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Reducing Water Cut Using Polyacrylamide Polymers

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Abstract

Most of the oil fields inject water as a secondary recovery to maintain the pressure at the reservoir when reservoir natural energy is consumed and pressure is declined during the initial production stage. The disadvantage of using water as injection fluid is that the injected water will tend to finger by the oil because of low viscosity of water compared to oil and moves through the shortest path to the production wells under high water-oil mobility ratio condition, so large amounts of oil are left behind. In order to avoid the high mobility condition of injected water, polymers have been used. It is simply a chemicals dissolved in the injected water and because of the polymer high molecular weight, small amount within several hundred ppm will give significant increase in viscosity of injected water. As a result, it leads to better mobility ratio, reduces fingering effect and increases sweep efficiency. The scope of the current work is to study the effect of polymer injection in porous media on water cut and oil recovery and compare the results with that of water flooding. This study has been done using artificial core with a permeability of 1.82 Darcy and porosity ranging from 32.7 % to 33.7%. Three types of polymers with different molecular weight have been used. Results from artificial core flood experiments show that polymers reduce water cut and improve oil recovery.

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1. Introduction

At the initial stage of production, reservoir is producing oil through natural displacement energy existing in the reservoir, a natural reservoir energy such as water drive, gas-cap drive, solution gas drive, fluid or rock expansion and gravity segregation are the main energy sources for oil displacement to the producing wells, this stage of production is called primary production. As reservoir pressure declines, the amount of oil produced will be uneconomical, most of the oil fields inject water or gas as a secondary recovery to maintain the pressure at the reservoir, in this case, gas may be injected in the gas-cap to maintain the reservoir pressure or into the oil zone to displace oil based on volumetric sweep out consideration and relative permeability. Immiscible gas injection process is not as efficient as water flooding, where water flooding is used frequently as a secondary process today. Because of reservoir geologic heterogeneity and viscosity differences between reservoir oil and injected water, water flooding will lead to an early breakthrough of water and undesirable oil recovery. In other words, the injected water will tend to finger by the oil because of low viscosity of water comparing with oil and moves in non-uniform manner taking the shortest path to the production wells under high water-oil mobility ratio condition, so large amounts of oil are left behind, this is in turn will lead to use enhance oil recovery (EOR) [1-4]. EOR processes include the injection of:

- Liquid chemicals: polymers and surfactants.
- Gasses: hydrocarbon gasses, CO_2, nitrogen and flue gasses.
- Thermal energy: steam, hot water injection and in-situ generation of thermal energy through oil combustion in the reservoir rock.

Formation type, oil type, oil saturation, distribution and post operation, all these factors should be considered in the designation of an EOR process for a given reservoir.

In this research, the study will be about polymer flooding, one of the promising enhance oil recovery methods. It is simply a chemical dissolved in the injected water and because of polymer high molecular weight, small amount within several hundred ppm will give a significant increase in viscosity of injected water, as a result, it will give a better mobility ratio, reduce fingering effect and increase sweep efficiency [5]. An applicable polymer flooding process for a certain reservoir depends on several parameters, such as viscosity of displaced oil, oil saturation, polymer stability under reservoir conditions, reservoir geologic heterogeneity, spacing between injector and producer wells and polymer injection rates [6].

2. Materials and Methods

Materials used in the experimental work were as follows. Three types of partially hydrolyzed polyacrylamides with different molecular weight were used in the experiments: Flopaam5205VHM, Flopaam 5205 and super pusher SAV 37. These polymers were supplied by SNF Floerger as a white powder. Table.1 shows the properties of the three polymers.

Table.1 Properties of polymers used in the experiments

Polymer type	FP5205 VHM	FP 5205	SAV 37
Mw x 10^6 (gm/mol)	14-17	9-11.5	3-6
Salt Resistance (gm/l)	Up to 200	Up to 200	Up to 200
Temperature Resistance (ºC)	Up to 95	Up to 95	Up to 105
Anionicity	High	Medium	Low

A stock polymer solution of 5000 ppm was prepared by slowly adding the powder of polymer into brine solution of 190, 204 ppm salinity, where magnetic stirrer speed was set at 600 rpm to form a strong whirlpool. Because of high salinity of the brine solution, the polymer solution was kept to stir at 600 rpm for two hours, then the stirrer speed reduced slightly to 300 rpm and the polymer solution kept stirring for 22 hours to ensure that the all polymer powder is fully dissolved. The beaker was covered with an aluminum plate to prevent the contact of oxygen with polymer solution. The same brine solution was used to dilute the 5000 ppm polymer solution in order to get the desired concentration for each experiment. The viscosity of the polymer solution was measured using kinexus pro$^+$ Viscometer with 60mm, 2° cone plate.

Brine solution was used for dissolving and diluting the polymer solution, also used to saturate the synthetic core. The synthetic brine solution was made by dissolving 160 gm of pure NaCl and 40 gm of pure $CaCl_2$ in 1000 gm of fresh water, the solution was then filtered through 10-micron filter to remove impurities or non-dissolved solids. Table.2 shows the properties for the synthetic brine.

