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Study on Flow Parameters Measurement Experiment of Polymer Solution in Porous Media

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Abstract

Due to the complexity of porous media and viscoelasticity of polymer solution, the flow behavior of polymer solution in porous media is more complex than that in the rheometer, and the flow regular pattern of polymer solution in porous media directly affects the formulation of polymer flooding projects. This paper designs experiment on flow parameters measurement of polymer solution (partially hydrolyzed polyacrylamide) in porous media, and the regular pattern of influence on resistance factor, residual resistance factor and flow viscosity in porous media caused by core permeability, polymer concentration, polymer molecular weight and polymer injection rate was given. The followings are the results: even for the same batch core with similar parameters, due to reasons such as natural fractures which could lead to comparatively large difference of core parameters between the same batch of core, thus in order to ensure the reliability of experiment data, it is necessary to detect core quality before core flooding experiment. Core end effect has significant effect on the results of core flooding experiment, it suggests that we should eliminate the effect of core end effect when carry out core flooding experiment, otherwise it is difficult to obtain valid experiment data. There exists a critical polymer concentration, when polymer concentration is lower than critical concentration, resistance factor is basically equal to apparent viscosity; when polymer concentration is higher than critical concentration, resistance factor is far less than apparent viscosity and the difference value increases with the increase of polymer concentration. Flow viscosity of polymer solution in porous media is far less than apparent viscosity in the rheometer and when polymer concentration increases, the increase extent of flow viscosity is far less than the increase of apparent viscosity. Results of this research are of great importance for enhancing flooding effect and guiding oilfield production.

Key words: Polymer solution; Porous media; Resistance factor; Apparent viscosity; Flow viscosity

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INTRODUCTION

In polymer flooding process, actual production pressure is far less than theoretical pressure which is calculated according to apparent viscosity. On the one hand, all the sections of polymer injection could lead the degradation of polymer molecular weight and then polymer viscosity is reduced[1-3]. On the other hand, the flow law of polymer solution in porous media differs from that in the rheometer[4-5]. The variation law of polymer viscosity(apparent viscosity, flow viscosity) in every section plays a crucial role for formulating polymer flooding projects, optimizing reformation measures and improving polymer flooding effect, especially in the deep reservoir. Therefore, studying flow parameters of polymer solution in porous media and their influential factors have important theoretical guiding significance and practical engineering value for enhancing displacement efficiency and guiding oilfield production.

Since the advent of polymer flooding, researchers extensively studied polymer flooding efficiency, polymer rheology and viscoelastic properties and so on. But there are three defects in the studies: Core quality wasn't detected before core flooding experiments and the experiment data is unreliable[6-8]; the influence of core end effect in core flooding experiment wasn't taken into consideration, and the experiments were carried out directly, specific measures to eliminate core end effect wasn't given[9-10]; the influence law of core permeability, polymer concentration, polymer molecular weight and polymer injection rate on various working parameters wasn't given systematically[11-12].

This paper designed core flooding experiment on flow parameters measurements of polymer solution in porous media, and on the basic of measuring the stability of polymer viscosity and eliminating core end effect, studied the variation law of apparent viscosity, resistance factor and flow viscosity in porous media under conditions of different core permeability and polymer molecular weight, provided effective basis for the determination of working parameters in polymer flooding.

1. EXPERIMENT

1.1 Experimental Condition

(a) Polymer. Partially hydrolyzed polyacrylamide with relative molecular weight of 9.5 million and 25 million, and solid content is 89.1% and 90.5%, respectively.

(b) Experimental Water. Artificial synthetic brine with salinity of 3,700 mg/L and 6,778 mg/L.

(c) Core. Artificial Berea core with different permeability (K_g) of 300 mD and 1,200 mD. Every core has a height, width, and length of 4.5×4.5×30 cm. In order to eliminate core end effect, drill two holes as pressure measuring points at a distance of 10cm from the two end of the core and install two three-way valves in the hole. Install a common valve in the injection side and outflow side respectively. Figure 1 shows the core with valves.

