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Research Article

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Screening Study on Rheological Behavior and Phase Transition Point of Polymer-containing Fluids produced under the Oil Freezing Point Temperature

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Abstract: For an increasing implementation of the low-temperature transportation in oilfield, it is urgent priority initially to study the physical and chemical properties to provide the vital technical support for the low-temperature transport of the polymer flooding. In this paper, the rheological behavior of polymer-containing fluid produced from the Daqing polymer flood were first studied for an adaptation of transportation under the oil's freezing point temperature. The experiments progressed with different temperature, shear rate, water content and polymer concentration which have great impacts on the viscosity of the fluids produced aiming to find the phase transportation point for the application of the low-temperature transportation. It was displayed that a significant discontinuity in the viscosity occurs at some range of water content. Before the phase transition point, presented in W/O (water-in-oil) emulsion, the viscosity was lifted with the increase of the water content while after the phase transition point, forming the O/W (oil-in-water) type emulsion, the viscosity was dropped with an increase of water content. The phase transition points strongly depend on the polymer concentration in the fluids Produced. It was demonstrated that the phase transition points of polymer-containing fluids were 65%, 70%, 50%, 50% and 50%, corresponding to the polymer concentrations of 315mg/L, 503mg/L, 708mg/L, 920mg/L and 1053mg/L, respectively. The characteristics are attributed to the viscous polymer. The fluidity of the fluid produced was decreased with the increase of polymer concentration.

Keywords: Oilfield; Polymer flooding; Polymer; Emulsion; Rheological Behavior; Phase transition point.

1 Introduction

Over the years, polymer flooding in Daqing oilfield of China has been widely used and has achieved relatively mature technical results [1, 2]. At present, oil field is implementing a low-temperature transportation technology of fluids produced, which is considered as a novel concept in oil gathering and transportation of the fluids produced, mainly for the purpose of water flooding under the oil freezing point temperature [3]. This concept has considerably saved energy and facilities with a good operation. This technique will be extended to the oilfield with a relatively larger area of promotion. The main goal of the next step is to study the low-temperature transport technology for the polymer flooding. Polymer flooding is complicated field in oil technology as vast amounts of polyacrylamide are produced, which has higher viscosity and composition of the produced liquid. Furthermore, the hydrolyzed polyacrylamide serves as a surface activity for the severe emulsion, the physical and chemical properties are largely differentiated from the one of the water flooding [4-6]. Hence, it is of practical significance to study the properties of polymer flooding liquids produced.

The rheology and phase transition point are critical parameters for oilfield fluid produced transport. In order to get a better understanding of rheological behaviors of crude oil emulsion, their study is vital due to the complex behavior of crude oil [7]. For efficient handling and delivery of the produced liquid, rheological behaviors of emulsion have been investigated [8, 9]. Rheological properties of the emulsion in the fluid produced can

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be determined by measuring the relationship between stress, strain, temperature and time. Moreover, the rheological characteristics can be described by several behaviors such as dilatant, Newtonian, pseudo plastic, and Bingham. Generally, fluids produced with water-in-crude oil emulsion exhibit non-Newtonian behavior, the viscosity could be changed under different condition [10]. The viscosity of emulsion depends on various factors such as shear rate, temperature, water volume fraction, the amount of solid, etc. The measurement of the viscosity of emulsion is an important assessment of production strategies [11]. Therefore, for polymer flooding fluids produced, the phase transition point could find out the relationship between viscosity and condition variable which could be determined by the rheological behaviors.

There are many studies on the rheological behaviors of fluids produced [12-16]. The major investigations were focused on the water flooding, which has been apparently improved [17-19]. Also, there are few researches which study the rheological properties of produced water from the polymer flooding, being mainly concentrated on the research of high-temperature transportation area (above the freezing point of crude oil). Wu and coworkers [20-22] studied the rheological behaviors and separation of the fluids produced from a polymer flooding reservoir at Daqing oilfield. They [21] probed the rheology and stability of EOR (Enhanced Oil Recovery) produced liquid in Daqing Oilfield. These studies were performed mainly for the high-temperature transport or treatment of the polymer flooding.

