IJCPE
Iraqi Journal of Chemical and Petroleum Engineering

Iraqi Journal of Chemical and Petroleum Engineering
Vol.17 No.1 (March 2016) 37- 46
ISSN: 1997-4884

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College of Engineering

Rheological Evaluation of Polymer (Sav 10) For Polymer Flooding Applications

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Abstract

Half of the oil production of the worldwide is a result of the water flooding project. But the main concern of this process is mobility control of the injected fluid, because the unfavorable mobility ratio leads to fingering effect. Adding polymer to the injection water increase the water viscosity, therefore, the displacement will be more stable and have a greater sweep efficiency.

Using of polymer flooding has received more attention these days. Polymer has great potential in the Middle East region, especially in reservoir with high temperature and salinity.

The main objective of this work is to show the effect of shear rate, salinity, temperature, polymer concentration on polymer viscosity and determine the target viscosity to further displacement experiments. Polymer solution was prepared with two types of water (fresh water, brine). The reason of using two types of water is the ability of polymer to prepare by fresh water or brine.

Results from this study show that as the shear rate increases, polymer viscosity decreases. Also, the results show that in spite of polymer viscosity decreased with increase in temperature and salinity, polymer (SAV 10) shows that high temperatures have less effect on its viscosity at the same shear rate and has a salinity resistant up 200000 ppm. As polymer concentration increase, polymer viscosity increase until reach the target concentration which can be used for displacement experiments. It was found that the target concentration with viscosity 6.99 cp is 2000 ppm, which is closest to reservoir viscosity.

Key Words: Polymer solution, rheology, polymer flooding.

Introduction

Oil recovery stages can classify into three stages; primary, secondary and tertiary stage. In the primary stage, reservoir natural energy such as gas drive, water drive, or gravity drainage will displace oil into production well and up to the surface. During primary stage, the reservoir pressure will fall and will not be enough to recover more oil from the formation. Water or gas is injected as a secondary stage to maintain the pressure of the reservoir and displace hydrocarbons toward the production well. The most common secondary recovery method is water flooding. However, the secondary recovery method still leaves behind a substantial amount of oil due to both incomplete sweep in heterogeneous reservoirs and residual oil saturation in the pores of the rock [1]. So, it became necessary to find other technologies to extract the remaining oil after secondary recovery processes. Enhanced oil recovery (EOR) was developed for this purpose.

In the tertiary recovery method (EOR), almost 30-60% of the original oil in place can be recovered which is high compared with primary and secondary recovery stages where the recovery factor is equal to 20-40% [2].

Chemical EOR processes which consider as a method of enhanced oil recovery play a key role to recover the remaining oil after the secondary recovery processes. There are different types of chemical EOR depending on the type of fluid used such as: polymer, alkaline and surfactant. In this thesis, polymer flooding was used as chemical EOR processes.

Polymer flooding is characterized by its possibility to use as secondary or tertiary recovery. When a polymer is added to water, solution viscosity increases due to high molecular weight of the polymer. Adding polymer to the injected water leads to reduce the mobility ratio between water/oil, get favourable flood and improve oil displacement. Also, polymer flooding is characterized by reducing the porous media permeability which leads to an increase in the areal and vertical sweep efficiency of the injected water and consequently, increases the oil recovery [3]

When a polymer solution is injected into a reservoir, the flow velocity, which is related to shear rate, will alter from well bore to reservoir in-depth; therefore, the polymer viscosity will also change from the near wellbore to reservoir in-depth correspondingly. Polymer rheology in a porous media is also affected by polymer type, molecular weight, concentration, water salinity of the reservoir, and reservoir permeability. Flow polymer solutions through a porous media is a complex topic, controlled by polymer rheology and retention behaviour, and is still not understood very well [1].

