

Potential of Welan gum to enhance oil recovery

Changhong Gao

Received: 21 April 2014 / Accepted: 17 August 2014 / Published online: 6 September 2014
© The Author(s) 2014. This article is published with open access at Springerlink.com

Abstract Polymer flooding is the most successful chemical enhanced oil recovery method. Large-scale commercial polymer flooding projects are being carried out in China. However, partially hydrolyzed polyacrylamide, the commonly-used polymer for polymer flooding projects is very sensitive to sodium and calcium ions. This limits the field applications of polymer flooding method. The industry longs for a polymer that can tolerate salinity and heat. Welan gum (WLG) is a promising biopolymer because of its performance under challenging conditions. This paper investigates the factors that influence the viscosity of Welan gum solution. Tests show that WLG maintains high viscosity under the attacks of sodium ion, calcium ion, high temperature and long-term heating. Core flooding tests reveal that WLG cannot effectively reduce residual oil saturation, but can reduce the time to reach residual oil saturation.

Keywords Welan gum · Polymer flood · Enhanced oil recovery · High salinity · High temperature

Introduction

Certain chemicals, such as polymers and surfactants, can be injected into reservoirs to improve oil recovery (Sheng 2010; Gao 2011). Polymer flooding is the most successful chemical EOR method. Large-scale polymer flooding projects are being carried out in China (Gao et al. 2014). This method is also being tried in Angola and Brazil

(Morel et al. 2010; Bruno 2010). The most widely used polymer for commercial EOR projects is partially hydrolyzed polyacrylamide (HPAM). However, HPAM is rather sensitive to salinity and temperature (Gao 2013). The industry has been looking for a polymer that can tolerate high salinity and high temperature.

Welan gum (WLG) is produced by fermentation of sugar by bacteria of the genus *Alcaligenes*. The molecule consists of repeating tetrasaccharide units with single branches of L-mannose or L-rhamnose (Rakitsky and Richey 1992). The molecular structure is presented in Fig. 1. It was reported that WLG exhibits good viscosity retention at elevated temperature, and in the presence of sodium ion (Chen 2007). WLG was patented to be used as cement additive (Allen et al. 1991) and water shutoff chemical (Hoskin et al. 1991). However, limited research has been conducted to investigate its effect on oil recovery. The objective of this study is to investigate the potential of WLG as a polymer for EOR.

Materials and methods

Welan gum was provided by BDL Chemical Company in China. Other materials included NaCl, CaCl₂, and distilled water. Crude oil for EOR tests was supplied by an oil company. The dead oil viscosity was 5.5 cP at 25 °C, and 3.1 cP at 85 °C. Viscosity was measured with a torque-type viscometer at varied temperatures and shear rates. Oil recovery was measured with core flooding equipment.

The test matrix is given in Table 1. For the first group of tests, WLG was added to water at different concentrations and the viscosity was measured at varied shear rates. For the second group of tests, NaCl was added to WLG solution to test its tolerance for sodium ions. For the third group

C. Gao (✉)
Sinopec Shengli Research Center, Dongying 257000, Shandong,
China
e-mail: 237184689@QQ.com

Fig. 1 Molecular structure of Welan gum

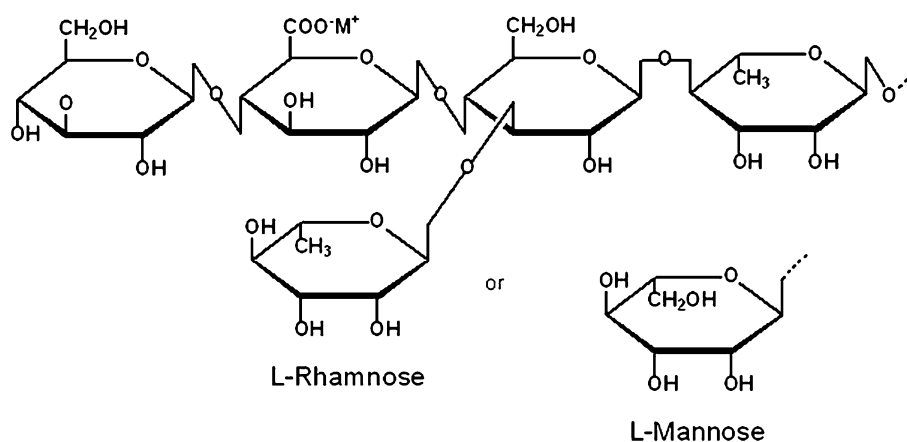


Table 1 Summary of test matrix

Test group	WLG concentration (g/L)	NaCl concentration (g/L)	CaCl ₂ concentration (g/L)	Temperature (°C)	Objective of tests
1	1; 2; 3; 5; 8	0	0	25; 40; 50; 60; 70; 85	Effect of WLG concentration and temperature
2	8	10; 50; 100; 150	0	50	Effect of sodium
3	3	0; 10; 50; 100	10; 30; 50; 70; 100	50	Effect of calcium/sodium
4	3	150	50	85 °C for 6 h	Effect of long-term heating
5	1	150	50	85	Oil recovery

of tests, CaCl₂ was added to WLG solution to test its tolerance for calcium ions. Fourthly, WLG solution was aged at 85 °C for 6 h to test its stability under long-term heating.