This paper took a research with the rheological behavior and phase transition point of the fluids produced containing polymer from the Daqing polymer flood firstly for an adaptation of transportation under the oil freezing point temperature. The rheological study includes, besides the analysis of the compositions, the dependence of viscosity on shear rate, temperature and volume water ratio. The rheological study is an important factor for the research of the polymer concentration. In view of the applications in low-temperature transportation and based on the obtained data, the phase transition points were identified.

2 Experimental Section

2.1 Chemicals and Materials

Polyacrylamide (30% hydrolysis, MW 25,000 g/mol, industrial grade) was received from Daqing Refining and Chemical. Fluids produced, water and oil were provided by the Daqing oilfield. The other chemicals such as the acid and alkaline, sodium and potassium salts, and calcium and magnesium salts, were used in the commercial analytical grade as received for the preparation of the simulated produced water.

2.2 Analysis of the compositions of the fluids produced

The fluids produced were sampled from the targeted polymer flooding in Daqing oilfield. The analysis was conducted by the conventional standards of the PetroChina.

2.3 Preparation of the tested samples of the fluids produced

Based on the data of the compositions, the samples were prepared by using the separated oil and produced water containing the varied concentrations of polyacrylamide by the different oil/water ratio. In brief, the mixture was stirred by a homogenizer for 1-2 min to get a stable crude-oil emulsion.

2.4 Measurements of rheological properties

Rheological measurements were carried out using HAAKE RS 1 rheometer (Germany).

Ethical approval: The conducted research is not related to either human or animal use.

3 Results and Discussion

3.1 Analysis of the compositions of the fluids produced

The composition of the fluids produced is shown in table 1. The composition of the fluids produced was determined on the basis on the standard of China petroleum industry. The samples of fluids produced were collected from the oil wells with polymer flooding (high PAM content) and the oil wells without polymer flooding (low PAM content).

Table 1: The data of the compositions of the fluids produced.

Compositions	Water(%)	Oil(%)	PAM(ppm)	Salinity(ppm)	Ca + Mg(ppm)
Contents or Concentration (%, ppm)	41.2 ~ 99.4	68.8-0.6	243-1120	6500	68

3.2 Rheological Behaviors of the fluids produced

Based on the data of the fluids produced, the experiments were designed as follows.

3.2.1 (1) the range of the water contents.

At present, the water content is in the range of 41.2% and 99.4%, and the average is 81.3%. The crude oil in the transition point contains 65% of water. Considering the comprehensiveness of the data, the water contents were set in the range of 40% ~ 80% % during the experiments, the water content are 40%, 50%, 55%, 60%, 65%, 70%, 75% and 80%.

3.2.2 (2) the range of the PAM concentrations

For a target, the PAM concentration is ranged in 243-1120mg/L. Considering the comprehensiveness of the data, the PAM concentrations were set in the range of 300 ~ 1100mg/L during the experiments, the PAM concentrations are 300mg/L, 500mg/L, 700mg/L, 900mg/L and 1100mg/L.

3.2.3 (3) the range of the temperatures

Currently, the production is operated for the transportation in the temperature of 10 ~ 35°C. Accordingly, the temperature was set to 20°C, 25°C, 30°C and 35°C in the tests.

It is necessary to consider the influence of shear rate on the fluids produced. The shear rate is usually measured from 0 and 100s^{-1}.

The rheological properties of the emulsion samples containing the crude oil, water and polymer were determined by the automatic rheometer under different temperatures and shear rates. Based on the measured data, the numerical simulation was conducted for the curves of the rheological properties, then, the phase transition points were determined.

