

Experimental Contrast of the Effective Viscosity Determination Methods of Binary Flooding System

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Abstract—For the development of oil and gas field, the effective viscosity determination of the viscoelastic fluid is always the problem of chemical flooding and there are technical problems to verify difficultly. The common methods include bulk phase viscosity method, the rheological curve method, and the drag coefficient method. This article tested and compared the methods respectively by adopting the binary system of fixed concentration. The results showed that using the method is more scientific that calculate the effective viscosity according to the curve transformation. The viscosity curve was obtained from the along sample tests in the long cores. For the experimental core with the length of 300mm and permeability of $2500 \times 10^{-3} \mu\text{m}$, the average of the injection viscosity and the viscosity of produced liquid is closer to the effective viscosity of binary system in the core.

Keywords—Offshore oil field; binary system; viscoelastic fluid; the effective viscosity; average viscosity method

I. INTRODUCTION

The sustained growth of production in offshore oil field has become an important part for the replacement of the oil production. With the increase of difficulty of exploration and the efficient development of offshore oil and gas resources, it is imperative to develop techniques to greatly improve the oil recovery in offshore oil field [1-2]. With the successful implementation of chemical flooding of onshore oilfield, all kinds of chemical flooding technology have been mature, especially the large-scale industrial application of polymer flooding. Chemical flooding technology has been developed gradually to the offshore oilfield with complex reservoirs, tough conditions of injection agents, high risk [3-5]. Polymer flooding and binary flooding as the most potential chemical flooding technology is the first choice to the offshore oil field after the water flooding.

This article chooses the binary system to study which contains the AP-P5 polymer and the BH-M2 surface

active agent, which is based on the indoor experiment of the chemical flooding after polymer flooding of typical blocks in offshore oil field. The related production and research units had researched the related parameters of the binary system [6], which had been applied in other blocks of offshore oil field. The performance of the reagent is relatively good. In this article, polymer solution concentration in the binary system is 1750mg/l, and selected surface active agent concentration is 0.2%. All experimental binary system formula adopts the component concentration in this article.

II. THE EXPERIMENT PART

A. Experimental Apparatus and Experimental Conditions

1. Incubator: accuracy within 1°C ;
2. Constant speed constant-flux pump: Xingda constant-flux pump, constant speed displacement, can set different velocity;
3. Rotary vane vacuum pump: ZXZ-8 type, to swab air and filter;
4. Magnetic stirrer: used for dispensing solution;
5. Pressure sensor: with different range;
6. Brinell viscosity meter: used to determine the initial viscosity of polymer;
7. Electronic digital display scales: precision is 0.001g.
8. The experimental temperature: dispensing solutions is under the constant temperature of 45°C , and the rest experiments are conducted under the condition of 65°C .
9. Injection speed: at the seepage rate of 3m/d which reduced to the flow rate of the artificial homogeneous core with the width of 45 mm and the thickness of 45mm is 1ml/min.
10. The experiment conducted with the method of constant speed.

B. The Preparation Methods of the Binary Composite System

1. Mixture concentration of 5000mg/L polymer mother liquid under the condition of 45°C firstly. The agitator rotational speed is set to 260 r/min when add the dry powder. As the samples get sticky, mix 4h at the speed of 400r/min, seal the beaker with plastic film in the mixing process. Place the samples 6-8h under the condition of the reservoir temperature (65°C) after the mixing;

2. Dilute the surface active agent to 10% under the condition 45°C;

3. Mix the polymer mother liquid, the surface active agent with the concentration of 10% and water of experimental simulation in proportion and stir the mixture 30min under the condition of 45°C according to the concrete experimental plan.

4. Use *warning* blender to implement the pro-shear of purpose binary compound solution, the shear mode is level one (adjust the pointer to the line between 2 and 3), and the shear time is 20s.

C. The Core for the Experiment

The cores used in the experiments of the drag coefficient and the residual resistance coefficient are conventional standard cylindrical cores.

The cuboid artificial cores used in the verification tests, whose air permeability is $2500 \times 10^{-3} \mu\text{m}^2$ and the size is $900 \times 45 \times 45 \text{mm}$. There lay pressure taps on the cores as shown in Fig. 1.