Finally, core flooding tests were carried out to evaluate WLG's efficiency in EOR. A Berea sandstone core was chosen and its properties were measured. The core sample had good porosity (20 %) and permeability (90 mD). The rock pore volume was 15.5 mL. The core flood tests followed standard recovery test procedures (Gao and Bellout 2013). The core was first saturated with brine, and then flooded with crude oil to irreducible water saturation (S_{wi}). The brine contained 150 g/L sodium chloride and 50 g/L calcium chloride. The same brine was injected afterwards to arrive at residual oil saturation (S_{or}). The oil recovery by water flooding is obtained. The second core flooding test followed the same procedures, but instead of brine, polymer solution containing 1 g/L WLG was injected till S_{or} .

Experimental results

WLG was mixed into water at varied dosages, and Fig. 2 presents the effect of WLG concentration on fluid viscosity. These tests were all conducted at 85 °C. The relationships between viscosity and shear rates closely follow linear trends on log–log plot. This reveals that WLG solution is a non-Newtonian fluid. It is obvious that WLG

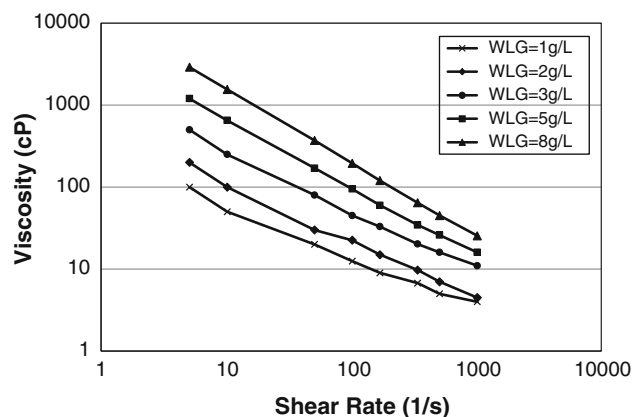


Fig. 2 Effect of WLG concentration on viscosity

greatly boosts viscosity, even at a low concentration. It was also observed that WLG quickly dissolved in water.

Temperature has negative impacts on polymer viscosity. Figure 3 compares the behavior of WLG solution at low and high temperature. For these tests, the concentration of WLG was fixed at 2 g/L. It is not a surprise that the viscosity of WLG solution decreased at high temperature. For example, the typical shear rate for flow in reservoir is 10/s. Under such shear rate and at 25 °C, the viscosity of WLG fluid was 151 cP, while it declined to 124 cP at 50 °C, and further declined to 103 cP at 85 °C. However, the viscosity still remains relatively high at high temperature.

