Flow Characteristics of Viscoelastic Polymer in Microchannel

Jipeng Zheng, Yulin Ye, Liuying Yan

***Abstract*—Polymer flooding can not only accelerate the rate of oil production but also improve the efficiency of oil production. The finite volume method is used to study flow characteristics of viscoelastic polymer in microchannel. The results showed that: the displacement efficiency of the viscoelastic polymer is better than that of water. The greater the viscosity of the polymer, the greater the drag force rid of residual oil and the displacement efficiency increases as well. As the polymer's viscosity increasing, the flow region of concave corner may increase but the retention area of residual oil may be decreased, the spread area of the polymer in the voids increase and the displacement efficiency increases. The results can provide a theoretical basis for oilfield polymer selection and optimization.**

***Index Terms*—Finite volume method, Numerical simulation, Viscoelastic properties, Microchannel**

I. Introduction

Oil is a nonrenewable resource and an important economic lifeline of the country's economic development. At present, most oilfields of the world has entered the later stages of water flooding development, which lead to water content increased and the production declined, capital investment and costs increased, economic indicators and technical indicators increased as well. Most of the remaining oil and residual oil in the reservoir layer could not be exploited due to differences between oil and water in nature, uneven distribution of oil layer and other factors. Water flooding is very difficult to open up the remaining oil and residual oil in the high water-cut stage. How to exploit in the cost-effective method is a topic which is unremitting research of the national reservoir engineering specialists. After years of research work, scientists have proposed polymer flooding, which is not only different from water flooding, but also can improve the displacement efficiency of flooding technology. It is applied to actual industrial production, that has achieved some good results [1-3].Tang Guoqing [4] observed and studied the polymer flooding mechanism by using the microchannel model, the results showed that: the polymer solution can expand swept volume and control the flow ratio through streaming around and control profile .In addition, the effect of adsorption and viscous resistance and the increased driving pressure can improve the displacement efficiency. Xia Huifen et al [5-6] obtained the mechanism of improving microchannel displacement efficiency of polymer solution by studying the experimental that the viscoelastic polymer solution can not only reduce the water flooding residual oil, but also can pull residual oil out from microchannel. In addition, the part of the residual oil was pulled into oil slick which forms a new oil flow by the polymer solution**.** Then the discontinuous residual oil was gathered a flowable oil by the normal force of the polymer solution and ultimately the microscopic oil displacement efficiency was improved. This paper study the flow characteristics of viscoelastic polymer in the micro tract with the finite element volume method and obtain its characteristic ,which is significant for further deepen the understanding and rich oil displacement mechanism and guide oilfield polymer flooding large-scale use and enhance recovery factor.

II. Problem description of viscoelastic polymer flow

The real pore shape in the residual oil reservoir is different and polymer is viscoelastic, which makes numerical calculation complex and solve difficult. the researcher simplify process of microscopic voids In order to facilitate the calculation of study, microscopic voids are simplified to some easier models ,for example, sudden expansion symmetric model, sudden contraction symmetric model , micro symmetric model with a blind end and so on[7]. The micro channel flow problems viscoelastic polymer in both sudden contraction sudden enlargement stage another stage is studied in this paper, as shown in Figure 1.the ratio between the width of the constriction and the width of the main channel is 1: 4, length ratio of 1: 1[8]. Take A = 10μm, B = 2.5μm as example. The convex angular position corresponds to dead oil area of microscopic pores, including both shear flow and extensional flow, which is the focus location of this study. The expansion - contraction - dilation tube model is characterized by simple geometry of the fluid flow area, which includes a variety of process flow rheological behavior of the flow process. The flow of the polymer solution is a simple shear flow on away from the upstream and downstream of die wall of the contraction zone. The fluid presents a pure extensional flow in the center line of the contraction zone. The flow includes both shear flow and stretched flow in lobes location, which can fully reflect the viscoelastic properties of the polymer solution in the micro mutation interface [9-11].