Moawad et al., (2007) [4] studied the main factors that can be affected on the polymer viscosity such as shear rate, salinity, polymer concentration, temperature. The type of polymer which is used in their lab was biopolymer (POLYMER). Their results show as follows:

1- As shear rate increases, polymer viscosity decreases.
2- The polymer viscosity decreases as the temperature increases at the same shear rate.
3- No salinity effect on polymer viscosity.
4- As polymer concentration increases, polymer viscosity increases.

Point 1, 2 and 3 can be seen in fig. (1). Finally, they indicated that with this type of polymer can be used in reservoirs with high salinity and high temperature.

Zhu, et al., (2015) [5] in recent years, the need of re-injection produced water of oil field in chemical flooding incremented and it was necessary to develop polymer solutions to resistant high salinities.

The development of salt tolerance polymer has been improved in China recently. Through modification in molecular structure, improving backbone strength, enhancing the regularity of bulk molecule structure.

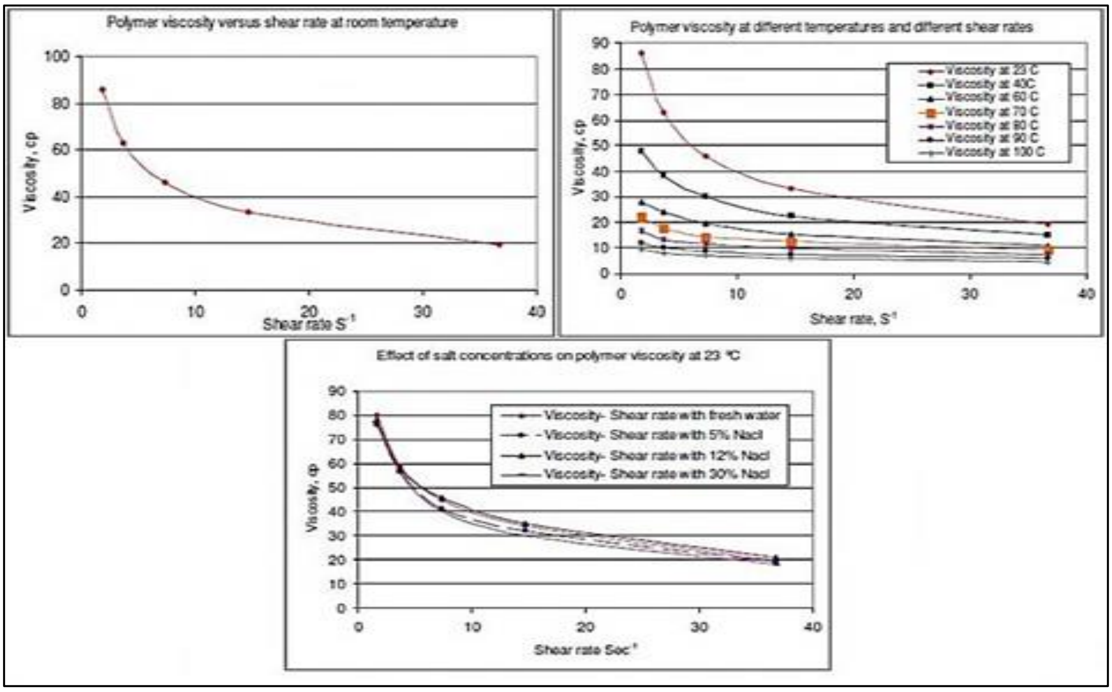

Fig. 1, Factors impact on polymer viscosity [1]

By this way new types of polymer can be produced and have a better salt tolerance performance. The chemical and physical properties of these polymers could meet the requirements of polymer products in re-injection the produced water of oil field with high salinity.

Types of Polymers

Polymers are long chain organic molecules made from joining together small molecules called monomers.

They are flexible with high molecular weight ranging from 2 x10^6 to 21x10^6 g/mole [6]. Two types of polymers mostly used in polymer flooding process are Polyacrylamide (PAM), in its partially hydrolyzed form (HPAM) and Xanthan. Fig. (2) shows the polymer types and structures for Xanthan, PAM & HPAM commonly used.

