

Research on Well Testing Interpretation Method of Polymer Flooding Considering Variety of Polymer Concentration in Reservoirs

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Abstract

Combining the theoretical analysis and actual production data statistics, the paper found that concentration of polymer solution at a point in the stratum had exponential relation with the distance away from injectors. Based on viscosity model considering shear degradation and polymer concentration, a non-Newtonian power-law fluid well test interpretation model is built. Then well test interpretation chart of polymer flooding is proposed by numerically resolving the new model. Example analysis shows that the polymer flooding well test interpretation method and chart provide a theoretical and technical support for explaining reasonably formation parameters under conditions of polymer flooding and quantitatively evaluating the effects of polymer flooding.

Key words: Concentration of polymer solution; Index; Viscosity model; Well testing interpretation method

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INTRODUCTION

Polymer flooding is an important technique for enhanced oil recovery technology, which has been applied to a large-scale production application especially in Daqing oilfield, China^[1-4]. Correspondingly, polymer flooding well test interpretation is developing rapidly. In the end of 20th century, well test interpretation model for non-Newtonian power law fluid in non-newtonian-newtonian composite reservoir was built, and the analytical solution in Laplace space was obtained^[5-6]. Based on the former researchers, then a new well test interpretation model considering comprehensively heat loss, effect of wellbore storage, skin effect and additional pressure drop was established^[7-9]. At the same year, polymer flooding streamline numerical well test interpretation models in production phase and shut-in phase were established individually^[10-11]. The ASP system was assumed to be non-Newtonian power-law fluid and a homogeneous well testing model was established. Addition variable separation method was used to exporting a series of concise analytical solution. A polymer flooding well test interpretation model in composite reservoir is established, and analytical method and numerical method for polymer injection wells and blocks were respectively used to explain the model. For carbonate reservoir, well testing model was studied^[12-13].

However, in the conventional polymer flooding well test interpretation model, most models use constant power law exponent to describe the flow event without considering variety of polymer concentration in the formation^[14]. Based on the research of polymer flooding well test of forerunners, synthesizes the influence of shear degradation and polymer concentration, viscosity model is established and applied to polymer flooding well test interpretation model. New well test model considering variety of polymer concentration has been presented in a form that suitable for interpreting the parameters well and truly^[15].

1. ESTABLISHMENT OF VISCOSITY MODEL

1.1 Concentration of Polymer Solution Varying Between Injector and Producer

The polymer solution concentration is gradually reduced from injector to producer, but there is no one to give a simple and reasonable expression used for well test interpretation model which describes distribution law of polymer in the strata. We know that polymer solution concentration at a point between injector and producer had exponential relationship with the distance away from injector through numerical simulation of CMG software in this paper.

$$C = a_1 e^{br}. \quad (1)$$

For any well, a_1 and b are constant, and two parameters are used to specify a_1 and b : concentration of injection polymer C_z and concentration of production polymer C_c , and producer injector spacing is d .

When the producer is center well, then $C_z = a e^{bd}$,

$$a_1 = \exp\left(\frac{\ln C_c - r_w/d \ln C_z}{1 - r_w/d}\right), \quad b = \frac{\ln(C_z / C_c)}{d - r_w}. \quad (2)$$

$$\mu_\alpha = \mu_w \left[1 + r_D^{1-n} \left(A_1 C_c \left(\frac{C_z}{C_c}\right)^{\frac{r-r_w}{d-r_w}} + A_2 C_c^2 \left(\frac{C_z}{C_c}\right)^{\frac{2(r-r_w)}{d-r_w}} + A_3 C_c^3 \left(\frac{C_z}{C_c}\right)^{\frac{3(r-r_w)}{d-r_w}} \right) \right]. \quad (5)$$

2. ESTABLISHMENT OF WELL TEST INTERPRETATION METHOD

2.1 Mathematical Model

Based on the new viscosity model, a non-Newtonian flow partial differential equation is established. The new well test interpretation model starts with the following assumptions.

Oil layer is homogeneous and isotropic single-layer reservoir. There is only one well in the center of oil reservoir. The outer boundary of the reservoir is circular and the well completely penetrate the formation. The fluid is horizontal, slightly compressible and single phase exhibits the characteristics of non-Newtonian pseudoplastic fluid characteristics. The fluid viscosity is in line with the viscosity model established in this paper. The polymer solution is injected with a constant ground speed. The impact of gravity is considered but effect of wellbore storage and skin factor is not.

(a) Partial differential equation

$$\frac{1}{r} \cdot \frac{\partial}{\partial r} \left(r \cdot \frac{1}{\mu_\alpha} \frac{\partial P}{\partial r} \right) = \frac{\phi c}{k_r} \cdot \frac{\partial P}{\partial t}. \quad (6)$$

(b) Primary condition

Equal original pressure P_i in the whole reservoir is assumed.