(d) Apparatus. Two Brookfield Viscometer (one with range of 0~100 mPa·s, the other 0~1,000 mPa·s), a 45℃ thermostat, a large simulation displacement equipment of sandstone reservoir, a vacuum pump and a hand pump.

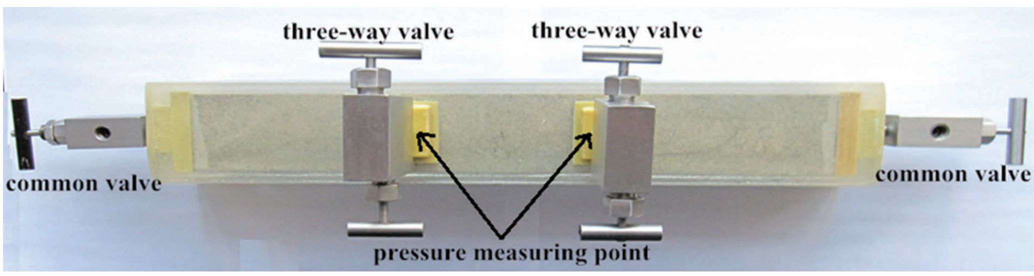

Figure 1
The Core With Valves

1.2 Experimental Method

(a) Analyze the stability of polymer viscosity. Measure and observe viscosity of polymer solution, and adjust volume of formaldehyde and potassium iodide when viscosity fluctuates.

(b) Detect core quality. Inject artificial synthetic brine into Berea core, which have been saturated by artificial synthetic brine, at the injection rate of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 mL/min respectively. After the pressure is stable, record the pressure difference between two pressure measuring points, and verify whether it is accord with Darcy equation, detect core quality and calculate core water phase permeability.

(c) Detect core end effect. In the process of core flooding experiment, measure the pressure difference at different positions of core; analyze the influence of core end effect on flow resistance. Select position where core end effect is weaker and measure flow parameters.

(d) Measure flow parameters in core flooding experiment. Inject polymer solution into Berea core at the injection rate of 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 mL/min respectively. After the injection processes is stable, record the pressure difference between two pressure measuring points, and take samples from two pressure points and outflow side, measure apparent viscosity of samples. Then inject artificial synthetic brine, record the pressure difference between two pressure points after it is stable and calculate residual resistance factor.

2. RESULTS ANALYSIS

2.1 Analysis of the Stability of Polymer Viscosity

The variation of viscosity retention rate is shown in Table 1 at different polymer concentration, different polymer molecular weight, and different salinity of brine. Table 1 shows that add the formaldehyde (100 mg/L) and potassium iodide (500 mg/L) into polymer solution, viscosity stability and repeatability of polymer solution can keep well in ten days, viscosity retention rate is high.

Table 1
Variation of Viscosity Retention Rate

Polymer concentration (mg/L)	Polymer molecular weight (×10^6)	Salinity of brine (mg/L)	Viscosity retention rate at different time (%)			
			0 day	3 days	6 days	9 days
200	9.5	3,700	100.0	128.6	142.9	114.3
		6,778	100.0	100.0	100.0	90.0
	25	3,700	100.0	75.0	100.0	87.5
		6,778	100.0	120.0	120.0	120.0
1,000	9.5	3,700	100.0	110.9	110.9	109.1
		6,778	100.0	117.8	113.3	117.8
	25	3,700	100.0	76.7	75.6	78.9
		6,778	100.0	107.7	105.8	105.8
1,800	9.5	3,700	100.0	99.5	101.1	101.6
		6,778	100.0	104.7	110.2	109.5
	25	3,700	100.0	98.5	100.5	102.5
		6,778	100.0	112.9	106.8	110.2