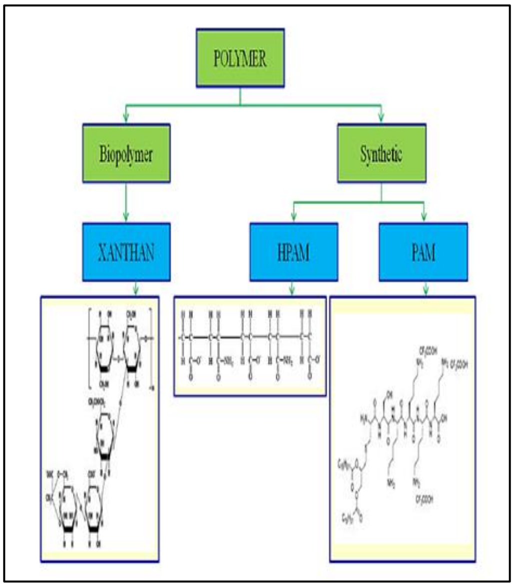

Fig. 2, Polymers for Enhanced Oil Recovery (EOR) [6]

Hydrolyzed Polyacrylamide (HAPM)

Polyacrylamides are water soluble polymers used in polymer flood applications in its hydrolyzed form. HPAM is a straight chain polymer that has acrylamide molecules as monomers as shown in Fig. (3) Polyacrylamides are the co-polymers of acrylic acid and acrylamide.

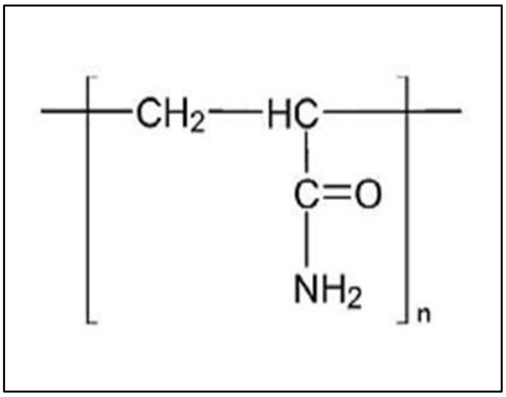

Fig. 3, Chemical structure of polyacrylamide Not (Hydrolyzed) [7]

Polyacrylamides used in flooding undergo partial hydrolysis, which causes the negatively charged carboxylic group (-COO-) to be scattered along the backbone of the chain. Typical degrees of hydrolysis are 25 – 35% of the acrylamide monomers; that are chosen to optimize the specific properties of polymer solutions such as viscosity, solubility and retention. If the degree of hydrolysis is too large, its properties are very sensitive to salinity and hardness. If it is too small, the polymer will not be water soluble. The typical molecular weight of HPAM used in polymer food is within the range of 2 – 20x10^6 g/mole. Molecular structure of partially hydrolyzed polyacrylamide is shown in Fig. (4) [8].

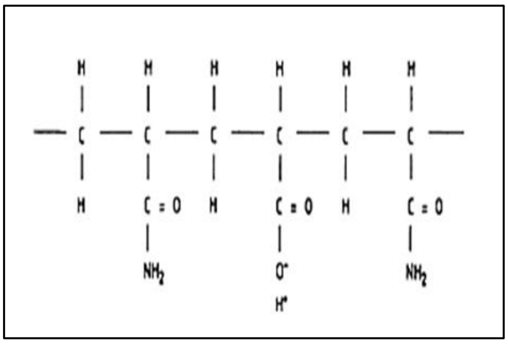

Fig. 4, Molecular structure of partially hydrolyzed polyacrylamide [8]

The viscosity-increasing feature of HPAM polymers is derived from the repulsive forces between polymer molecules and between the segments of the same molecule. This repulsion causes the molecules to lengthen and snag on other molecules, thus causing the viscosity to increase [9].

