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Application of Biopolymer Schizophyllan Derived from Local Sources in Malaysia for Polymer Flooding Operation

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Abstract. After the application of primary and secondary recovery methods, a significant amount of oil gets left behind in the reservoir. Thus, Enhanced Oil Recovery (EOR) methods are the only viable options. Polymer flooding has been widely used for many years. The ability of a polymer to sustain high temperature and salinity reservoir conditions, while taking into account the cost of the polymer, is a challenging aspect of its application in polymer flooding. Due to the forthcoming environmental regulation, the eco-friendly biopolymers have been gaining importance. This study aims to investigate the biopolymer schizophyllan produced utilizing locally and cheaply available sources in Malaysia for its rheological property at various range of biopolymer concentration. Also, the effect of aging at high temperature on the biopolymer viscosity was studied. A core flooding experiment was also performed utilizing a Berea sandstone core at an 80 °C reservoir temperature and a salinity of 90,000 ppm. The rheological studies showed a shear thinning behavior at all biopolymer concentrations. The effect of aging up to a period of 6 months exhibited insignificant decrease in biopolymer viscosity. Core flooding experiments using the biopolymer derived from local sources showed an incremental oil recovery of 17.25% after waterflooding.

INTRODUCTION

A chemical Enhanced Oil Recovery (EOR) process which utilizes polymers is termed as polymer flooding. During polymer flooding, high molecular weight polymers are added to water which are effective in increasing the viscosity therby reducing water-oil mobility ratio. Although, there are certain limitations related to polymer degradation, economic cost and in some cases loss of injectivity, it has been successfully implemented in oilfields both on a pilot as well as commercial scale [1-5]. Due to concerns about the use of synthetic polymers and their impact on the environment, researchers have been looking for polymers that are environmentally friendly, cost effective, and can withstand harsh reservoir conditions. The main advantage of using environmentally friendly or biopolymers is that they can be produced using cheap and readily available natural resources. Schizophyllan is one such biopolymer that has been found to have more advantages over others. It is produced by the fungus schizophyllum commune, which utilizes glucose as a carbon source along with a variety of other sources, contributing to its higher cost. Since the cost of the polymers plays an important role in polymer flooding applications, studies have been conducted to replace the high cost carbon and nitrogen sources in schizophyllan production with cheaply available local sources. Various carbon sources such as corn fiber, sucrose, coconut water, rice hull, DDGS, date syrup and nitrogen sources such as corn steep liquor, beef extract, and so on, have been used in schizophyllan production in the past [6-13]. But the previous studies for schizophyllan production using cheaply available carbon and nitrogen sources showed no characterization studies which were carried out in terms of cost effectiveness, stability under various temperature and salinity range, thermal stability and oil recovery. [14] in their studies reported for the first time, production of

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schizophyllan using cheaply available sago starch as a carbon source and potato extract as a nitrogen source respectively. The Fourier Transform Infrared (FTIR) spectroscopy exhibited structural similarity in comparison to that of the commercial one and hence was confirmed to be schizophyllan. The Thermo Gravimetric (TG) analysis showed thermal stability up to a temperature of 125 °C. The recovered schizophyllan also exhibited a high molecular weight of 14.73 million Dalton.

This paper reports the rheological property for the locally produced schizophyllan to determine the effect of biopolymer concentration on the viscosity of the solution. The article also includes the study of effect of aging on the viscosity of the solution. Finally, application of locally produced biopolymer in EOR.

METHODOLOGY

Materials

The biopolymer schizophyllan produced using local sources was produced as per the procedure mentioned by [14] and was provided in the powder form. The other chemicals utilized in the study were: Sodium chloride (NaCl), Calcium chloride ($CaCl_2$) and Magnesium chloride ($MgCl_2$).

The field test for commercial schizophyllan was performed on oil fields in northern and western Germany, where the reservoir brine composition was as follows (g/L): NaCl: 132.0; $CaCl_2$: 42.6; $MgCl_2$: 10.5 [15]. This ratio of salt composition is considered as a reference ratio in preparing the synthetic brine.