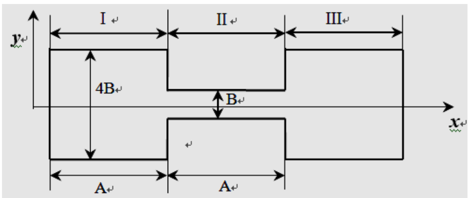


Fig.1-flow channel model

This paper select the Bird-Carreau constitutive model to describe the rheological properties of viscoelastic polymer with the first normal stress difference as the main feature in the reservoir conditions. This constitutive model， which considered viscosity and elasticity of the polymer solution, can accurately reflect the fundamental rheological properties of the polymer solution. Under actual flow conditions, the polymer solution flow in the pore is isothermal, incompressible and unsteady flow. Excluding the mass force, the control equation is as follows:

1) Continuity equations:

$$\frac{\partial u_x}{\partial x}+\frac{\partial u_y}{\partial y}=0 \qquad (1)$$

Motion equations

$$\frac{\partial u_x}{\partial t}+u_x\frac{\partial u_x}{\partial x}+u_y\frac{\partial u_x}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{1}{\rho}\left(\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{xy}}{\partial y}\right) \qquad (2)$$

$$\frac{\partial u_y}{\partial t}+u_x\frac{\partial u_y}{\partial x}+u_y\frac{\partial u_y}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{1}{\rho}\left(\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}\right) \qquad (3)$$

Where

τ_{ij} = Stress tensor, τ_{xx} 、τ_{yy} were the stress of the first law and the stress of the second law and τ_{xy} was the Shearing stress, pa;

λ = relaxation time, s

$\eta=\mu$ the apparent viscosity of the fluid, m pa·s

u = velocity, m/s

u_x = the X direction of the velocity, m/s

u_y = the Y direction of the velocity, m/s

ρ = fluid density, kg/m^3

p = pressure, pa

T = temperature, T

k = Heat transfer coefficient of the fluid

c_p = Specific heat capacity.

2) Bird-Carreau Constitutive model equation:

$$\eta=\eta_\infty+(\eta_0-\eta_\infty)\left(1+\lambda^2\gamma^2\right)^{\frac{n-1}{2}} \qquad (4)$$

Where

η_0 = Zero shear viscosity, pa·s;

η_∞ = Infinite shear viscosity, pa·s.

Viscoelastic polymer has some features that are storage modulus, relaxation time, the first normal stress difference, Wesson Borg Number ($We=\lambda v/L$), Deborah Number ($De=\lambda/t$) and so on. In this paper, polymer viscoelastic is only characterized by relaxation time and Wesson Borg number.

The viscosity of viscoelastic polymer ranges from 0.0008 pa·s to 0.0543 pa·s, The density of the flowing medium is 968.8kg/m^3,the density of water is 990.1kg/m^3,the viscosity of water is 0.623 mpa·s. Inlet is defined as the flow which is 8.0×10-6m^3/s and outlet is defined as the outflow. The model was meshed and the boundary conditions were set. The flow properties of the polymer are described by the Bird-Carreau constitutive model and the fluid control equations, and the model is solved by finite volume method.

III. Flow Characteristics of Viscoelastic Polymer in Microchannel Analysis

A. Effect of Viscosity

The viscosity of viscoelastic polymer, the relaxation time and the shear rate are considered in this study, and the values are 0.0008 pa·s, 0.236s, 0.4627s^{-1}. Fig 2 shows the streamline diagram of viscoelastic polymer in microchannel.In the same condition, fig 3 shows the streamline diagram of water.