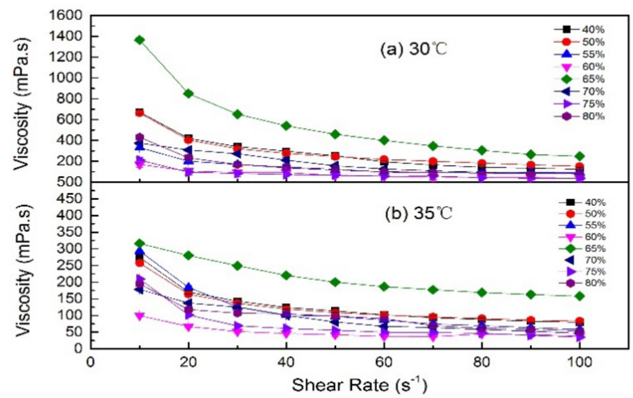

Figure 1: The influence of polymer concentration (315mg/L) on rheological behaviors at the temperatures (a) 30°C and (b) 35°C.

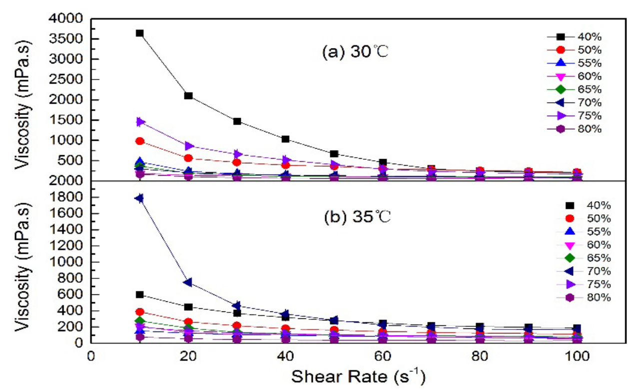

Figure 2: The influence of polymer concentration (503mg/L) on rheological behaviors at the temperatures (a) 30°C and (b) 35°C.

In the early stage of oilfield development, the fluids produced was a mostly water-in-oil emulsion, which caused difficulties of the oil and water separation and many problems for the gathering and transportation. Compared with water flooding, the rheological properties of polymer flooding fluids can significantly improve their non-Newtonian properties and apparent viscosity. Crude oil from the tertiary oil recovery, through the polymer flooding and ASP (alkaline/surfactant/polymer) flooding, is mostly oil-in-water emulsions, which has been transited from the water-in-oil to oil-in-water emulsions due to the difference in water contents. It has been demonstrated that the phase transition is dominated by the polymer originated from the EOR technologies.

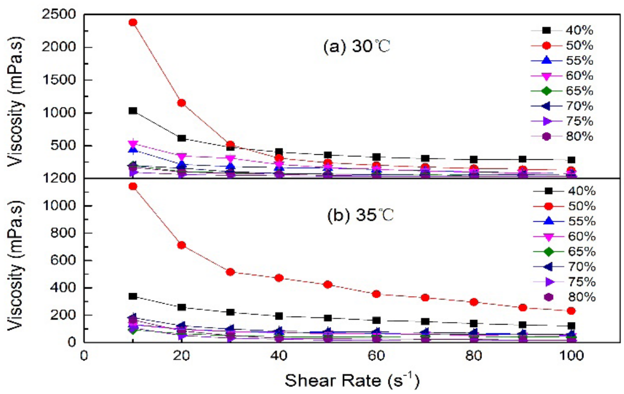

Figure 3: The influence of polymer concentration (708mg/L) on rheological behaviors at the temperatures (a) 30°C and (b) 35°C.

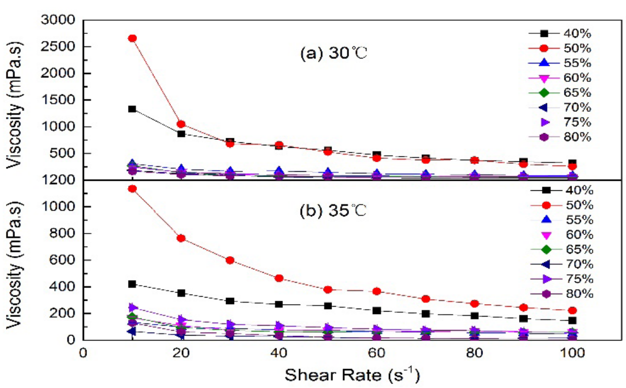

Figure 4: The influence of polymer concentration (920mg/L) on rheological behaviors at the temperatures (a) 30°C and (b) 35°C.