Table.2 Synthetic brine properties

Density (gm/cc)	1.125
Viscosity (cp)	1
TDS carbonates (ppm)	0
TDS Ca (ppm)	10 906
TDS (ppm)	190 204

The crude oil used in the experiments was provided by Al-Dura refinery (Baghdad, Iraq). Table.3 shows the physical properties of the crude oil measured at room temperature (25 ºC).

Table.3 crude oil physical properties

Sp.gr (gm/cc)	0.863
API	32.4
Viscosity (cp)	16

Fine glass beads with a diameter ranging from 45-120 micron were used to simulate the porous media. Table.4 shows the physical and chemical properties for the glass beads.

Table.4 physical and chemical properties for the glass beads

shape	Round
Color	Clear/White
Density	2.5 gm/cc
Free silica content	0 %
Chemistry	Soda-lime glass

The core flood system involved ***Syringe pump***, NE-1010 syringe pump was used to give constant flow rate for injection polymer solution, saturate the sandpack with synthetic brine and crude oil and inject solvent for cleaning the sand pack at the end of each test. It also included using ***Sandpack holder,*** a stainless steel sandpack holder with a length of 21 cm and a diameter of 3cm was used to contain the sandpack. Two 40 µm mesh screens were positioned on each side of the holder in order to contain the glass beads inside the holder during flow without distracting the passage of the fluids, an O-ring positioned between the stainless steel cover and the holder to ensure pressure seal.

A Digital pressure gauge (Model Crystal Pressure XP2i) was used to record the injection pressure at the inlet of the holder. The pressure gauge was set to record pressure for each 10 seconds. A clamp heater with maximum temperature of 300 ºC was used to heat the holder after cleaning the sandpack. A digital heat reader with a sensor was used, the sensor contacted the glass beads in a distance of about 0.5 cm in the middle of the holder in order to measure the inside temperature during the polymer flood test and also during sandpack cleaning. An electrical board was used to operate the pump, heater clamp and heat sensor. A separation cylinder was used to collect effluent samples during the tests.

Figure1 shows a schematic diagram of the experimental setup.

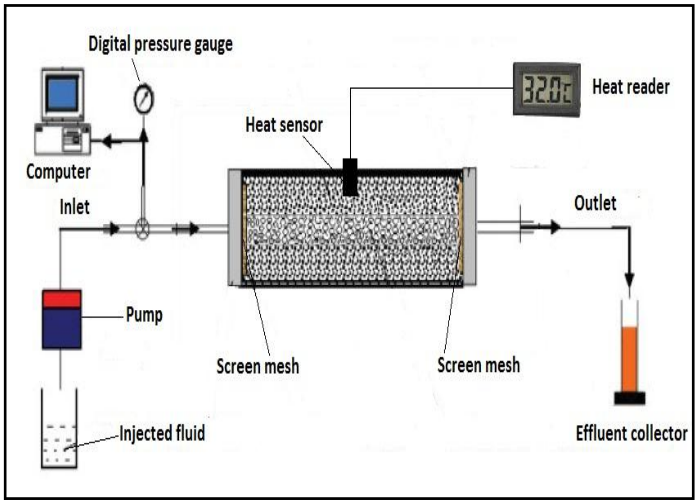

Figure .1 Experimental setup schematic

Fine glass beads with a diameter ranging from 45-120 micron were poured into the sandpack holder to simulate the porous media. The flooding experiments were directed as in the following procedure:

1. Saturate the sandpack with synthetic brine in order to determine pore volume and porosity using material balance method.
2. Inject brine into sandpack at variable rates in order to measure initial brine permeability using Darcy equation.
3. Flood the sandpack with oil at 2 PV to determine initial oil saturation (S_{oi}) and connate water saturation (S_{wc}). Volume of oil in place is equal to the volume of brine displaced by oil.
4. Using a syringe pump, inject 2 PV of polymer solution into the sandpack at a constant flow rate.

Figure 2 shows the system used in permeability measurement and for Sandpack flood tests.