Characterization Studies

Rheological Study

The rheological study to understand the effect of concentration on schizophyllan solution viscosity was performed using Brookfield RST-CC Rheometer. The studies were carried out at a temperature of 30 °C, with shear rates ranging from 1 - 250 s^{-1} at various biopolymer concentrations ranging from 0.05 to 0.5 wt.% dissolved in 100 ml of deionized water. All the readings were repeated for three replicate measurements.

Aging / Long Term Thermal Stability

The degradation of biopolymer over the period of time can be a major concern. Hence 0.4 wt.% biopolymer solution was aged at ambient temperature as well as at 80 °C in an oven in tightly sealed stainless-steel accumulator for a period of 168 days under aerobic conditions. The viscosity of biopolymer solution was measured on day 1, 7, 14, 28, 42, 84 and 168 respectively using RST-CC Rheometer at a temperature of 30 °C with shear rates ranging from 1 - 250 s^{-1}. All the readings were repeated for three replicate measurements.

Core Flooding Experiment

The performance study of biopolymer schizophyllan produced using local sources for polymer flooding operations was carried out using the following materials/equipment:

- Type of Core: Berea sandstone
- Equipment: High Temperature-High Pressure (HTHP) equipment by FARS EOR technologies
- Parameters of core sample:
    - Average diameter = 3.75 cm
    - Average length = 7.05 cm
- Properties of oil sample:
    - Type of oil: Paraffin
    - API gravity = 36.95 °API

- Dynamic viscosity = 26.9 cP

Soxhlet apparatus was used to clean the core sample using the solvent toluene. The core was further dried in an oven. A desiccator with a synthetic brine of concentration 90,000 ppm was used to saturate the core sample. The porosity and permeability of the core sample under study were found to be 16.42 % and 63.17 mD respectively. Prior to flooding, the core was saturated with paraffin oil at 0.4 mL/min flow rate until there was no water produced at the outlet. The oven temperature was set to 80 °C and the system was maintained at a confining pressure of 1000 psi. In order to attain equilibrium, the system was further aged for 24 hours.

During water flooding synthetic brine was injected at 0.4 mL/min flow rate until the oil-cut percentage in the effluent falls below 1% and the effluents were collected. The cumulative oil recovery was measured after injecting 0.5, 1, 1.5, and 2 PV of brine respectively. The process was carried until the ratio of volume of oil to that of water collected was less than 1%. The following Eq. 1 was used to calculate the recovery factor for the water flooding process.

$$\text{Recovery Factor (RF)} = \frac{\text{volume of oil displaced}}{\text{pore volume}} * 100 \tag{1}$$

After the water flooding technique, polymer flooding was utilized to recover the remaining oil in the Berea sandstone cores. 0.4 wt.% of schizophyllan biopolymer solution was injected at 0.4 mL/min flow rate. The process was continued until no further oil recovery was observed in the effluent, at which point the effluents were collected. Further, cumulative oil recovery was measured at 0.5, 1, 1.5, 2, 2.5, and 3 PV of schizophyllan solution injection following which the recovery factor was calculated using Eq. 1.

RESULTS AND DISCUSSIONS

Effect of Concentration

Figure 1 shows the rheological study of the effect of schizophyllan concentration on the viscosity of the solution performed at 30 °C measured as a function of shear rate ranging from 1 - 250 s^{-1}. From the graph, it can be inferred that, viscosity of schizophyllan solution follows a non-Newtonian / shear thinning behavior where the viscosity was found to be decreasing with increasing shear rates. Further, the viscosity of the biopolymer solution increases with an increase in biopolymer concentration at all shear rates. The increase in biopolymer concentration, increases the polymer molecules. This results in an increase in the interaction between polymer chains which in turn results in more frictional effects, therefore increasing the solution viscosity [16]. The viscosity of biopolymer obtained from the graph at 0.1 wt.% is comparable to the viscosity of commercial schizophyllan at 0.1 wt.% at a shear rate of 10 s^{-1} [16-18]. From the graph, there is a strong shift in the slope of the viscosity at the schizophyllan concentration, 0.3 wt.%, which is referred to as critical concentration, where the solution transitions from dilute to semi dilute. Thus, a concentration above critical concentration 0.4 wt.% was chosen throughout the studies.