Xanthan Gum

Another widely used polymer, a biopolymer (Polysaccharides), is xanthan gum (corn sugar gum). These polymers are formed from the polymerization of saccharide molecules, a bacterial fermentation process. The structure of a xanthan biopolymer is shown in Fig. (5).

Xanthan gum has a more rigid structure and is quite resistant to mechanical degradation. These properties make it relatively insensitive to salinity and hardness. It is susceptible to bacterial attack after it has been injected into the reservoir. The polymer is relatively nonionic and, therefore, free of ionic shielding effects of HPAM. Molecular weights of xanthan biopolymer used in EOR processes are in the range of 1 million to 15 million.

Xanthan is supplied as a dry powder or as a concentrated broth. It is often chosen for a field application when no fresh water is available for flooding. Some permanent shear loss of viscosity could occur for polyacrylamide, but not for polysaccharide at the wellbore.

However, the residual permeability reduction factor of polysaccharide polymers is low. Other potential EOR biopolymers are scleroglucan, simusan, alginate, etc. [10] and [11]

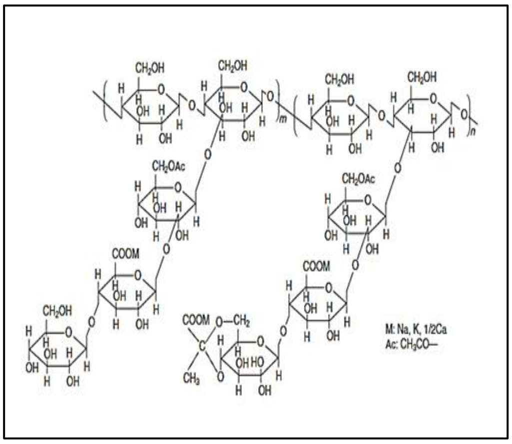

Fig. 5, Molecular structure of xanthan [10]

Experimental

Materials

The following materials were used in the experimental work;

Polymer

A commercial polymer (SUPERPUSHER SAV 10) was used in this study. SUPERPUSHER SAV10 is partially hydrolyzed polyacrylamide (HPAM) supplied by SNF Floerger in a white powder. Fig. (6) shows a polymer sample beaker. The main characteristics of (SUPERPUSHER SAV 10) are-:

- Molecular weights range from 3 to 8 Million Daltons (g/Mol .
- Wide range of anionicity (quantify).
- Nontoxic and non- bioaccumulative.
- Powder is safe and easy to handle excellent solubility.
- Stable up to 140°C, 200g/l of temperature and salinity respectively, (Fig. (7)) [14].

Brine

Sodium chloride (NaCl) was used for preparing synthetic brine. Brine solution was used for preparing polymer solutions.