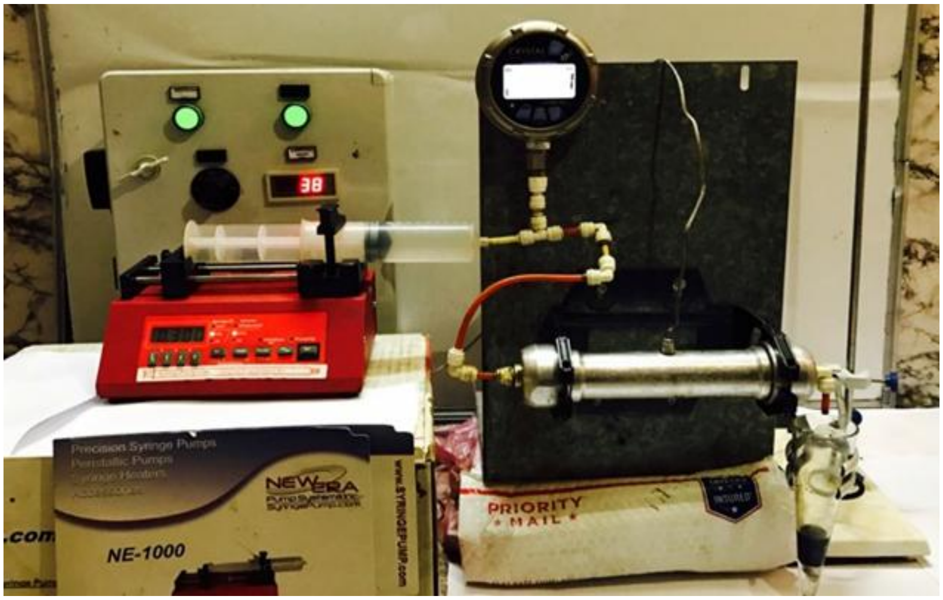

Figure. 2 System used in permeability measurement and Sandpack flood tests

3. Results and Discussion

A series of core flood experiments were conducted to show the effect of different parameter on the performance of the polymer flooding process under high salinity condition. Three types of polymers with different molecular weight were used. Different parameters such as polymer concentration, injection rate and the salinity of the dissolving brine were investigated in the sandpack flood experiments to show their effect on water cut and oil recovery. The results and discussions of the results are divided based on the goal of various sets of experiments and are presented below.

4.1 Effect of polymer concentration

Different polymer concentration ranging from 500 ppm to 3000 ppm was injected to investigate the effect of polymer concentration on water cut and oil recovery. According to the literature (Wu, 2010) [7], shear rates in most formations are between 0.01 and 10 s^{-1}. In this study, the polymer solution viscosity was measured under a shear rate of 7 s^{-1} at 25ºC. Table. 5 shows the viscosity for each concentration.

Table.5 Polymer Viscosity measured by Kinexus pro$^+$ viscometer

Polymer type	Polymer Concentration (ppm)	Viscosity at 7 s^{-1} (CP)
FP 5205	500	4.269
FP 5205 VHM	1000	8.942
FP 5205 VHM	1500	14.38
FP 5205 VHM	2000	21.22
FP 5205	3000	29.47
FP 5205 VHM	3000	52.54

Figure 3 simulates the oil recovery and water cut data for water and FP 5205 VHM polymer as a percent of pore volume injected.

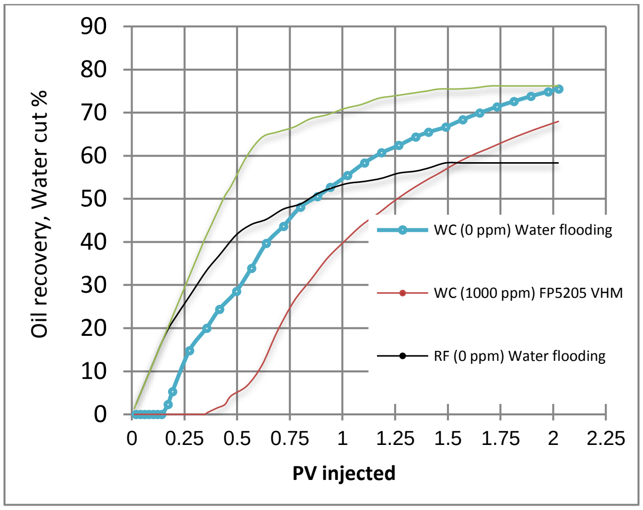

Figure.3 Oil recovery and water cut for water and polymer flood

From this figure, it can be seen that for water flooding, water breakthrough (W_{BT}) starts after injecting 17% PV and the oil recovery at breakthrough (BT) about 20% from the initial oil in place. Comparing the results with polymer flood, FP 5205 VHM at a concentration of 1000 pm gives oil recovery of about 46% at BT and BT starts after injecting about 40% PV which is more than the value obtained by water flooding. After injecting 0.5 PV the recovery and water cut for the water flooding case will be 41% and 28.5% respectively, while in polymer flood the recovery is about 52% and only 4% water cut is obtained. With continuous injection and after 1 PV, injected water gives a recovery of about 53% and water cut 55% while in polymer case, the recovery will be 70.9% and 40% water cut is obtained. It is clear that after 1.5 PV no additional recovery can be obtained and only water is produced.

Figure.3 also indicates the efficiency of polymer solution to displace oil at favorable mobility ratio and reduce fingering effect while in water flood the mobility of water injected is higher than that in polymer case because of low viscosity of water compared with oil displaced which in fact will lead to early breakthrough of water and high water cut with continuous injection of water.

Figures 4 and 5 show the relation between injected polymer concentration versus pore volume of porous media and oil recovery at which the water start to breakthrough. From Figure 4, it can be seen that in water flooding, the water will start to BT when only 17% of pore volume invaded by water, while when injecting polymer solution, more delay in water BT is achieved. This behavior illustrates the stability of polymer bank when displacing oil because of good mobility condition and as polymer concentration increased, the polymer mobility would be more less than the displaced oil and polymer would invade more pore volume leading to better volumetric sweep efficiency. In water flood, the mobility of water is higher than the displaced oil and the water would tend to finger by the oil and move in non-uniform manner, so more oil is left behind leading to bad sweep efficiency.