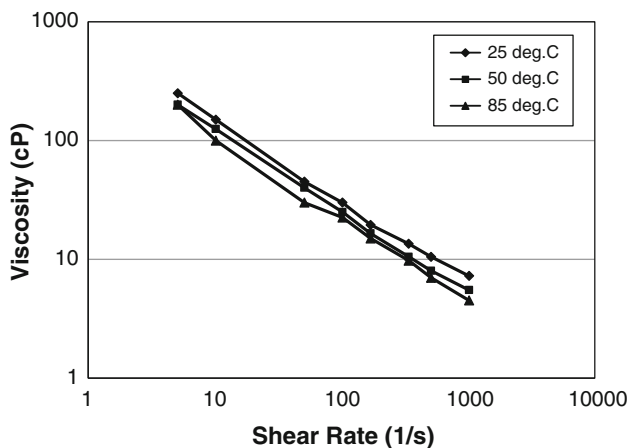


Fig. 3 Effect of temperature on viscosity of WLG solution

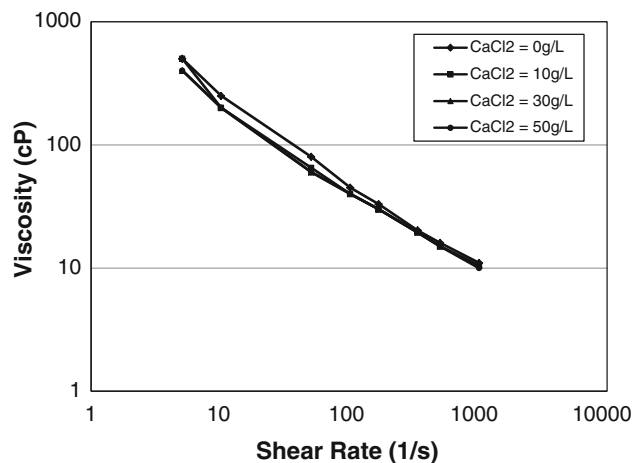


Fig. 5 Effect of calcium on viscosity of WLG solution

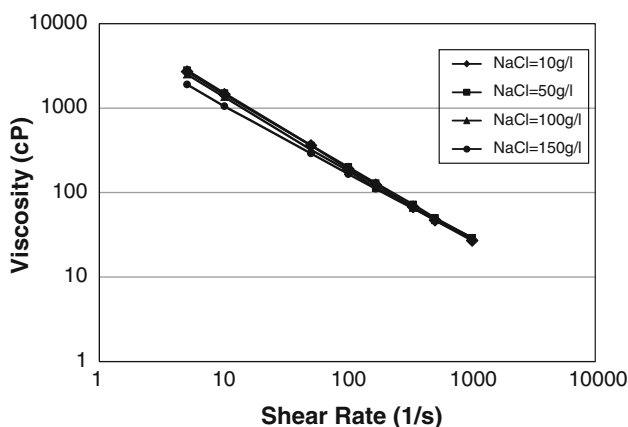


Fig. 4 Effect of sodium on viscosity of WLG solution

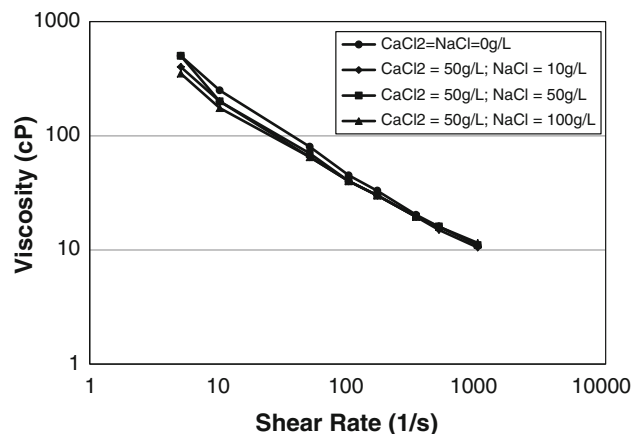


Fig. 6 Effect of calcium and sodium on WLG viscosity

Sodium chloride was added to WLG solution containing 8 g/L WLG, and the viscosity data are given in Fig. 4. It can be seen that sodium ion has certain damaging effect on viscosity of WLG solution. For example, under shear rate of 10/s, when concentration of sodium chloride increased from 10 to 100 g/L, the viscosity of WLG solution dropped from 1,510 to 1,380 cP. Its viscosity further dropped to 1,070 cP when sodium chloride reached 150 g/L. However, it cannot be denied that the viscosity of WLG still remained high at very high concentration of sodium.

HPAM is very sensitive to calcium ion (Gao 2014), while WLG is less sensitive to calcium, as seen in Fig. 5. For the tests in Fig. 5, the WLG concentration was 3 g/L, and no sodium was added. WLG in fresh water demonstrated a viscosity of 252 cP under shear rate of 10/s. After calcium was added, the viscosity declined to 204 cP at the same shear rate. However, the viscosity did not decline further at higher concentration of calcium.

It is also meaningful to investigate the effect of combining sodium and calcium ions. The test solution contained 3 g/L WLG. Concentration of calcium chloride was

maintained at 50 g/L. The concentration of sodium was increased from 10 to 50 g/L, and further to 100 g/L. The test data are given in Fig. 6. At the shear rate of 10/s, the viscosity of WLG solution in fresh water was as high as 253 cP. At high concentration of calcium and sodium, its viscosity declined to 175 cP. WLG still maintains relatively high viscosity at high salt concentration. The loss of viscosity at high salinity is a common phenomenon for polymers. It is believed that polymers are relaxed in fresh water, but shrinks and coils in the presence of monovalent and divalent ions. Shrinkage of polymer chains leads to reduction in viscosity (Sheng 2010).

WLG solution containing 3 g/L WLG, 100 g/L NaCl and 50 g/L CaCl₂ was sealed in a container at 85 °C for 6 h. The viscosity data are presented in Fig. 7. It is clear that viscosity of WLG solution reduced after aging. For instance, at the shear rate of 10/s, viscosity dropped from 175 cP before aging to 125 cP afterwards. This is possibly due to collapse of polymer chains under high temperature.