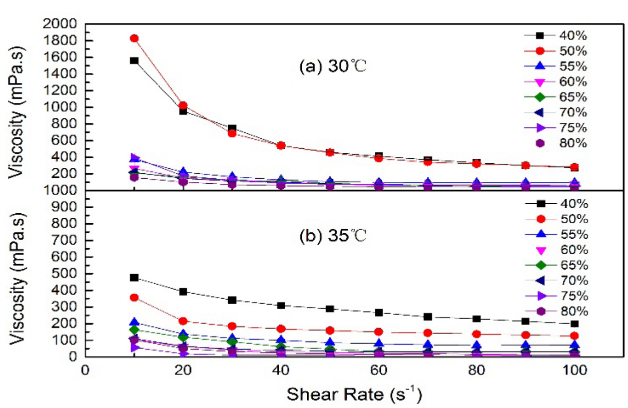

Figure 5: The influence of polymer concentration (1053mg/L) on rheological behaviors at the temperatures (a) 30°C and (b) 35°C.

3.2.4 Influence of polymer concentrations on rheological behaviors under different temperatures.

The variations of polymer concentration on rheological behaviors under different temperatures are shown in Figure 1 to 5.

It can be seen from the rheological curve group that the rheological behavior of the produced liquid containing polymer in the presence of high concentration polymer is non-Newtonian flow behavior. Temperature, shear rate and water content had great impacts on the viscosity of the fluids produced. The viscosity was decreased with the increase of shear rate at the identical concentration, temperature and water content. Under the same condition, the apparent viscosity of the sample increased with the rising of the polymer concentration. The viscosity increased significantly with moisture content at the same shear rate.

At the same time, a “critical water content” can be found in the rheological properties of the samples. Even though the “critical water content” values were different, the same change was presented below and above this value: below the critical point, the apparent viscosity was lifted with the increase of the water content, while the apparent viscosity was decreased with the increase of the water content above the critical point. It is believed that the “critical water content” should belong to the phase properties of the corresponding fluids produced (see the results of the “phase transition point”). Before the phase transition point, the fluids were presented with W/O (water-in-oil) type emulsion. Beyond the phase transition point, the fluids formed the O/W (oil-in-water) type emulsion. The viscosity was dropped with increasing water content, but when the system had a high-water content, this change tended to be constant. In addition, the viscosity was increased with the raising of the water content and was affected by the temperature. While the shear rate also had a more obvious effect, the viscosity of the transition point decreased significantly with the increasing shear rate. High shear rates make it difficult for wax crystals to aggregate and grow. Small droplets outside the oil film were destroyed, causing the viscosity to drop.

It could be concluded from the experiments that the viscosity of the polymer fluids produced increases with the rising shear rate and polymer concentration while decreases with the rising temperature.

3.2.5 Determinations of phase transition point under different polymer concentrations

It was found that when the temperature was 20 °C and 25 °C, most of the samples were nearly glued as a gelling state, which result in the lifted apparent viscosity with the temperature. For the actual gathering and transportation conditions, the system will be severely solidified.