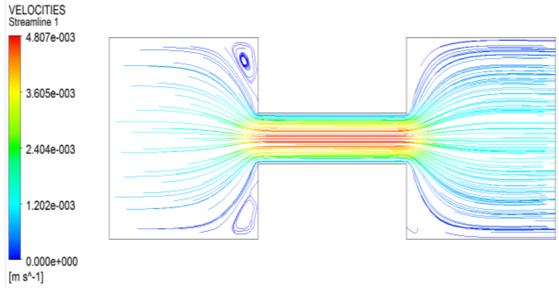


Fig.2-streamline contour diagram of viscoelastic polymer

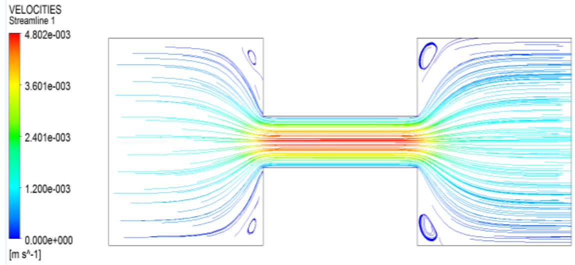


Fig.3-streamline contour diagram of the water

Fig 2 and Fig 3 show the streamlines of viscoelastic polymer solution in inlet contractive stage is similar to that of water. A cone border is formed due to the sudden contraction of flow channel interface, which makes the flow lines no longer parallel. Two whirlpools of certain rules generates on the corner, whereas the spread area of viscoelastic polymer is larger than that of water. The streamlines deformed again because the channel interface is enlarged, when the polymer solution extrudes the throat, then enters into the large pores through the equal sectional holes of flow channel, and the extruded diameter of viscoelastic polymer solution is greater than that of the water in varying degrees. Fig 2 and fig 3 also show that water generates significant whirlpool around the corner, however, viscoelastic polymer solution doesn't generate whirlpool. The reason of the phenomenon is swelling effect extrusion of viscoelastic polymer solution or Buras effect [12].

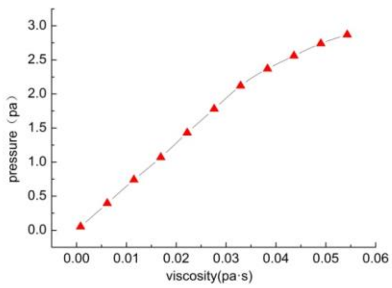
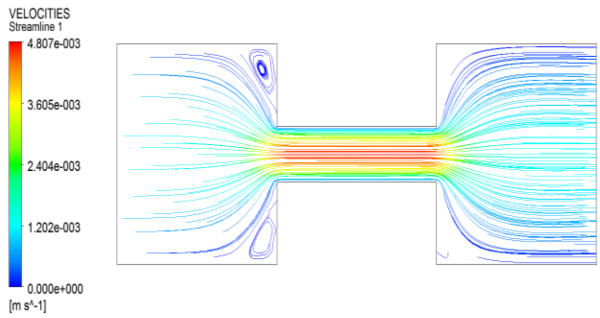


Fig.4-pressure change graph with the change of viscosity

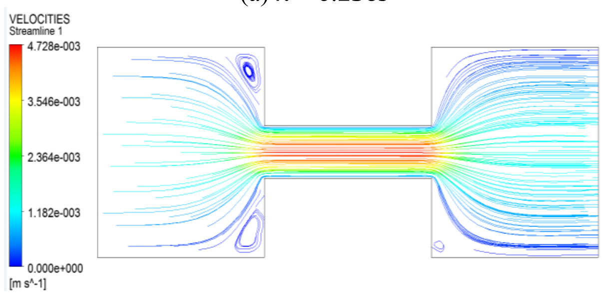
Fig 4 shows that the flowing pressure of the polymer solution in the microchannel changes with the change of viscosity. The polymer pressure increases as the viscosity increasing. Long-term heoretical study and experimental practice have proved that the pressure different between inlet and outlet not only increase when the fluid viscoelastic increase, but also the flowing resistance also increases. The force that generated by the contact portion between polymer and wall surface increase with the viscosity increasing and the flow resistance increasing. When there are residual oil in the wall surface, the pulling force of polymer to residual oil will increase in flowing process, then that lead to the residual oil of pores reduce. As viscosity of the polymer increasing, the effect that the polymer solution carry residual oil of pores gets better, and the displacement efficiency gets higher. The results accord with the research [13] that Xia Huifen studies the influence of viscoelastic polymer solution to oil displacement efficiency.