2.2 Quality Detection of Core

In order to ensure the reliability of experiment data, detect core quality before experiment and select good quality core for experiment. The relationship between the pressure difference of two pressure points and injection rate is shown From Figure 2 to Figure 3. As shown form Figure 2 and Figure 3, for NO. 1, 2, 3, 4 core with permeability of 300 mD and 1,200 mD, the relationship between the pressure difference and injection rate is basically linear, and accord with Darcy equation. The quality of this kind of cores is good and these cores can be used in experiment. For other cores, maybe due to the existence of natural fracture, partly heterogeneous, or vibration in workpiece process and so on, the relationship between the pressure difference and injection rate isn't accord with Darcy equation, and these cores can't be used in experiment. Therefore, in order to ensure the reliability of experiment data, it is necessary to detect core quality before core flooding experiment.

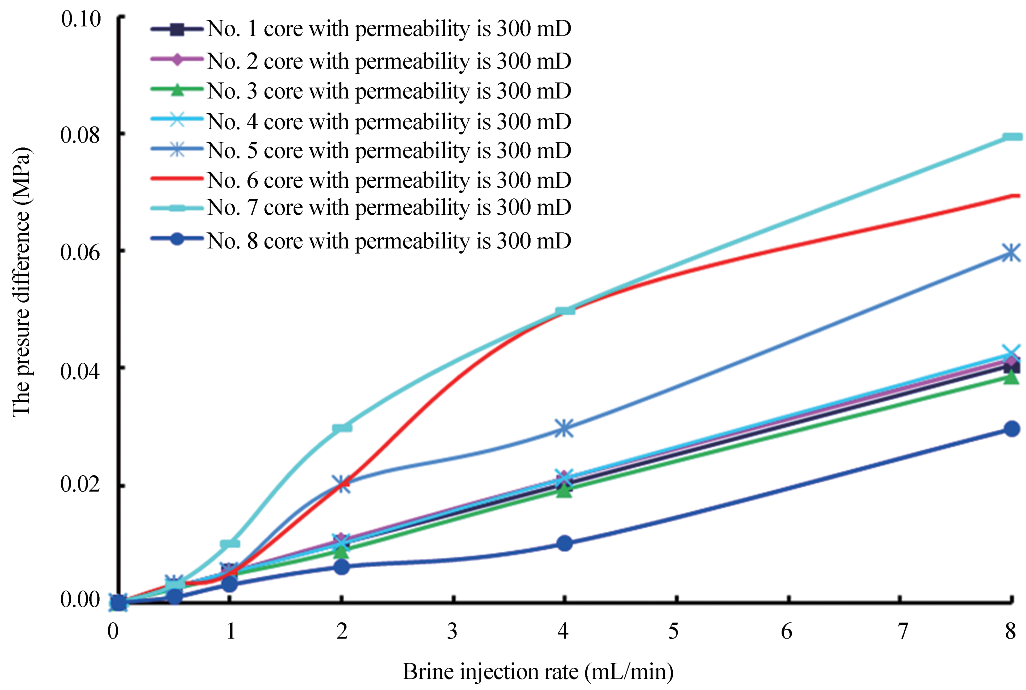

Figure 2
Quality Detection Curve of Eight Cores With Permeability of 300 mD

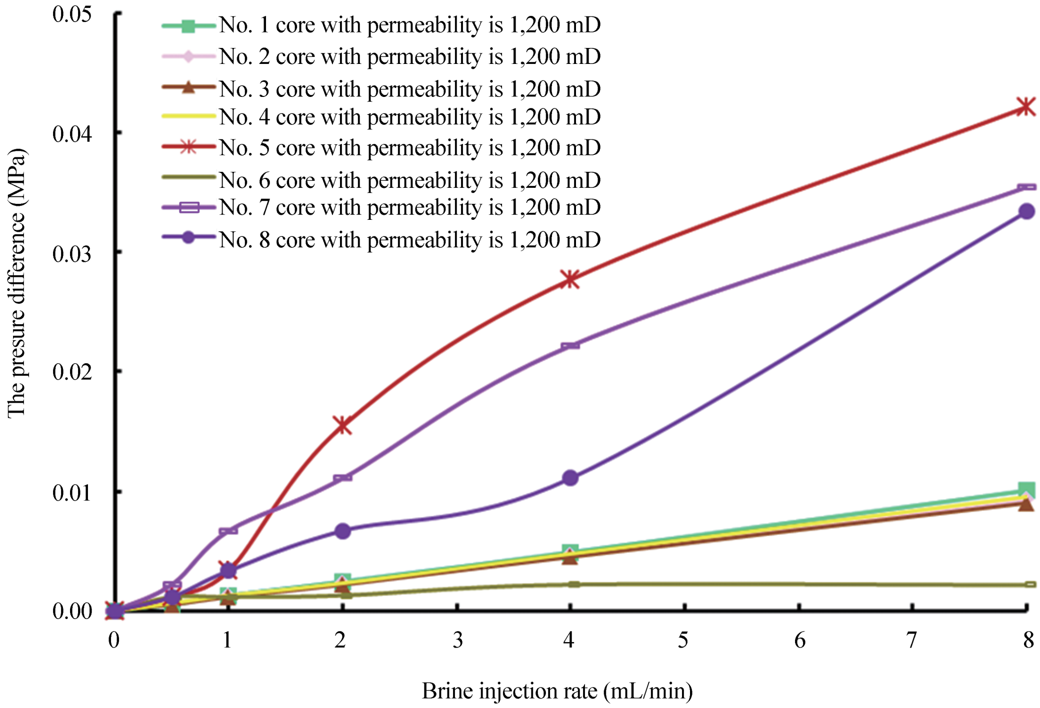

Figure 3
Quality Detection Curve of Eight Cores With Permeability of 1,200 mD

2.3 Analysis of Core End Effect

In the process of teeming Berea core, on one hand, there may form stoppage at the end of the core, on the other hand, injection fluid may concentrate at the end of the core. Both factors will lead to the increase of flow resistance and it is difficult to measure accurately. This experiment overcomes this problem, analyzes the influence core end effect on experiment results.

The relationship between polymer solution injection rate and the pressure difference is shown from Figure 4 to Figure 5 at different positions (the former 10 cm of core, the middle 10 cm of core, and the later 10 cm of core), different polymer concentration (200 mg/L, 1,200 mg/L). As shown from Figure 4 and Figure 5, due to end plug, the pressure difference of the former 10 cm and the later 10 cm is greater than the pressure difference of the middle of 10 cm, and the pressure of the former 10 cm is always greater than the pressure difference of the later 10 cm. End effect in the injection side is more apparent than that in the outflow side. And in injection process, as a result of polymer molecular chains may be pulled where the end plug happens, thus the pressure difference of the former 10 cm and the later 10 cm always fluctuates and the relationship between injection rate and the pressure difference is not linear. In the middle 10 cm of core, the relationship between injection rate and the pressure difference is basically linear, and eliminate the end effect. Therefore, we must eliminate core end effect as far as possible; otherwise it is difficult to obtain valid experimental results.

2.4 Analysis of Flow Parameters

The relationship between concentration and flow parameters of polymer solution is shown from Figure 6 to Figure 7 at different polymer molecular weight (9.5 million, 25 million), different core permeability (300 mD, 1,200 mD).