When $a = a_1 \cdot e^{br_w}$, combining Equation (2), the expression about distribution law of the polymer solution concentration between producer and injector is shown in Equation (3).

$$C = C_c \left(\frac{C_z}{C_c} \right)^{\frac{r-r_w}{d-r_w}}. \quad (3)$$

1.2 Viscosity Model

In most cases, polymer solution shows a pseudo-plastic behavior. Power law model can be used to describe the relationship between viscosity and shear rate. At the well point, μ_α is denoted by μ^* , then

$$\frac{\mu^*}{\mu_\alpha} = r_D^{n-1}. \quad (4)$$

Viscosity Model in Equation (4) only takes into account the relationship between shear rate and viscosity of the polymer solution, which is not according with the true condition. Based on Equation (4), considering both shear degradation and changes in polymer concentration, a new viscosity model is established in the paper, which is shown as follows:

$$P_D(t_D = 0) = 0. \quad (7)$$

(c) Inner boundary condition
Skin effect

$$P_{wD} = P_D(1, t_D) - \frac{\mu^*}{\mu_\alpha} \cdot \frac{\partial P_D}{\partial r_D} \Big|_{r_D=1} \cdot S. \quad (8)$$

Effect of wellbore storage

$$-\frac{\mu^*}{\mu_\alpha} \frac{\partial P_D}{\partial r_D} \Big|_{r_D=1} = 1 - C_D \frac{dP_{wD}}{dt_D}. \quad (9)$$

(d) Inner boundary wellbore condition considering new viscosity model

When $r_D = 1$, then $\mu^* = \mu_\alpha$, the Equations (8) and (9) about skin effect, and effect of wellbore storage become as follows:

$$P_{wD} = P_D(1, t_D) - \frac{\partial P_D}{\partial r_D} \Big|_{r_D=1} \cdot S, \quad (10)$$

$$-\frac{\partial P_D}{\partial r_D} \Big|_{r_D=1} = 1 - C_D \frac{dP_{wD}}{dt_D}. \quad (11)$$

(e) External boundary condition

Infinite outer boundary $P_D(\infty, t_D) = 0$, (12)

Constant pressure outer boundary $P_D(r_{eD}, t_D) = 0$, (13)

Closed outer boundary $\frac{\partial P_D}{\partial r_D} \Big|_{r_D=r_{eD}} = 0$. (14)

(f) Partial differential equation considering new viscosity model

$$\frac{1}{r_D} \frac{\partial}{\partial r_D} \left[r_D \frac{1 + (A_1 C_c + A_2 C_c^2 + A_3 C_c^3)}{1 + r_D^{1-n} \left(A_1 C_c \left(\frac{C_z}{C_c} \right)^{\frac{r_D-1}{d_D-1}} + A_2 C_c^2 \left(\frac{C_z}{C_c} \right)^{\frac{2(r_D-1)}{d_D-1}} + A_3 C_c^3 \left(\frac{C_z}{C_c} \right)^{\frac{3(r_D-1)}{d_D-1}} \right)} \frac{\partial P_D}{\partial r_D} \right] = \frac{\partial P_D}{\partial t_D} \quad (15)$$

2.2 Model Solving

The new well test interpretation model established in this paper is non-linear. It is difficult to solve the analytical

solution, thus, the numerical method is used to solve the model. Then the differential equation is described as follows:

$$\frac{1}{e^{2\beta_i} \Delta\beta_i} T_{i-\frac{1}{2}} P_{Di-1}^{n+1} - \left(\frac{1}{e^{2\beta_i} \Delta\beta_i} T_{i+\frac{1}{2}} + \frac{1}{e^{2\beta_i} \Delta\beta_i} T_{i-\frac{1}{2}} + \frac{1}{\Delta t_{Dn}} \right) P_{Di}^{n+1} + \frac{1}{e^{2\beta_i} \Delta\beta_i} T_{i+\frac{1}{2}} P_{Di+1}^{n+1} = -\frac{1}{\Delta t_{Dn}} P_{Di}^n \quad (16)$$

The error of differential equations in Equation (16) is as follows:

$$E_{n+1} \leq E_0 + \left(\sum_{j=0}^n \Delta t_{Dj} \right) M \quad (17)$$

From the above Equation (17), when $E_0 = 0$, if the time and grid spacing approach zero, E_{n+1} also tends to zero. When $E_0 \neq 0$, because M is bounded, the error at any one time step is bounded. As a result, implicit difference scheme of Equation (17) is unconditional convergence.