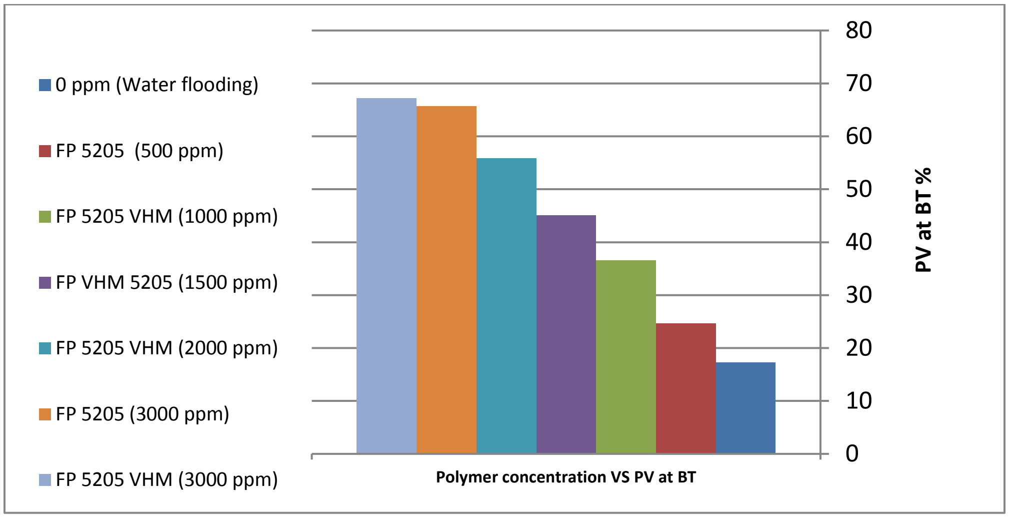

Figure.4 Water breakthrough for different polymer concentration

More delay in W_{BT} would improve also the recovery of oil, Figure 5 shows oil recovery data at W_{BT} for different polymer concentrations.

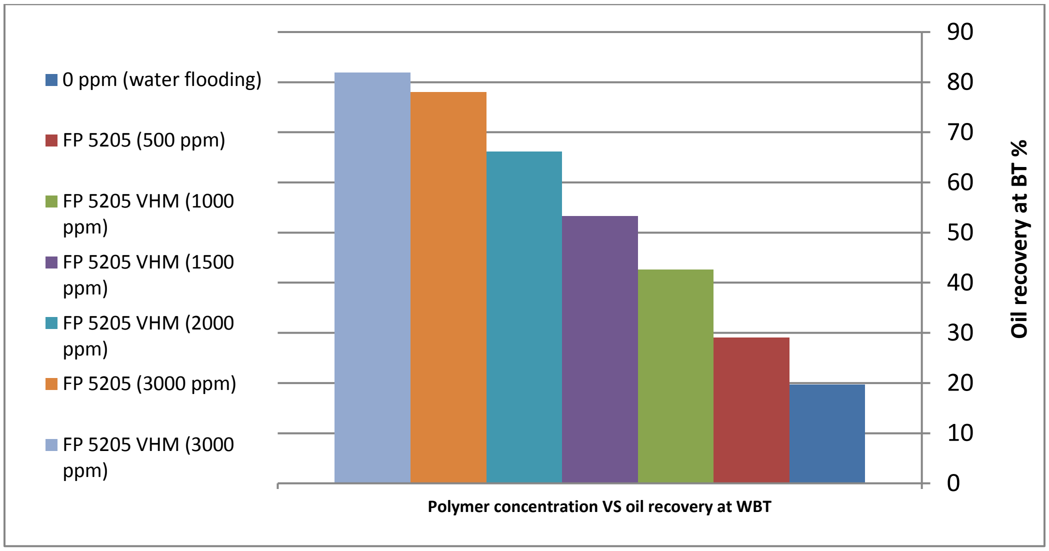

Figure.5 Oil recovery at W_{BT} for different polymer concentration

Figures 6 and 7 show oil recovery and water cut data as a percent of pore volume injected for water and different concentrations of polymer solution.