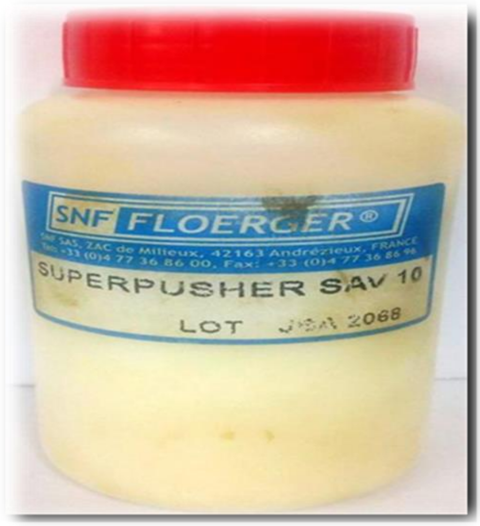

Fig. 6, Polymer sample beaker

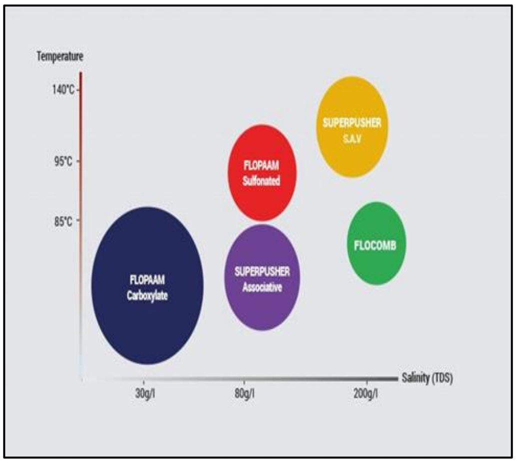

Fig. 7, Types of polymer according to salinity and temperature

Experimental Procedure

Polymer Preparation

The polymer solution was prepared with two types of water:

- Fresh water, which consider as river water.
- Brine with concentration (160000 ppm) which consider as formation water.

The purpose of using two types of water (brine, fresh water) is as follows:

1- If the sources of fresh water are available, reservoir preconditioning with fresh water and no formation mineralogy problem, fresh water can be used to prepare the polymer solution.

2- If the sources of fresh water not available, reservoir not preconditioning with fresh water or formation mineralogy problem. Therefore, brine can be used to prepare polymer solution. In many cases formation water preferred to prepare a polymer solution to avoid the treatment cost of fresh water.

To prepare polymer solution, brine solution should be prepared first by dissolving required amount of sodium chloride (NaCl) in the beaker fill with 1000ml demineralised water and then stirred by a magnetic stirrer for 20 minutes. In order to add polymer to the brine solution, the stirrer has to be set up at a speed approximately 500- 600 RPM to build a very strong vortex. Then, the weighted polymer is added slowly by sprinkling it into the wall of the vortex to avoid agglomeration of polymer particles. After 3-6 min of mixing, the magnetic stirrer speed reduced to 300 - 400 RPM. Finally, the solution is stirred for 3 hours. The mouth of the beaker was covered with an aluminium foil to prevent contact with air.

Magnetic stirrer come with a thermal plate used to heat the solution to improve the dissolution process. The same procedure was repeated for different polymer concentrations and salinities used for experimental work.

Fig. (8) shows the magnetic stirrer which used in polymer preparation.

It should be pointed out that the same procedures were used to prepare polymer solution in fresh water without needing to procedure of preparing the brine solution.

Fig. 8, Magnetic stirrers used in polymer preparation

Viscosity Measurement

Most of polymers that used for enhanced oil recovery are characterized by their high viscosity yield. The purpose of using polymer is to increase the water injection viscosity which improves the sweep efficiency and increasing the oil recovery factor.

Factors impacting on the polymer viscosity such as shear rate, polymer concentrations, salinity and temperature should be studied to clarify the behaviour of the polymer viscosity in porous media. Therefore, the effect of these factors on the polymer viscosity was measured as a function of shear rate by using a Kinexus rheometer as shown in Fig. (9).

Fig. 9, Kinexus rheometer

Results and Discussions

Impact of Different Shear Rates on Polymer Viscosity

Polymer solutions are classified as (Pseudo plastic fluids) which exhibits a smaller resistance to flow as the shearing rate increases. The effect of different shear rates on the polymer viscosity was measured at 90oC. Polymer concentration with 1500 ppm was used. Fig. (10) shows the relationship between polymer viscosity and shear rate.

From the Fig. 10 its observed that at low shear rates polymer viscosity shows Newtonian behaviour. From some critical rate (γc) as the shear rate increases the polymer viscosity decreases. This decreases in polymer viscosity is attributed to the structural characteristics of polymer chains, which are aligned along the flow streamlines with respect to the increase in shear rate (Non-Newtonian behaviour).