2.3 Analysis of Typical Plate and Pressure Buildup Curve

According to the new well test interpretation model established in this paper, computer software is worked out. Then, we can get the dimensionless pressure change curves and dimensionless time change curves. Under the three kinds of outer boundary conditions, the relation curves between dimensionless pressure and dimensionless time are shown in Figures 1, 2 and 3.

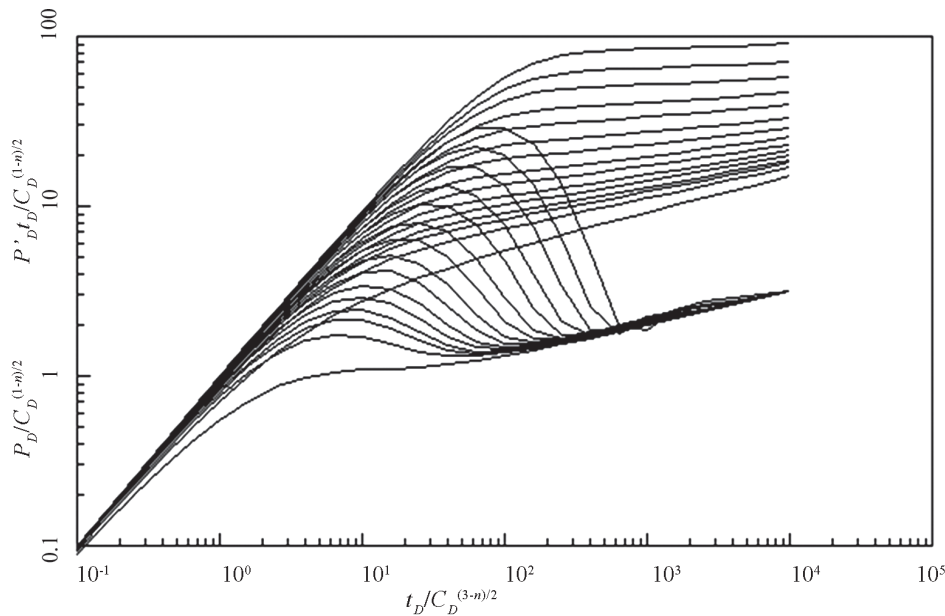


Figure 1
Well Test Plot for Non-Newtonian Fluid Flow in a Infinite Reservoir ($n = 0.5$)

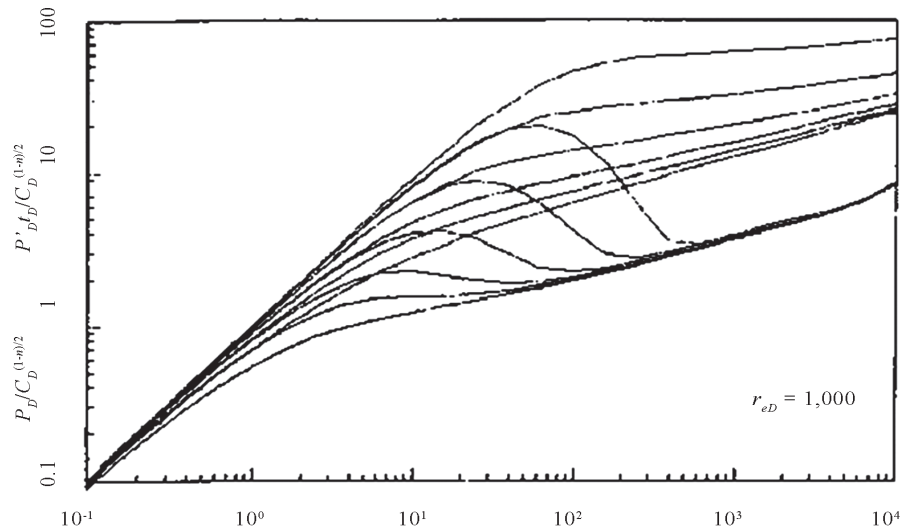


Figure 2
Well Test Plot for Non-Newtonian Fluid Flow in a Reservoir With Closed Outer-Boundary ($n = 0.2$)