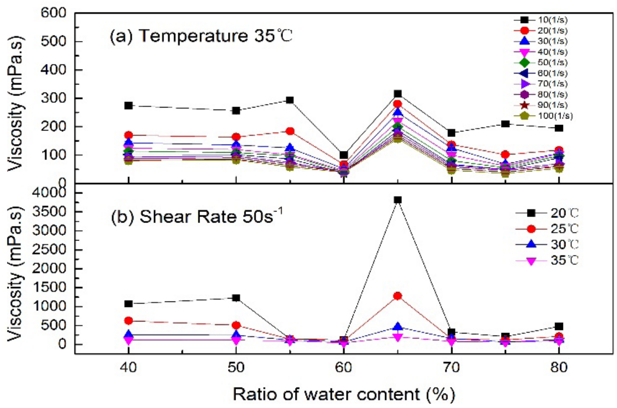

Figure 6: Dependencies of viscosity on the water content in the system of polymer concentration (315mg/L) and (a) temperature (35°C) (b) shear rate (50s-1).

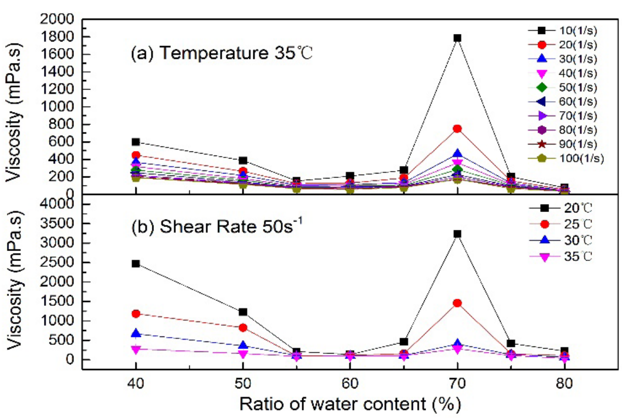

Figure 7: Dependencies of viscosity on the water content in the system of polymer concentration (503mg/L) and (a) temperature (35°C) (b) shear rate (50s-1).

Therefore, in order to analyze the transition phase of the polymer fluids with a suitable flow state, the tests were performed at 30 ° C and 35 ° C.

The phase transition points under different polymer concentrations are shown in Figure 6-10.

As can be seen from figure 6, for the fluids produced with polymer concentration of 315 mg/L, when the water content increases to 65%, the curve shows a sharp rise and fall point. At this point, as the water content continues to increase, the viscosity drops. It can be determined that under these conditions, the phase transition point is 65%.

Similarly, the curve has a sharp rise and fall point from Figure 7. Thus, it can be concluded that the phase transition point was determined for 70% of water at a concentration of 503 mg/L polymer.

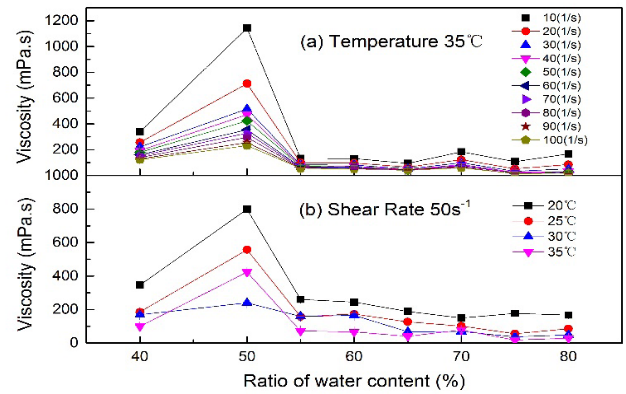

Figure 8: Dependencies of viscosity on the water content in the system of polymer concentration (708mg/L) and (a) temperature (35°C) (b) shear rate (50s-1).

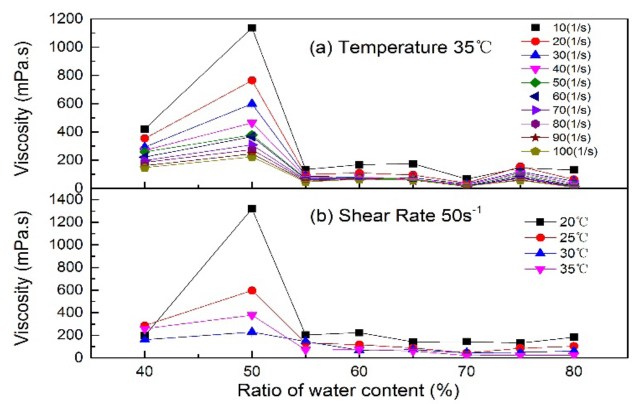

Figure 9: Dependencies of viscosity on the water content in the system of polymer concentration (920mg/L) and (a) temperature (35°C) (b) shear rate (50s-1).