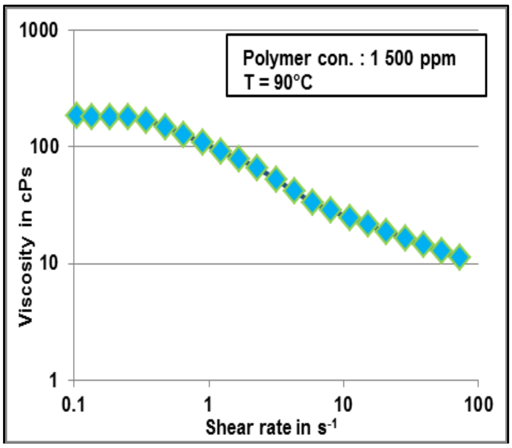

Fig. 10, Impact of shear rate on viscosity [14]

Impact of different salinity on polymer viscosity

Usually oil reservoirs have brine as formation waters. One of the most common flaws of the polymer solution, to be applied for enhanced oil recovery, is its sensitivity to salinity. The salinity of water has a major impact on polymer viscosity. Any change in the water salinity has a direct effect on polymer viscosity. When a polymer solution, as HPAM, is tested under different salinity water, its anionic and cationic in the water cause an attraction/repulsion to polymer chain, which make it compressed or stretched. When it's exposed to the distilled or low salinity water, the electrostatic repulsion between anionic groups along the polymer chains would be unshielded and cause an extensive expansion of polymer molecules. The expansions of polymer molecules give the polymer a relative high viscosity and make it hard to pass through a porous medium. When it encounters the high salinity water, a double layer of electrolytes shield electrostatic repulsion which decreases the stretch between the polymer chain and the molecules and a low viscosity is produced at a high salt concentration. Fig. (11) shows that polymer viscosity as a function of different shear rates, decreases as salt concentrations increase.

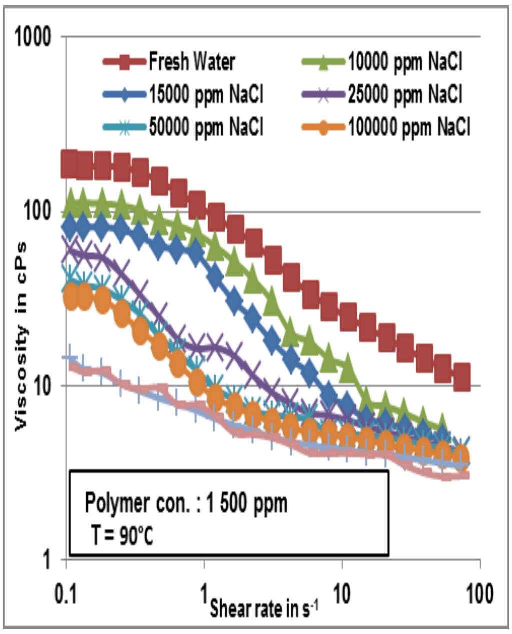

Fig. 11, Effect of salt concentrations on polymer viscosity [14]

Fig. (12) illustrates the stability of polymer viscosity under different salinity conditions and it was observed that polymer viscosity (SAV 10) shows a resistance against salinity up to 200000 ppm. Hence, SVA 10 could be a suitable candidate for polymer flooding processes of reservoirs with high salinity concentration.

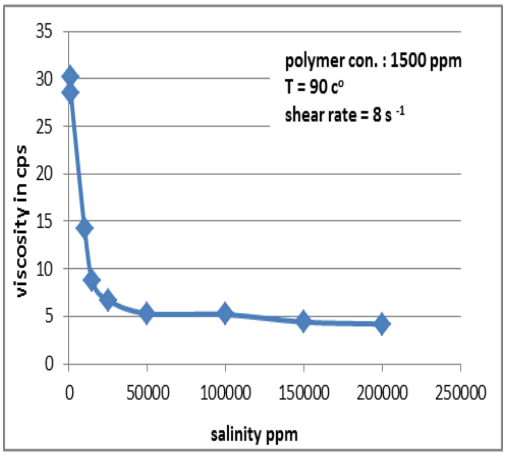

Fig. 12, Stability of polymer viscosity [14]