As shown from Figure 6 to Figure 7, exist a critical polymer concentration, when polymer concentration is lower than critical concentration, resistance factor is basically equal to apparent viscosity; when polymer concentration is higher than critical concentration, resistance factor is far less than apparent viscosity. Therefore, reservoir pressure drop calculated by resistance factor is far less than that calculated by apparent viscosity, and the difference value is increased when polymer concentration is increased (under the study conditions，critical concentration is 500-1,000 mg/L). Besides, flow viscosity of polymer solution in core is far less than apparent viscosity in the rheometer and when polymer concentration increases, the increase extent of flow viscosity is far less than the increase of apparent viscosity. Under the condition of injection rate is 0.5 mL/min, inject polymer solution with 950×10^4 molecular weight into Berea core with 1,200 mD permeability for core flooding experiment. When polymer concentration increase from 200 mg/L to 1,200 mg/L, flow viscosity increase from about 0.95 mPa·s to about 3.16 mPa·s and apparent viscosity increase form about 1.6 mPa·s to about 49.0 mPa·s.

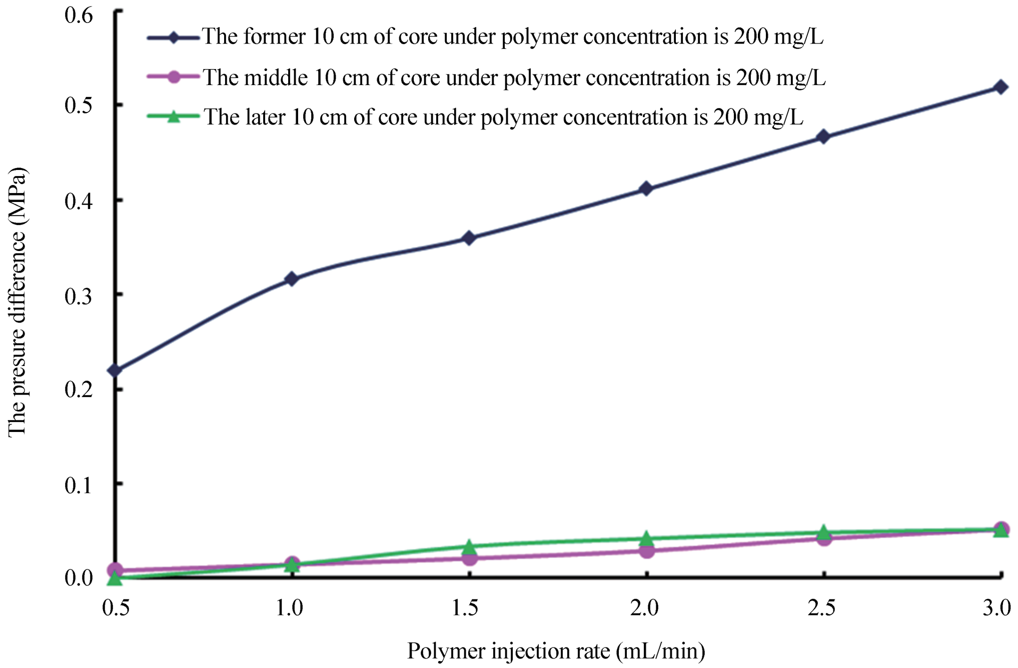

Figure 4
The Pressure Difference at Different Positions Under the Polymer Concentration is 200 mg/L