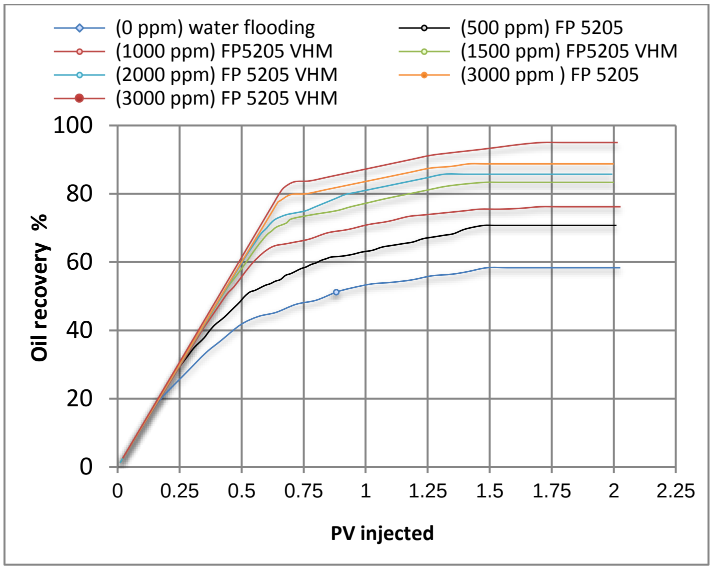

Figure.6 Oil recovery for different polymer concentration

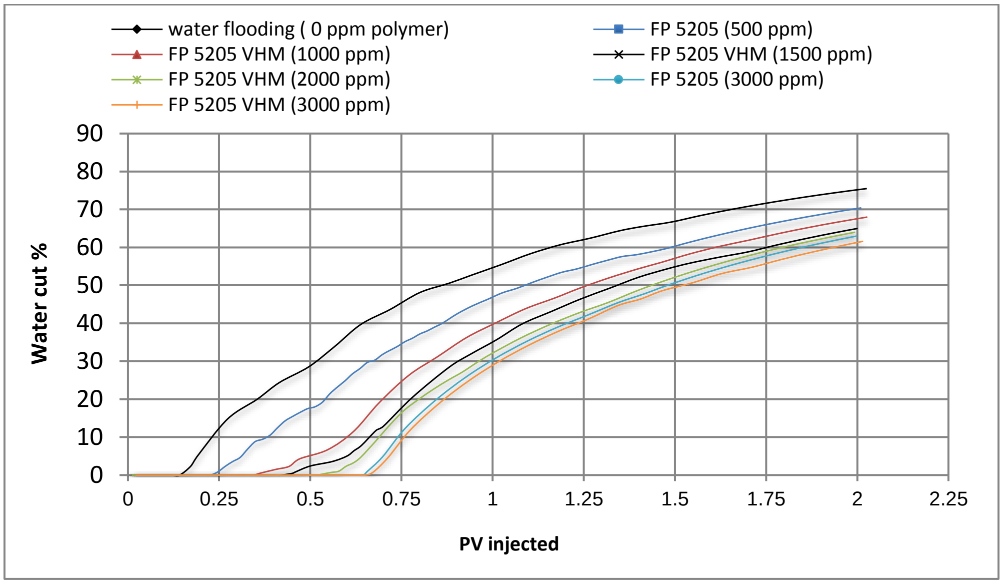

Figure.7 Water cut for different polymer concentration

The figures above show that lower water cut and high oil recovery result from the injection of higher polymer concentration, this is because higher polymer concentration improves mobility ratio and sweep efficiency, thus increasing oil recovery and reducing water cut.

Also the figures show that the higher polymer concentration requires less pore volume injected to reach the same recovery factor and water cut compared to the other concentration injected. For comparison, Yang Fulin[8] studied the effect of injecting high concentration polymer on oil recovery in core flood experiment, the results indicated that earlier injection of high viscosity HPAM can further improve oil recovery.

4.2 Molecular weight effect (M_w)

In order to show the effect of M_w, three polymers with different molecular weight were used, Table 6 shows the molecular weight and concentration for each polymer.

Table.6 Mw and concentration for the three polymers

Polymer	C (ppm)	Mwx106 (gm/mol)	Viscosity @ 7 s-1 (cp)
SAV 37	2000	3-6	12.14
FP 5205	1500	9-11.5	10.04
FP 5205 VHM	1000	14-17	8.942

From Figures 8 and 9 and after injecting two PV of polymer solution, it is clear that FP 5205 VHM which is a high molecular weight polymer with a concentration of 1000 ppm has almost the same recovery and water cut obtained for FP 5205 at a concentration of 1500 ppm (moderate M_w polymer) and also it is the same when using a higher concentration of 2000 ppm for SAV37 (low molecular weight polymer). This behavior is related to the high viscoelasticity of the high M_w polymer which acts to reduce mobility of injected polymer and increase sweep efficiency.