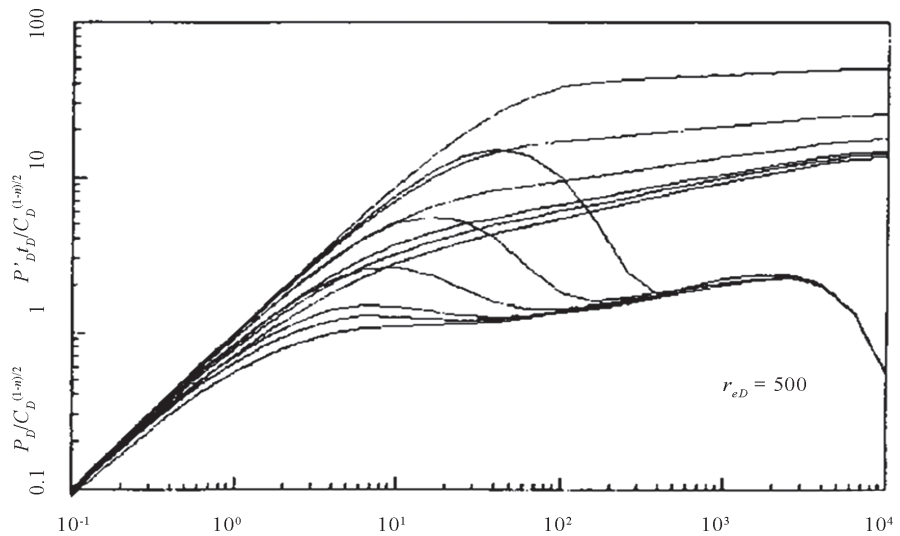


Figure 3
Well Test Plot for Non-Newtonian Fluid Flow in a Reservoir With Constant Pressure Outer-Boundary ($n = 0.5$)

As can be seen from the chart, for polymer wells which the testing of build-up curve is performed on during the shut-in period, when pressure recovers the radial flow, pressure rangeability decreases gradually, darcy velocity and shear rate are reduced, but the fluid apparent viscosity increases, which result in pressure recovery rate is lower than that of Newton flow. And the pressure derivative curve in the double logarithmic coordinate system is no longer a 0.5 horizontal line, but a line with a certain slope. With the decrease of the parameter n , the slope of the straight line segment of the pressure derivative curve in radial flow increases gradually.

3. EXAMPLE ANALYSIS

The designed software is applied to explain pressure build up curves of partial oil and water wells in polymer injection block in Daqing oil field, and build up curves

before and after polymer flooding is compared. As can be seen from actual pressure build up curves of both oil and water wells, the curves have changed significantly, which is to say that, in the early stage, rate of pressure recovery and decline become slower and pressure rangeability in oil wells is more obvious than that in water wells. In the middle stage, rate of pressure recovery and decline are faster and pressure rangeability in water wells more obvious than that in water wells. Meanwhile, the difference becomes more and more significant with cumulative polymer injection increasing.

Taking polymer production well B1-D4-P53 in Sazhong oilfield of Daqing as an example, its test pressure curve is studied in March 2000 and fitting pressure build up curve shows in Figure 4. According to well test interpretation method established in the paper, flow coefficient is 0.319 and skin factor is 1.38 by calculating.

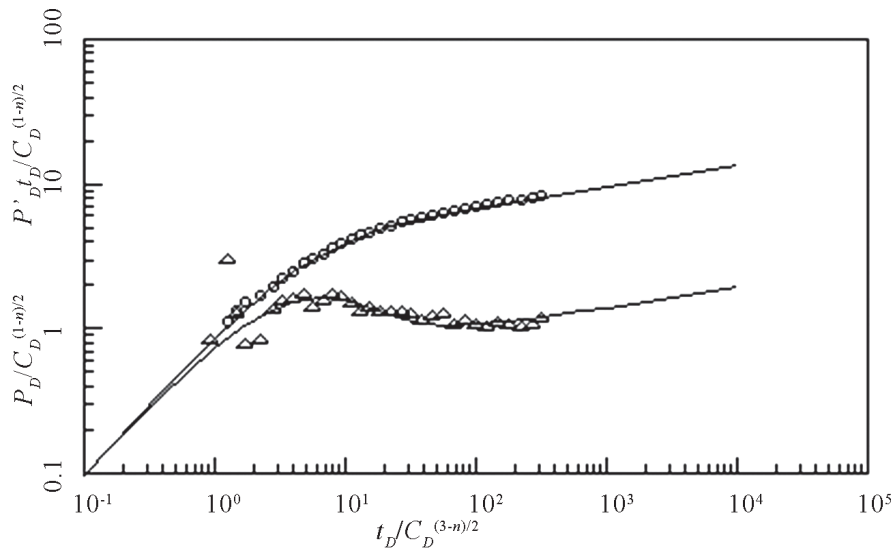


Figure 4
Log-Log Pressure Build Up Fitted Curve of Well B1-D4-P53

CONCLUSION

(a) The polymer solution concentration is gradually reduced from injector to producer. The polymer solution concentration in the strata has exponential relation with the distance away from injector.

(b) Based on the new viscosity model established in the paper, fluid viscosity in basic seepage equation is described, and new well test interpretation model in polymer flooding is established. In the actual well test interpretation, the forecast of formation parameters under polymer flooding conditions can be predicted more accurately.

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