting, which is as shown in Fig. 5.

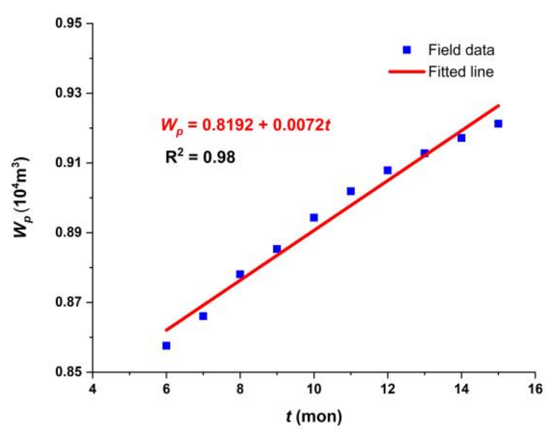

Fig. 5. Linear fitting on W_p and t of the JX well

Based on the expression of Eq. (6) and the fitted equation in Fig. 4, it has been known that the Q_{li} is

508m^3/mon, D_l is 0.0647mon^{-1}, A is 0.0183, E is 1.8961, F is 7.7968×10^{-4}m^3. Finally, the practical comprehensive model of oil production decline for the JX well can be obtained by substituting the fitted equation in Fig. 6. into the Eq. (6). After calculation, the oil production decline curve is obtained as shown in Fig. 6. It can be clearly seen from Fig. 6 that the calculated and forecasted production decline curve obtained by the proposed PDA method is in good agreement with the actual field data. According to the forecasted results, it can be inferred that the monthly oil production of the JX well will drop to below 50m^3 in half a year.

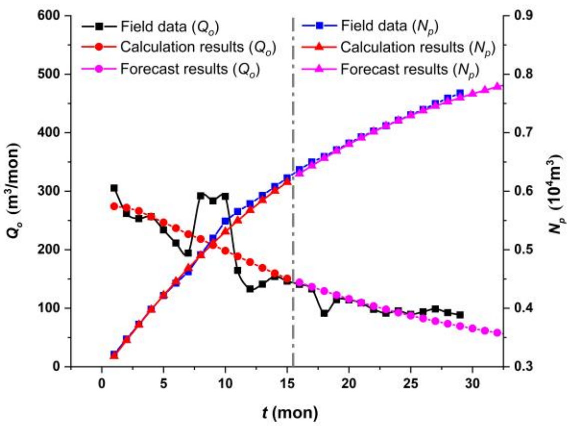

Fig. 6. Comparisons of forecasted production decline curve and cumulative oil production curve with field data

In order to further verify the accuracy of the forecasted results for cumulative oil production, the cumulative oil production curve has been calculated by using the practical comprehensive model for the JX well, which is also drawn in Fig. 6. Obviously, the calculated and forecasted results are also in pretty good agreement with the actual field data, which proves that the novel practical method for PDA of the single well during natural depletion in tight reservoirs after fracturing proposed in this paper is pretty accurate. According to the forecasted results, it can be inferred that cumulative oil production of the JX well will increase slowly in the late production stage, and the cumulative oil increment will be about 330m^3 after continuous production for 6 months.

Assuming that the economic-limited oil production is 0.5t/d, then it can be forecasted that the economic recoverable reserves controlled by the JX well is 0.8514×10^{4}m^3 (assuming that oil relative density is 0.85). As of August 2017, the recovery factor of recoverable reserves for the JX well is almost reaching 90.2%. Theoretical forecast indicates that the production mode needs to be changed urgently. In fact, the JX well has turned to the mechanical production stage, and the yield has increased significantly.

4. SUMMARY AND CONCLUSIONS

(1) A novel and practical method for production decline analysis (PDA) of the single well during natural depletion in tight reservoirs after fracturing was proposed.

(2) Based on the proposed method, the production decline curve of the case well was calculated and the future production trend was forecasted for application.

(3) Compared with the Logistic model and actual field data, the accuracy of the practical PDA method was verified, the economic recoverable reserves and the corresponding oil recovery factor of the case well were further forecasted.

(4) The novel PDA method proposed in this paper is of great help for field engineers to evaluate the current production status of oil wells and predict their future production trends quickly and conveniently.

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