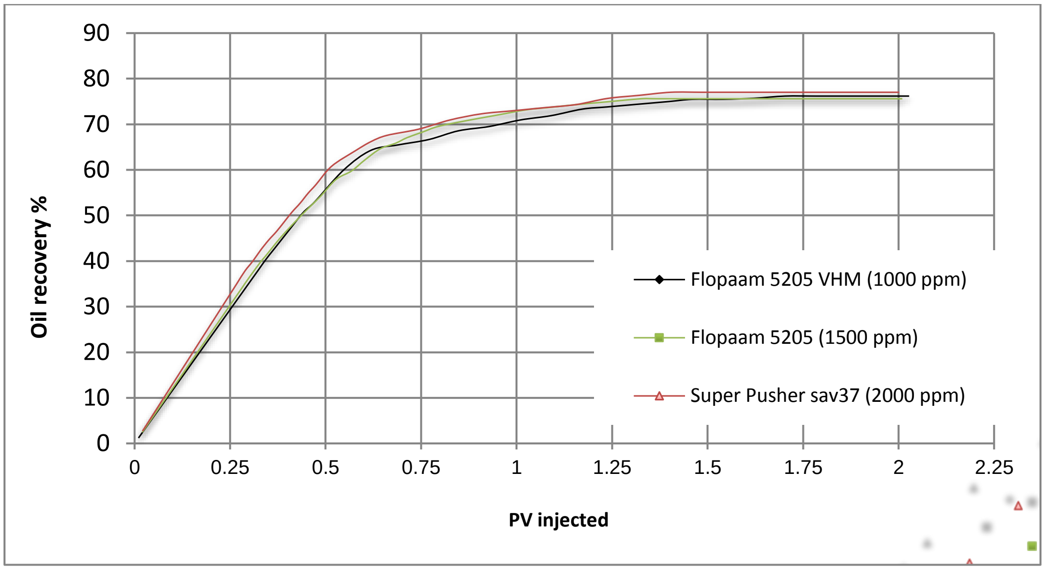

Figure.8 Oil recovery for different M_w polymers

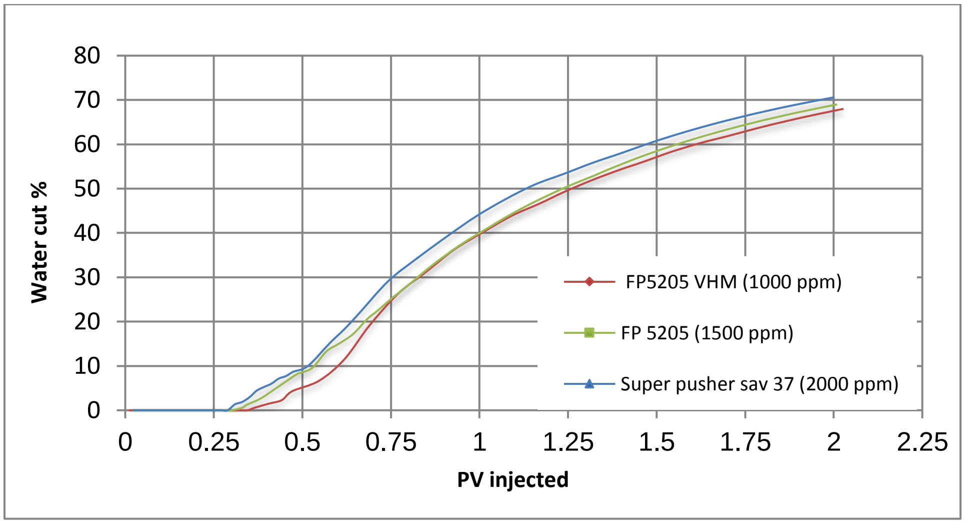

Figure.9 Water cut for different M_w polymers

4.3 Effect of mobility ratio

Figure 10 shows the relation between mobility ratio, oil recovery and water cut after injecting two pore volume of water and different concentrations of polymer solution, relative permeability for displacing and displaced fluid were neglected when measuring mobility ratio and only viscosity values were considered.

Figure.10 shows clearly that as the mobility ratio decreased, the oil recovery increased and water cut decreased and it is better to inject a polymer solution that will give a mobility ratio less than 1, as it becomes clear that as the viscosity of polymer increased, the mobility would decrease, this in turn would lead to high oil recovery and low water cut.

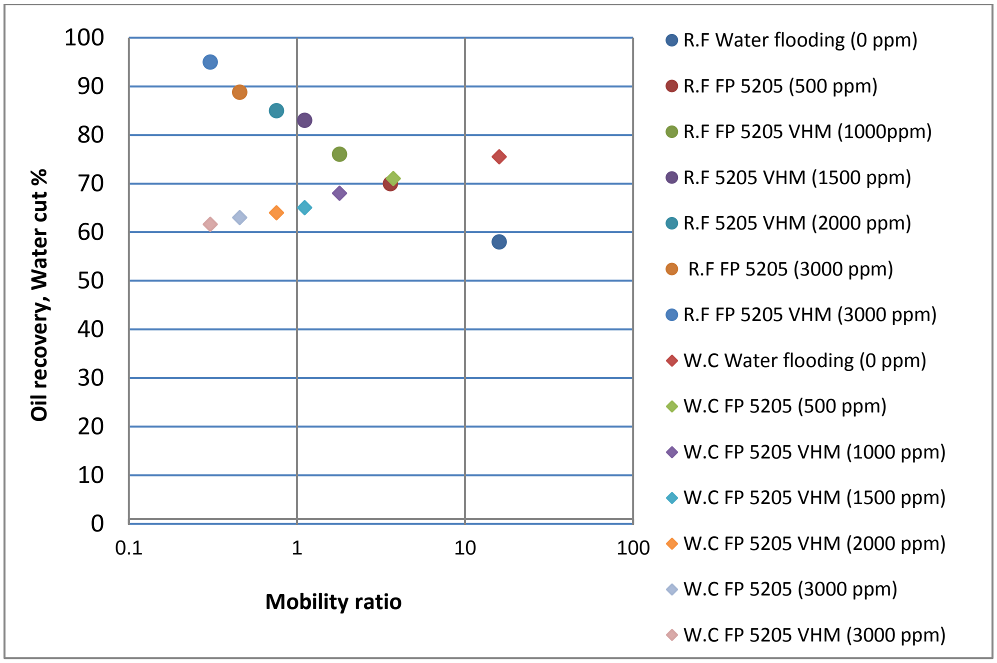

Figure.10 Mobility ratio effect on oil recovery

4.4 Effect of injection rate

Super Pusher SAV 37 with a concentration of 2000 ppm was injected at different rates, ranging from 0.3 to 0.95 cc/min, to simulate the influence of injection rate on oil recovery and water cut. Figure 11 shows the results of these experiments