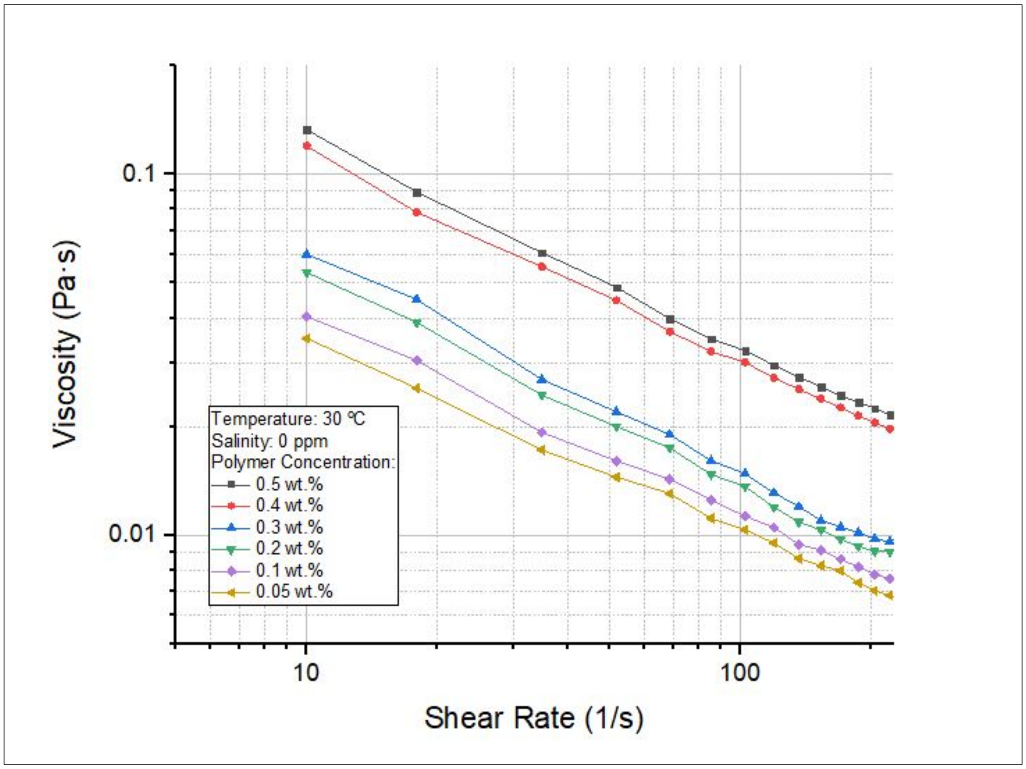

FIGURE 1. Effect of schizophyllan concentration on solution viscosity

Effect of Aging

Figure 2 and Figure 3 show the schematic for the effect of aging on viscosity of biopolymer solution. It can be observed that in the presence of dissolved oxygen, the viscosity of biopolymer solution exhibited an insignificant decrease up to a period of 168 days while retaining its shear-thinning behavior and original viscosity indicating that their structure remains non-degraded under aerobic conditions unlike commercial schizhophyllan where the biopolymer solution completely degraded after a period of 15 days, due to the attack of a free-radical in presence of an oxygen molecule under the similar conditions [18].