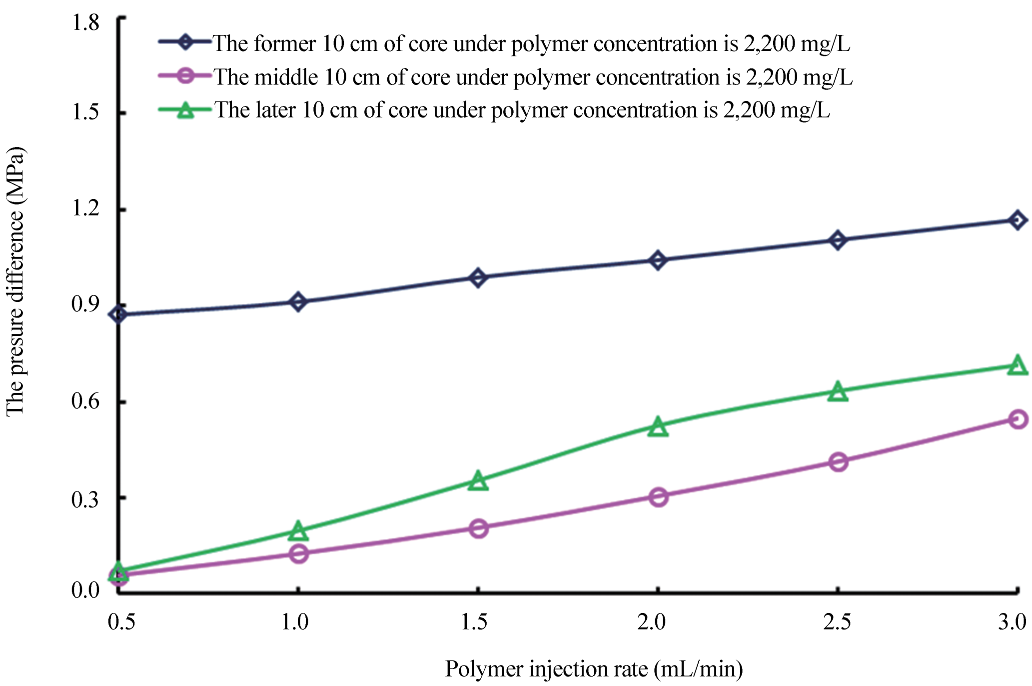

Figure 5
The Pressure Difference at Different Positions Under the Polymer Concentration is 2,200 mg/L