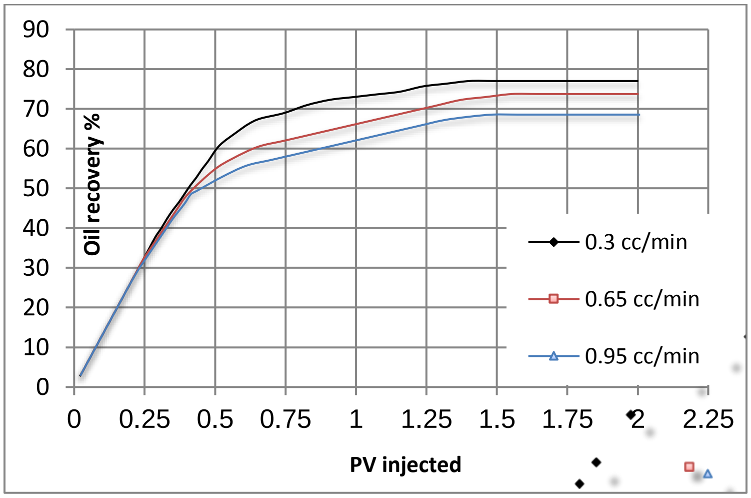

Figure.11 effect of injection rate on oil recovery

The results of these experiments show that oil recovery is higher at lower injection rates, regardless of the concentration of the polymer solution injected into the porous media. This behavior might be due to the more significant effect of viscous fingering at higher injection rates.

Figure 12 shows the effect of injection rate on oil recovery at BT. It is clear that as the injection rate increased, the recovery factor at BT decreased. This is due to fingering effects that cause a reduction in time of breakthrough. K. Asghari, 2008[9] studied the effect of polymer injection rate on oil recovery using unconsolidated sandpack, result showed that the higher injection rate leads to lower oil recovery.

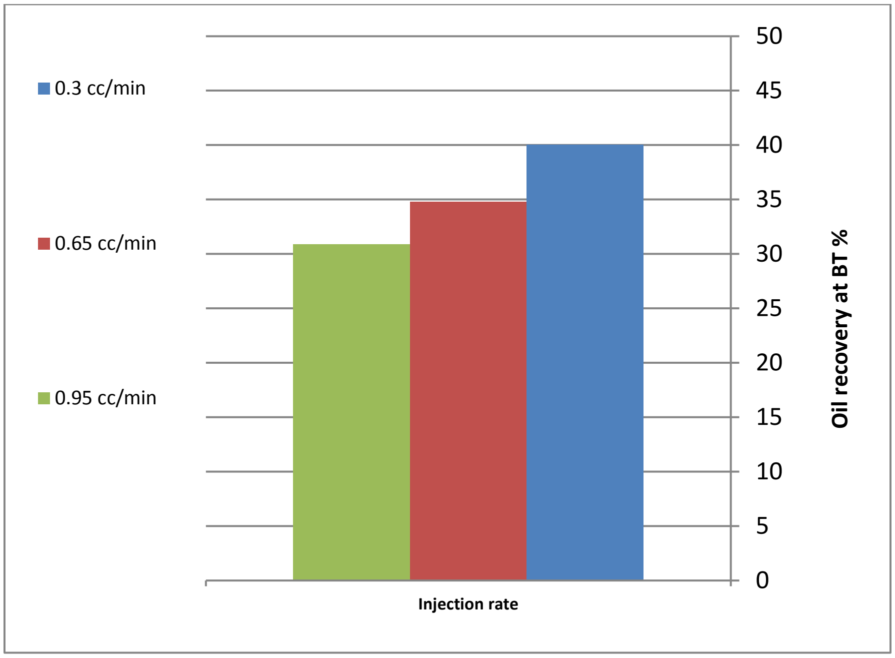

Figure.12 Effect of injection rate on oil recovery at BT

4.5 Effect of salinity

The viscosity of polymer solution decreased as the salinity of water increased. In order to proof that in sandpack flood experiment, SAV 37 polymer was dissolved in fresh water at a concentration of 1000, SAV 37 also dissolved in 200,000 ppm brine at a concentration of 2000 ppm. Figure 13 shows the result of these experiments.