Impact of Different Temperatures on Polymer Viscosity

As mentioned previously, there are many parameters that effect on polymer viscosity. Therefore, one of these parameters is reservoirs temperature. Petroleum reservoirs are characterized by their high temperatures. Most of the polymers viscosity, which are used in polymer flooding application decreases as temperature increase. In order to start with a polymer flooding project, reservoir temperature should be measured and choose a polymer product withstand the reservoir temperature to avoid thermal degradation. In this study, the effect of the temperature on the polymer viscosity was investigated at different shear rates. Fig. (13) and (14) shows the effect of the temperature from 50°C to 90°C on the polymer viscosity at concentration 1500 ppm.

These figures show that as the temperature increases, polymer viscosity decreases at the same shear rate. The results in table (1) shows that the polymer (SVA 10) can be used in reservoir with high temperature without missing its property and it will be stable up 120°C. But the measurement was done up 90°C because Kinexus rheometer has a temperature range up 90°C.

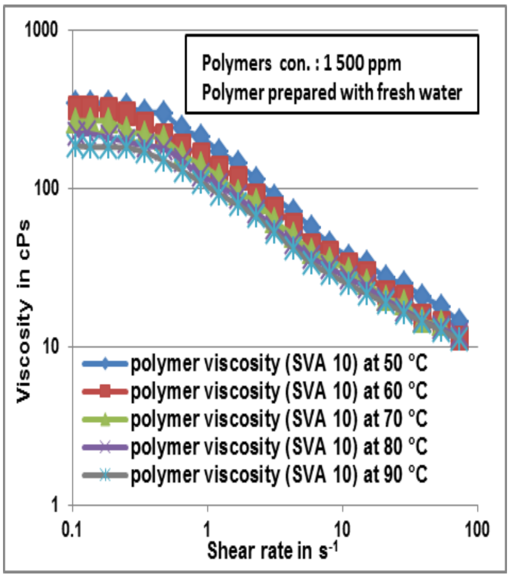

Fig. 13, Effect of different temperatures on the polymer viscosity prepared in fresh water [14]

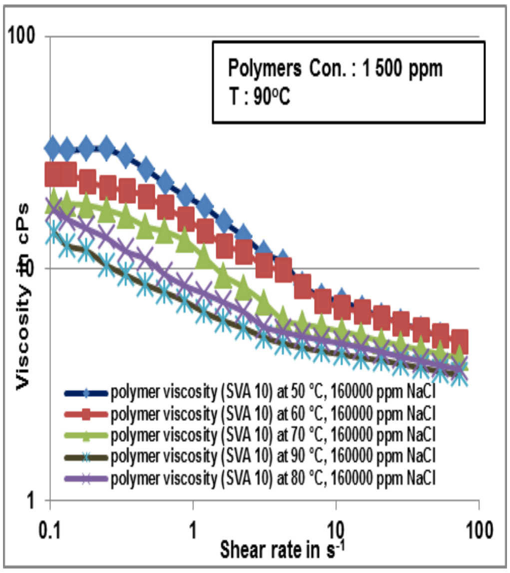

Fig. 14, Effect of different temperatures on the polymer viscosity in brine [14]

Table 1, Polymer viscosity at different temperature [14]

Temperature °C	polymer viscosity in Fresh water cp @ 39 s-1	Polymer viscosity in brine cp @ 39 s-1
50	20.62	5.44
60	15.6	5.4
70	14.61	4.5
80	14.5	4.01
90	14.4	3.75

Effect of Polymer Concentration on Polymer Viscosity

Five polymer concentrations were investigated which are 500, 1000, 1500, 2000 and 2500 ppm to show the effect of polymer concentrations on polymer viscosity with different shear rates. For each experiment, the temperature was remained constant at 90oC. The results in Fig. (15) and (16) show that the polymer viscosity increases as polymer concentration increases because the number of polymer chains increase in a given volume, which strongly interact with each other resulting in more friction affects which increases the viscosity.