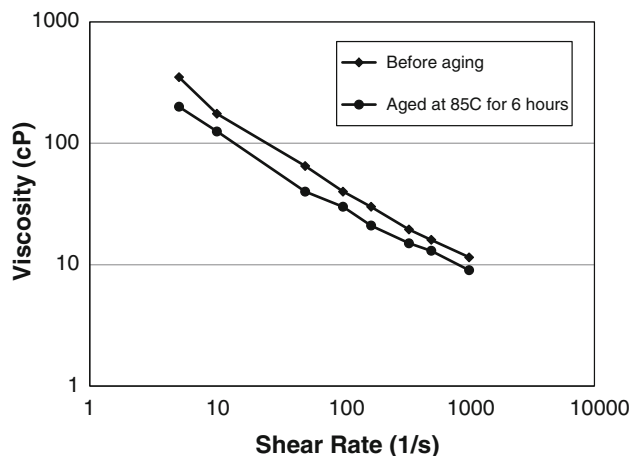


Fig. 7 Effect of aging on viscosity of WLW solution

However, the WLW solution still maintained relatively high viscosity after aging.

The first recovery test was to establish OOIP and the baseline recovery with water flooding. The injected brine contained 150 g/L NaCl and 50 g/L CaCl₂. The injection rate was controlled at 0.1 mL/min. The OOIP was found to be 10 mL. After five pore volumes of injection, 7 mL of oil was produced. This was equivalent to 70 % OOIP. The second test injected WLW solution containing 1 g/L WLW at the same injection rate. This low concentration of WLW was chosen because in field projects, oil companies must reduce the costs of chemicals to achieve maximum profits. After injection of 2.5 pore volumes of polymer fluid, WLW recovered 70 % OOIP. Subsequent injection of WLW fluid did not further improve recovery. This indicates that WLW has limited capability to reduce S_{or} , but it reduces the time required to reach residual oil saturation.

It cannot be denied that the price of Welan gum is much higher than HPAM. However, Welan gum demonstrates much better resilience to high salinity and high temperature. On the other hand, the Welan gum in the market is produced for food industry at a very high grade. Field implementation of polymer flooding will require lower grade products that are cheaper than food grade. Field implementation will require production of polymers at a large scale, which also helps to reduce the cost of Welan gum.

Conclusions

This paper studies the viscosity of WLW under the influences of sodium ion, calcium ion, high temperature, and long-term heating. Experiments show that WLW can tolerate high concentration of sodium and calcium ions. WLW also maintains relatively good viscosity under high temperature. WLW shows good potential for application in polymer flooding projects.

Open Access This article is distributed under the terms of the Creative Commons Attribution License which permits any use, distribution, and reproduction in any medium, provided the original author(s) and the source are credited.

References

- Allen F, Best G, Lindroth T (1991) Welan gum in cement compositions. United States Patent 5004506
- Bruno R (2010) Brightwater trial in Salema Field Brazil. SPE 131299 presented at SPE EAGE annual conference and exhibition, 14–17 June, Barcelona, Spain
- Chen F (2007) Study of factors affecting property of Welan gum solution. *Food Sci* 28(9):49–52
- Gao C (2011) Scientific research and field applications of polymer flood in heavy oil recovery. *J Pet Explor Prod Technol* 3(1):65–70
- Gao C (2013) Viscosity of partially hydrolyzed polyacrylamide under shearing and heat. *J Pet Explor Prod Technol* 3(3):203–206
- Gao C (2014) Empirical correlations for viscosity of partially hydrolyzed polyacrylamide. *J Pet Explor Prod Technol* 4(2):209–213
- Gao C, Bellout A (2013) An evaluation for two *Bacillus* strains in improving oil recovery in carbonate reservoirs. *Pet Sci Technol* 31(11):1168–1174
- Gao C, Shi J, Zhao F (2014) Successful polymer flooding and surfactant-polymer flooding projects at Shengli Oilfield from 1992 to 2012. *J Pet Explor Prod Technol* 4(1):1–8
- Hoskin D, Mitchell T, Shu P (1991) Oil reservoir permeability profile control with cross linked Welan gum biopolymers. United States Patent 4991652
- Morel D, Vert M, Bouger Y (2010) First polymer injection in deep offshore field Angola. SPE 135735 presented at the annual technical conference and exhibition, 19–22 September, Florence Italy
- Rakitsky W, Richey D (1992) Rapidly hydrating Welan gum. United States Patent 5175277
- Sheng J (2010) Modern chemical enhanced oil recovery: theory and practice. Gulf Professional Publishing, Oxford, pp 101–111