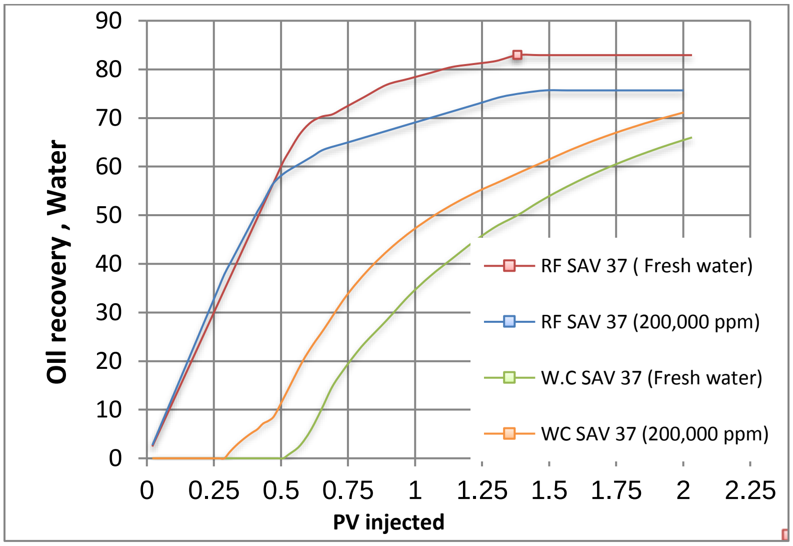

Figure.13 Oil recovery and water cut for polymer prepared in fresh water and brine

It is clear from Figure 13 that higher oil recovery with less water cut is obtained when using polymer solution prepared with fresh water, normally, this is because the viscosity of polymer solution prepared with fresh water is much more than that prepared with salt water and high viscosity leads to better mobility and sweep efficiency; however, reservoir mineralogy problems and cost treatment limit the use of fresh water. M. Algharaib[10] conducted a series of flooding experiments in order to determine the relationships between recovery factor and pre-flush brine salinity, results showed that injecting pre-flush at low salinity improved oil recovery.

4.6 Injection pressure

Figure 14 shows the injection pressure data for water and different concentrations of polymer solution recorded from pressure gauge readings as a function of time.

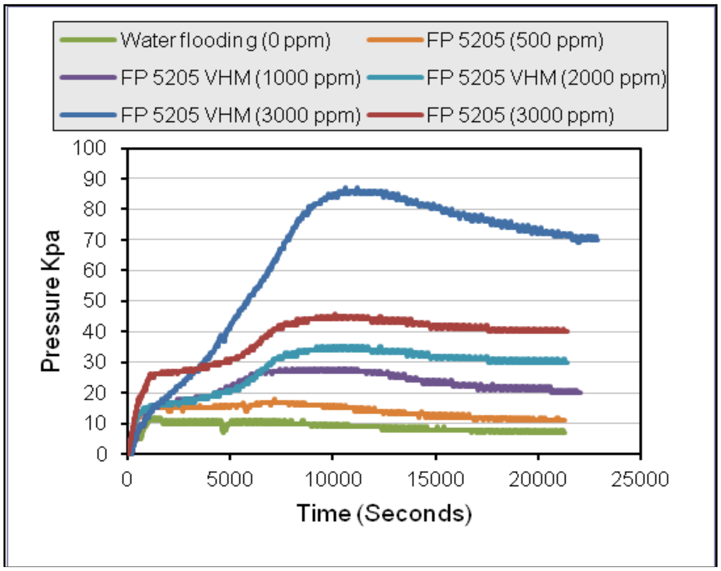

Figure.14 Injection pressures for water and different polymer concentration

It is clear from figure 14 that as the polymer concentration increased; the injection pressure would also increase. The high injection pressure indicates to the longer period of low water cut production because the polymer solution would contact large amount of oil and as the pressure increased more amount of oil can be recovered with low water cut while at water flooding the injection pressure is low compared to polymer flood, this is attributed to the sever fingering of water into the oil so the low amount of oil recovered compared to polymer flood.

Acknowledgements

The authors wish to thank the Petroleum Technology Department/ University of Technology, Baghdad/Iraq for facilitating this work.

5. Conclusions

In light of the previous discussion, the following conclusions are drawn:

(1) Comparing between water and polymer flood, water flooding will lead to early breakthrough of water, this is because the injected water will tend to finger by the oil because of low viscosity of water compared to oil and moves under high water-oil mobility ratio condition while in polymer flood and because of high viscosity of polymer compared to water, polymer solution will displace oil at favorable mobility ratio condition and the displacement efficiency will also increase and fingering effect reduced so more oil can be recovered with low water cut comparing to water flooding.

(2) As the polymer concentration increased more delay in water breakthrough can be achieved.

(3) Low water cut and high oil recovery resulted from the injection of higher polymer concentration, this is because higher polymer concentration improves mobility ratio and sweep efficiency, thus increases oil recovery and reduces water cut.
(4) Higher polymer concentration requires less pore volume injected to reach the same recovery factor and water cut compared to the other concentration injected.
(5) Higher M_w polymer has a higher viscoelasticity.
(6) As the mobility ratio decreased the oil recovery increased and water cut decreased and it is better to inject a polymer solution that would give a mobility ratio less than 1.
(7) Higher oil recovery and more delay in W_{BT} can be observed at lower injection rates, regardless of the concentration of the polymer solution injected into the porous media. This behavior might be due to the more significant effect of viscous fingering at higher injection rates.
(8) As the polymer concentration increased, the injection pressure would also increase. The high injection pressure indicates to the longer period of low water cut production because the polymer solution would contact large amount of oil and as the pressure increased more amount of oil can be recovered with low water cut while at water flooding the injection pressure was low compared to polymer flood, this is attributed to the sever fingering of water into the oil so low amount of oil recovered compared to polymer flood.

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