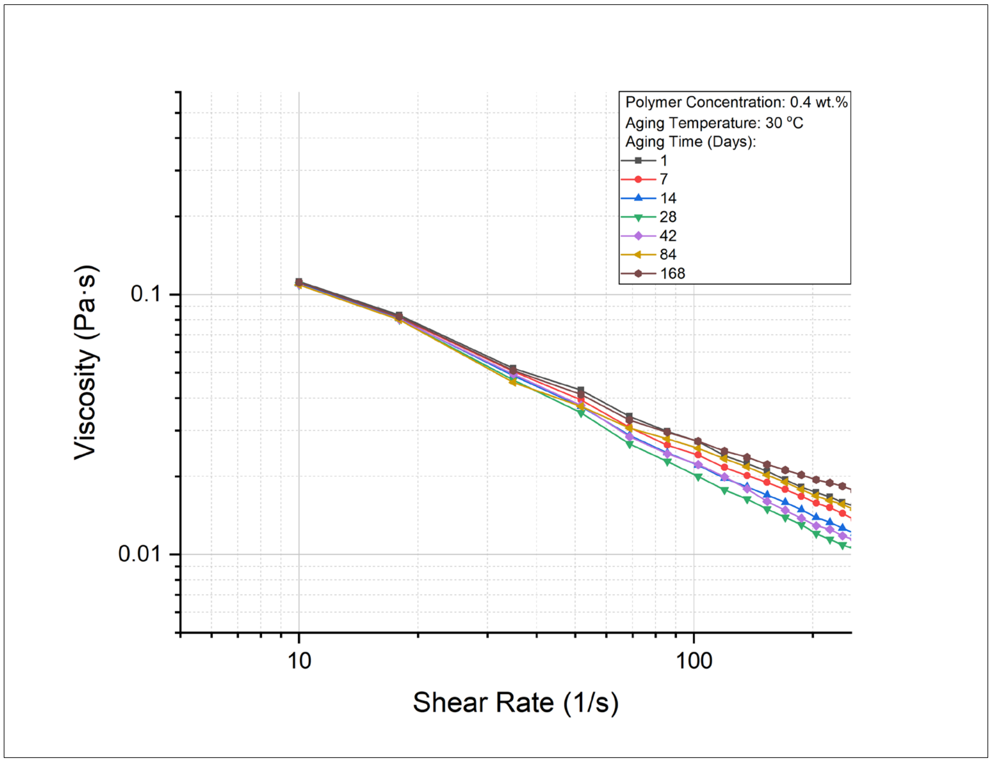

FIGURE 2. Effect of aging on schizophyllan solution viscosity at 30 °C

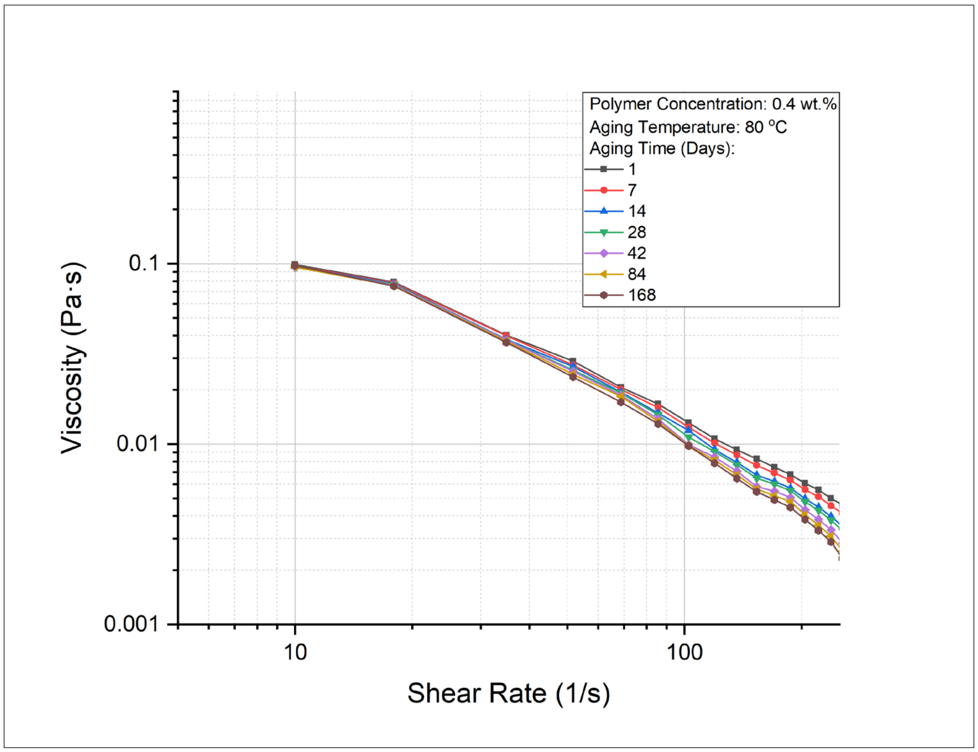

FIGURE 3. Effect of aging on schizophyllan solution viscosity at 80 °C

Core Flooding Results

Figure 4 illustrates the cumulative oil recovery versus pore volume plot for improved oil recovery using biopolymer schizophyllan. At a temperature of 80 °C and a salinity of 90,000 ppm, secondary recovery by water flooding recovered 65.88 % oil in place (OOIP). This means that due to the fingering effect caused by the water flooding, 34.12 % of the oil was left out in the core. As a result, the tertiary recovery process using a 0.4 wt. % biopolymer solution was successful in recovering 17.25 % extra oil over water flooding after injecting 3 PV schizophyllan solution, resulting in a total oil recovery of 83.13 % after secondary and tertiary flooding. According to the studies, utilizing commercial schizophyllan increased oil recovery by 7 to 10% [16, 18] and 28% [7]. The results of oil recovery utilising schizophyllan derived from local sources are found to be comparable to commercial one while being more cost effective.