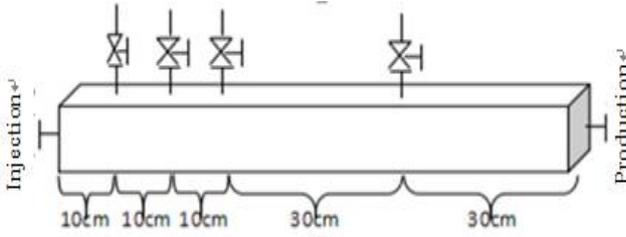


Figure 1. Effective viscosity test model for the core

III. DIFFERENT METHODS OF VISCOSITY DETERMINATION [7-8] AND THE EXPERIMENTAL RESULTS AND COMPARISON

A. The Rheological Curve Method

In the process of polymer flooding, polymer solution viscosity and shear rate relate closely. What used directly in physical simulation experiment of polymer flooding is the seepage velocity, thus the conversion of the seepage velocity and the corresponding shear rate was needed. For a system, in order to determine the real velocity called v , firstly give an advance velocity called v_1 . Put the values of the power-law index called n of this system, the water permeability measurement called K_w and the porosity called ϕ of the experimental core into the formulas of displacement velocity and shear rate for the power law fluid which flows in the porous media. Shear rate can be obtained as follow:

$$g = \left[\frac{3n+1}{4n} \right]^{\frac{n}{n+1}} \times \frac{12u}{(150K_w j)^{\frac{1}{2}}} \quad (1)$$

By the curvilinear regression of shear rate and viscosity of the solution, the formula of the change relation between viscosity and shear rate is the formula (2):

$$m = K \cdot g^a \quad (2)$$

The experimental measurement of oil in the offshore is shown in TABLE I :

TABLE I . THE MEASURED PARAMETERS OF POLYMER SOLUTION

Polymer solution concentration (mg/l)	Index, a	Coefficient, K
500	-0.3426	14.304
1000	-0.371	32.663
2000	-0.503	155.39

Fit the coefficient called K and the polymer solution concentration of the binary system (as shown in Fig. 2) by the formula (2), and obtain the formula as follow:

$$y = 6.558e^{0.0016x} \quad (3)$$

Type: x - polymer solution concentration.

Fit the index (a) and the polymer solution concentration of the binary system (as shown in Fig. 3), the formula can be obtained:

$$y = -5E - 08x^2 + 2E - 05x - 0.3393 \quad (4)$$

So the formula of the change relation between viscosity and shear rate are:

$$m = 6.558e^{0.0016x} \cdot g^{-5E-08x^2+2E-05x-0.3393} \quad (5)$$

When the concentration of the binary system is that the polymer is 1750mg/l, the surface active agent is 2000mg/l, calculate the viscosity is 15.8mPa·s.

Analysis of the Methods: the method can better reflect the shear effect of the core within porous medium to the displacing fluid, and it is the more commonly used viscosity processing method.

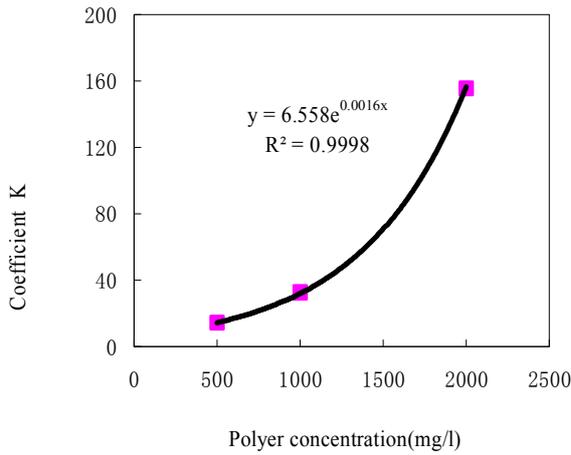


Figure 2. Relation of measured concentration and the coefficient of polymer solution

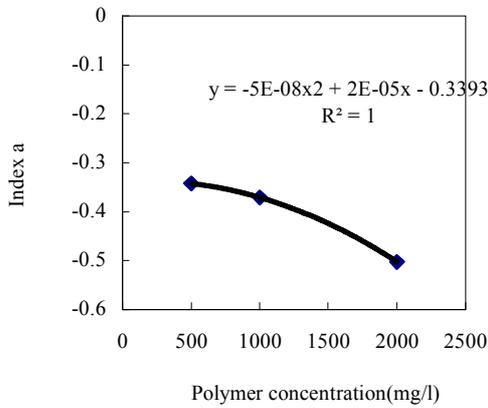


Figure 3. Relation of measured concentration and the index of polymer solution

However, this method only considered the shear effect on the viscosity, and ignored the adsorption of the displacement liquid in the core. The adsorption of the binary system must exist in the core, so this method is not applicable to process and analyze the data under the condition of oil in the offshore.