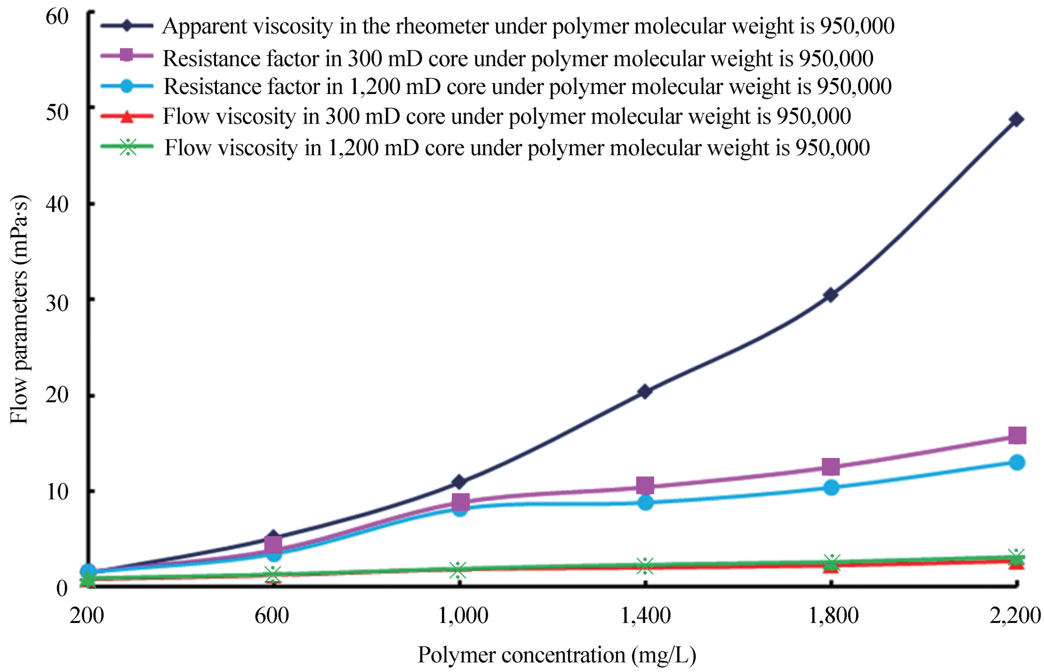

Figure 6
Comparison of Flow Parameters Under Polymer Molecular is 0.95 Million

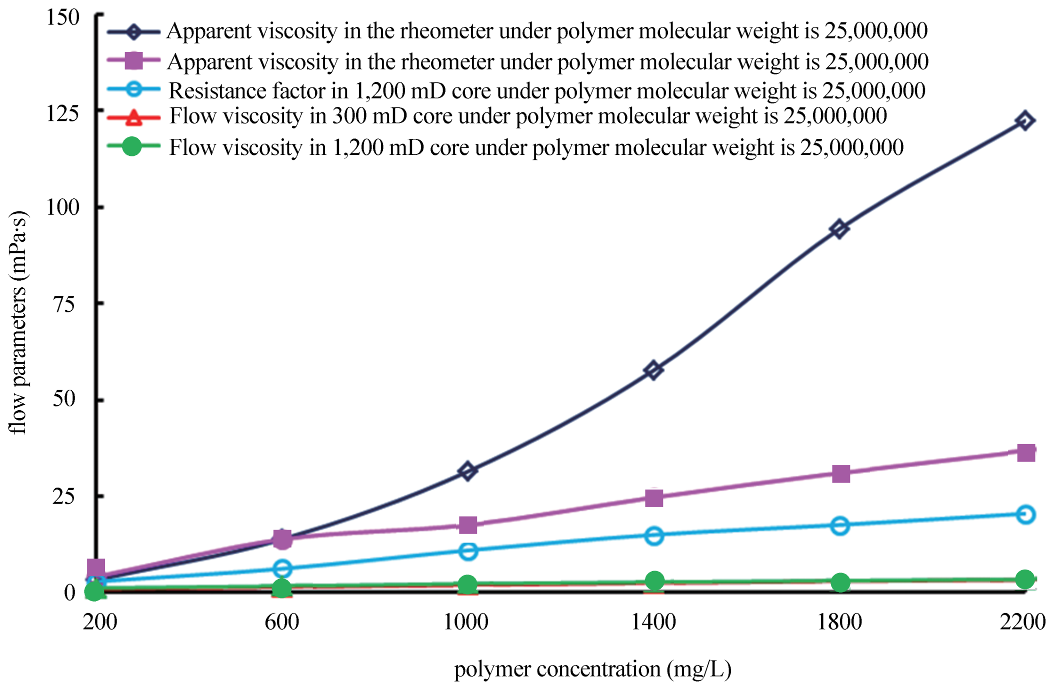

Figure 7
Comparison of Flow Parameters Under Polymer Molecular is 25 Million

CONCLUSION

(a) The core detection results show that: even for the same batch core with similar parameters, due to reasons such as natural fractures which could lead to comparatively large difference of core parameters between the same batch of core, thus in order to ensure the reliability of experiment data, it is necessary to detect core quality before core flooding experiment.

(b) Core end effect has significant effect on the results of core flooding experiment, we must eliminate the effect core end effect when carry out core flooding experiment; Otherwise it is difficult to obtain valid experimental results.

(c) There exists a critical polymer concentration, when polymer concentration is lower than critical concentration, resistance factor is basically equal to apparent viscosity. When polymer concentration is higher than critical concentration, resistance factor is far less than apparent viscosity. Therefore, the reservoir pressure drop calculated by resistance factor is far less than that calculated by apparent viscosity, and the difference value is increased when polymer concentration is increased (under the study conditions, critical concentration is 500-1,000 mg/L).

(d) Flow viscosity of polymer solution in core is far less than apparent viscosity in the rheometer and when polymer concentration increases, the increase extent of flow viscosity is far less than the increase of apparent viscosity. Under the condition of injection rate is 0.5 mL/min, inject polymer solution with molecular weight of 9.5 million into Berea core with 1,200 mD permeability for core flooding experiment. When polymer concentration increase from 200 mg/L to 1,200 mg/L, flow viscosity increase from about 0.95 mPa·s to about 3.16 mPa·s and apparent viscosity increase form about 1.6 mPa·s to about 49.0 mPa·s.

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