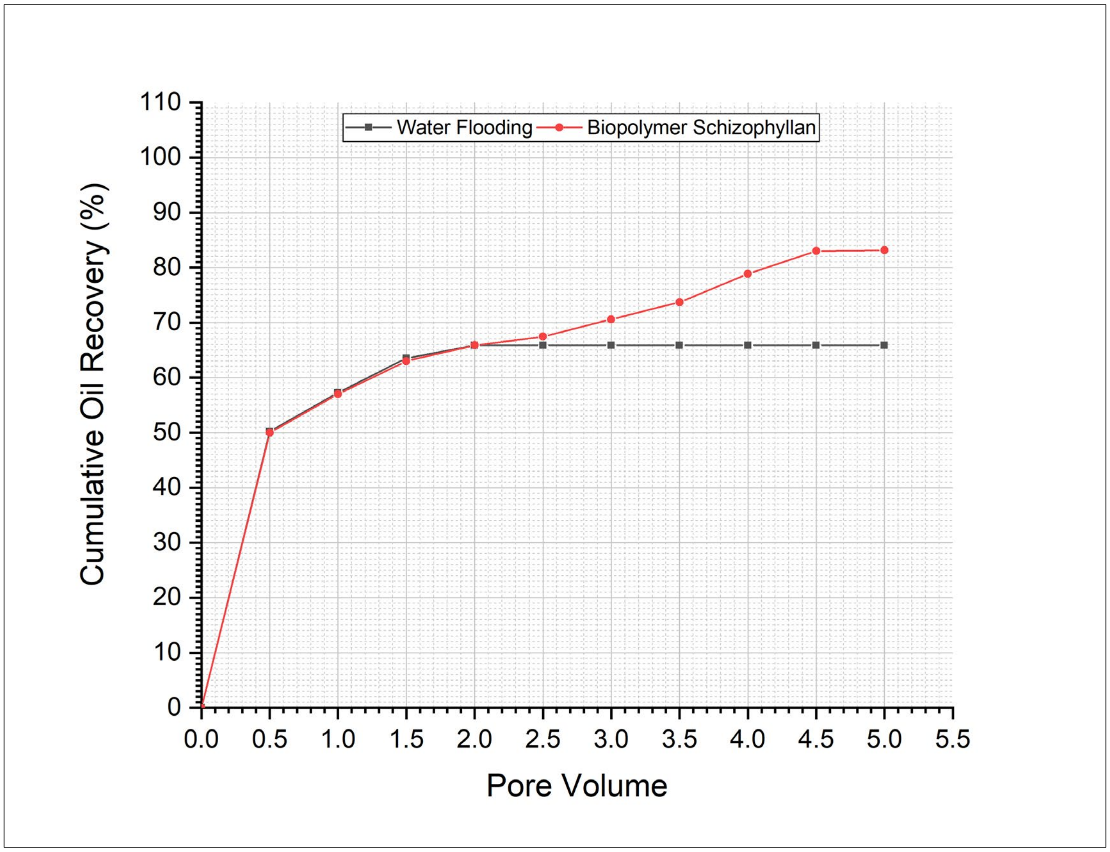

FIGURE 4. Cumulative oil recovery versus pore volume after water flooding and biopolymer flooding at 80 °C and 90,000 ppm

CONCLUSIONS

The rheological study for the locally produced schizophyllan indicates a good shear thinning behavior at high biopolymer concentrations. The biopolymer retained its original viscosity up to a period of 168 days without significant change which is the result of its triple helix structure. Finally, core flooding experiments on Berea sandstone core samples resulted in an additional 17.25% oil recovery after water flooding. As a result, this study proposed the use of schizophyllan from local sources for bulk applications in polymer flooding operations.

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