B. Effect of relaxation time

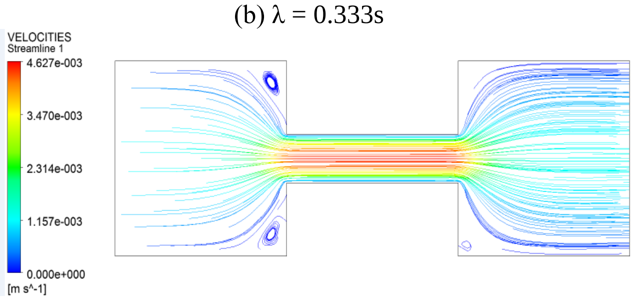
Fig 5 shows the streamline contour diagram of viscoelastic polymer at different relaxation time.



(a) λ = 0.236s



(b) λ = 0.333s



(c) λ =0.532s

Fig.5-polymer streamlines contour diagram at different relaxation time

Fig 5 shows that the whirlpool gradually decreases for the same viscosity polymer in the inlet contraction state as the relaxation time increasing, when the fluid flows from micro channels to the corner, and the flow line gradually close to the big gap of the channel. As the fluid elasticity increasing, the fluid agitation in the corner of flow path occurred more severely, and formed the vortex that can transfer energy to residual oil on the corner and make residual oil into movable oil, then it is flooded out. The spread area of polymer flooding will increase, and the area of residual oil in the concave corner becomes smaller and flowable area becomes larger. This experiment further indicates that the oil displacement efficiency of viscoelastic fluid will be increase with the increase of fluid elasticity and spread area. The experiment that Xue Xinsheng[14] studied the blind-side displacement experiment by using microscopic displacement device also appeared the vortex, which confirmed each other.

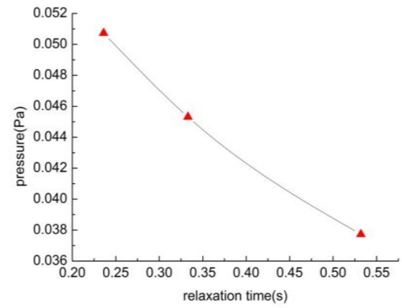


Fig.6-pressure difference varies with polymer relaxation time graph

Fig 6 shows that the pressure of the polymer solution between inlet and outlet in the pores reduces, as the relaxation time increasing. The needed pressure of large elastic fluid in the same speed and viscosity stage is smaller, which indicates that the injectivity of large elastic polymer is better. As the polymer elasticity increasing, viscoelastic polymer has still an remaining recoverable elastic modulus , which makes the volume expansion of fluid become large, improving the spread area of the fluid in the pores, then reach the effect improving the efficiency.

IV. CONCLUSIONS

A detailed CFD model for the flow of polymer solution was successfully implemented with finite volume method. This method that improve the accuracy and convergence, is very suitable to analysis the flow characteristics of large viscoelastic polymer solution. This model can accurately reflect the actual condition of reservoir condition. The method can also be extended to more the constitute equations, for example, Maxwell model and Oldroyd-B model or other Simplified model of porous media.

This model provides detailed information about the flow characteristics of viscoelastic polymer for different viscosity and different relaxation time. The analyzed results show that the higher viscosity polymer lead to higher drag force and the higher ability to carry the residual oil and higher oil displacement efficiency in the above model. And the spread area of polymer flooding is larger than that of water and it's displacement effect is better than that of water flooding, the results are consistent with experiments of Xia Huifen et al (2002)

The agitation in the" Blind Side" generates the vortex that can make residual oil into the movable oil to get rid of corner, as elastic polymer increasing. The area of residual oil is reduced. Flooding area of residual oil is larger. And the injectivity of polymer get better, then the spread area of polymer in the gap model increases .The efficiency of displacement gets higher improve the efficiency of polymer flooding. The results are consistent with experiments of Xue Xinsheng et al (2005).

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