B. Bulk Phase Viscosity Method

The method is to calculate by putting the static viscosity value of the test before the injection of the binary composite system into the capillary number formula [9-10] directly. Analysis of the Method: the method is operated simply and calculated easily. There is no consideration of the viscosity loss in the core, so this method also is not applicable to process and analyze the data under the condition of oil in the offshore.

C. Drag Coefficient Method

The viscosity was tested by the conventional drag coefficient method which uses the following formula:

$$m_{ef} = m_w R_F / R_{RF} \quad (6)$$

In this paper, the selected binary system is used in the experiment of determination of the resistance coefficient and residual resistance coefficient, and the initial viscosity

of the binary solution is 34.6mPa·s. The permeability of the used core is the permeability of the reservoir of the typical offshore oil field. The permeability is $2500 \times 10^{-3} \mu\text{m}^2$. The drag coefficient of the binary solution is 40.45. The residual resistance coefficient is 10.3. The calculated effective viscosity of the binary solution is 3.89.

D. Experiment of Core flow Test the Viscosity of the Binary System

This article uses the method by laying the test point on the 90cm long core to test the change of distance and the binary system viscosity (as shown in Fig. 1). The data graph is shown in Fig. 4.

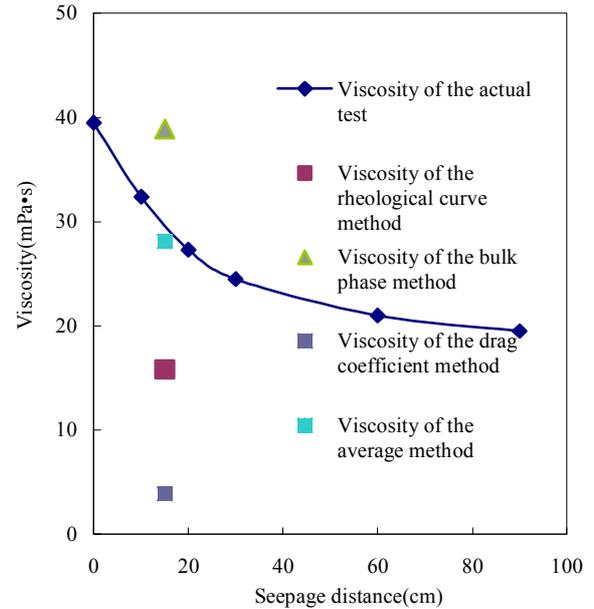


Figure 4. The change of viscosity along the flow direction

The viscosity curve fitting formula is: $y=0.0039X^2-0.554X+38.155$. Put $L=15\text{cm}$ in it, and get the viscosity of 30.72mPa·s. At 30.72mPa·s as the effective viscosity in the process of core displacement, compare the value of viscosity calculated with the above methods. It is found that the calculation result with the average viscosity method is the most closed to the value.

The comprehensive analysis result of the above test methods is shown in Table II .

TABLE II . COMPARISON OF THE ADVANTAGES AND DISADVANTAGES OF FITTING METHOD ON MEASURED DATA

Methods	Advantages	Disadvantages	Viscosity value (mPa·s)
The rheological curve method	The method can better reflect the shear effect of the core within porous medium to the displacing fluid, and it is the more commonly used viscosity processing method	It ignores the effects of the adsorption of the displacement fluid in the core and of Chromatographic separation on viscosity	15.8
Bulk phase viscosity method	The method is operated simply and calculated easily	Without considering the viscosity loss in the core	38.9
Drag coefficient method	Mature method, considering the shear and adsorption of the displacement liquid in the core	Pressure is not easy to stabilize, and the error is big	3.89
Average viscosity method	The average viscosity on behalf of the effective viscosity in the process of seepage, and it is closed to the work viscosity	It is only used to one by one measurement for the experiment and to popularization and can't be popularized and applied	28.1

What can be seen from TABLE II is that the viscosity data calculated by the average method is more closed to the effective viscosity in the actual displacement process. While this approach is accurate relatively, the workload of the experimental method is huge. In the actual applications, each of the experimental binary systems needs to be tested. Because the permeability of the actual core is different, the core shear situation will be different.

IV. CONCLUSIONS

1. The methods to determine the effective viscosity of the binary flooding system in the core contain the rheological curve method, phase viscosity method, drag coefficient method, etc. Through the comparison and verification, using the method is more scientific that calculate the effective viscosity according to the curve transformation, and the viscosity curve is obtained from the along sample tests of long cores.

2. The average of the injection viscosity and the viscosity of produced liquid is closer to the effective viscosity of binary system at the core for the experimental core with the length of 300mm and permeability of $2500 \times 10^{-3} \mu\text{m}$.

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