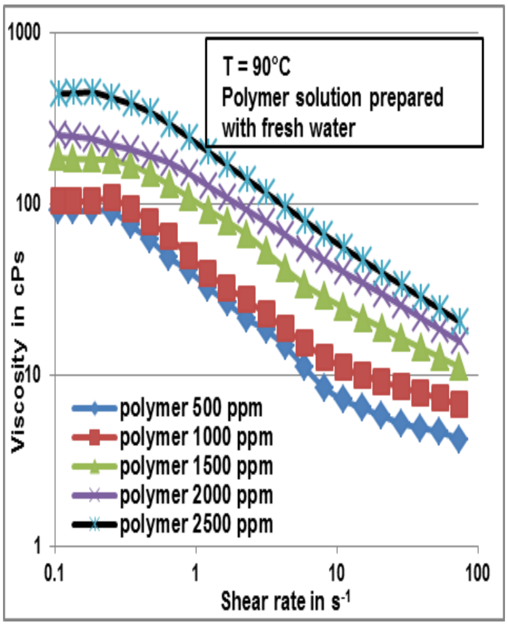

Fig. 15, Effect of polymer concentrations on polymer viscosity in fresh water [14]

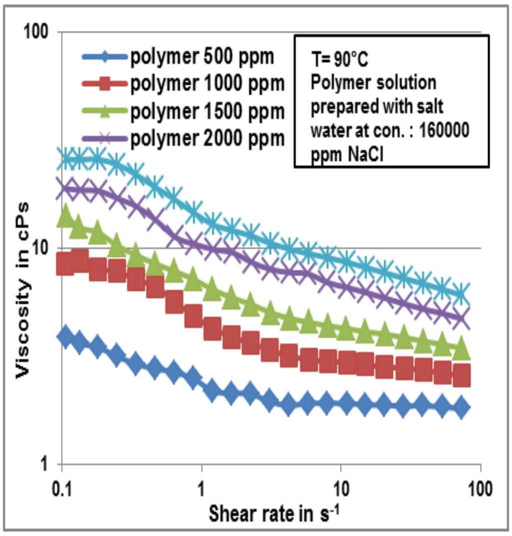

Fig. 16, Effect of polymer concentrations on polymer viscosity in brine [14]

Based on Fig. (15) and (16), in order to determine the target polymer concentration for displacement tests, polymer concentration with viscosity closest to oil viscosity should be selected. Oil with viscosity of 7 cp was used. Therefore, polymer concentration with viscosity of 8.4 cp of 500 ppm was selected in case of the polymer solution prepared in fresh water. But in case of polymer solution prepared in brine, 6.985 cp polymer viscosity of 2000 ppm polymer concentration should be selected [12]. The tow viscosities are selected at shear rate of 8 s^{-1}. The reason of choosing 8 s^{-1} is that the displacement in the reservoir is considered to be 1-2 ft/day, which around 8 s^{-1} of shear rate [13]

Conclusion

1- The polymer viscosity (SVA 10) has been tested for different salinity and it was observed that, it's viscosity decreases as salinity concentration increases.

2- The polymer viscosity (SVA 10) shows a resistance against salinity up to 200000 ppm. Hence, SVA 10 could be a suitable candidate for polymer flooding processes of reservoirs with high salinity concentration.

3- The effect of the different temperatures on the polymer viscosity was investigated and as the temperature increases, polymer viscosity decreases at the same shear rate.

4- Results in table (1) show that polymer (SVA 10) can be used in reservoir with high temperature without missing its property.

5- As polymer concentration increase, polymer viscosity increase.

Nomenclature

HPAM:	Hydrolyzed Poly Acryl Amide
PAM:	Polyacrylamide
PPM:	Part Per Million
EOR:	Enhanced Oil Recovery
TDS:	Total Dissolved Solids
NaCl:	Sodium Chloride
RPM:	Revolutions Per Minute

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