As can be seen from figure 8, the curve has a sharp rise and fall point. Therefore, the phase transition is at the point of 50% water content with the polymer concentration of 708 mg/L.

Accordingly, a sharply increasing and dropping point appeared in the water content of 50%. The phase transition point was resolved in 50% at a concentration of 920 mg/L polymer from Figure 9.

In the same case, a sharply increasing and dropping point occurred when the moisture content is reduced to 40% of water. As can be seen from figure 10, when the polymer concentration is 1035mg/L, the phase transition point is 40%.

In the same case, a sharply increasing and dropping point occurred when the moisture content is reduced to 40% of water. As can be seen from figure 10, when the

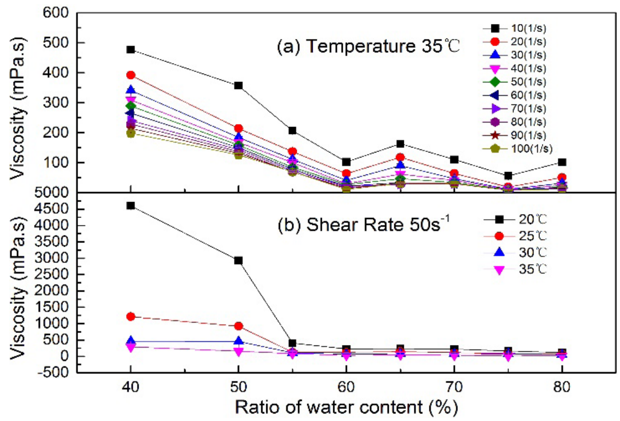

Figure 10: Dependencies of viscosity on the water content in the system of polymer. concentration (1053 mg/L) and (a) temperature (35°C) (b) shear rate (50s-1).

Table 2: Summary of the phase transition points fluids produced containing different polymer concentrations.

Polymer Concentration, mg/L	Phase transition points, Water % V/V
315	67
503	65
708	50
920	50
1053	<40

polymer concentration is 1035mg/L, the phase transition point is 40%.

The data of the phase transition points are summarized in Table 2.

As it is demonstrated that the phase transition points of polymer-containing fluids were represented by a water content of 65%, 70%, 50%, 50% and 50%, corresponding to the polymer concentrations of 315mg/L, 503mg/L, 708mg/L, 920mg/L and 1053mg/L, respectively. The transition points are not significantly affected by the shear rate and temperature.

The changing transition points wtih the content of polymer is attributed to the viscosity of polymer. The fluidity of the fluids produced was decreased when it was glued as a gelling state by the increasing concentration of the polymer. As a result, the phase transition points were ahead of the normal positions to some extent due to the significant emulsifying and thickening effect.

4 Conclusions

In this paper, the rheological behaviors of the polymer-containing fluids produced from the Daqing polymer flood was studied for an adaptation of transportation under the oil freezing point temperature. Temperature, shear rate and water content had great impacts on the viscosity of the fluids produced. The viscosity of the fluid was decreased with the increase of the shear rate and temperature, and with the decline of the polymer concentration. It was noted that a significant discontinuity in the viscosity occurs at some range of water content. It is demonstrated that the phase transition points of polymer-containing fluids were 65%, 70%, 50%, 50% and 50%, corresponding to the polymer concentrations of 315mg/L, 503mg/L, 708mg/L, 920mg/L and 1053mg/L, respectively. The study can offer the vital technical support for the low-temperature transport of the fluids produced from the polymer flooding.

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Conflict of interest: Authors declare no conflict of interest.

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