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The Effect of Polymer Additives on Oil Recovery In Conventional Waterflooding

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ABSTRACT

This paper discusses the results of a laboratory investigation utilizing water soluble polymer additives in conventional waterflooding. The investigation of polymerflooding was performed while a student at The University of Oklahoma. A conventional waterflood was conducted through each core utilizing a 50,000 ppm brine solution as the displacing medium. Also, a polymerflood was conducted through each core utilizing a 0.05 percent polymer solution as the displacing medium. The results of this investigation indicate that oil recovery at breakthrough and that ultimate oil recovery was increased when polymer solution was used as the displacing medium. Expressed as a percent of the original oil in place, the recovery at breakthrough ranged from 7.60 to 10.76 percent higher when compared with a conventional waterflood. Increased oil recovery after 2.5 pore volumes of fluid were injected ranged from 3.3 to 10.0 percent. It was concluded from this investigation that increased oil recovery was a result of the viscosity effect of the polymer additive.

References and illustrations at end of paper.

INTRODUCTION

It has been known for some time that certain water-soluble polymers thicken or increase the viscosity of water. Also, it is known in petroleum research that conventional waterflooding is often times not successful or very efficient, because the displacing medium, water, has a much lower viscosity than the displaced medium, oil. Therefore, water tends to seek a path of least resistance in the reservoir rock and bypasses large quantities of oil. If the viscosity of the displacing medium can be increased to some value approaching that of the oil, less bypassing or channeling of the flood water could be expected. That is, the mobility of the flood water would be decreased and a more piston-like displacement of the flood front could be anticipated.

In this investigation, a comparison of the following properties are made:

1. The viscosities of various polymer solutions.
2. The mobility ratio or water-oil rati of the flowing fluids in a conventional waterflood and a polymerflood.
3. The ultimate recovery in a conventional waterflood and a polymerflood.
4. The absolute permeability to water a to oil prior to and after a polymerflood.

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REVIEW OF PREVIOUS INVESTIGATION

There is a limited amount of published work in the area of polymerflooding; however, patents are available which give further insight into this area. Sandiford and Keller[1] used partially hydrolyzed acrylamide polymer additives in varying concentrations to displace a 2 cp and 207 cp oil from a core 1 inch in diameter and 2 inches long. They reported in all cases except one that an increased oil recovery at breakthrough and at the end of the flood resulted. McKennon[2] found that hydrolyzed polyacrylamide polymers characterized by a molecular weight of at least 500,000 and preferably 1,000,000 are desirable additives for waterflooding. He conducted a waterflood and a polymerflood through two different Berea cores with an air permeability of 250 md. McKennon found that the polymerflood oil recovery at breakthrough was 19.5 percent, expressed as a percent of original oil, higher when compared with a conventional waterflood. Also, he found that oil recovery was increased 27 percent after the fraction of water in the effluent stream reached 97 percent. Pye[3] and Sandiford[4] reported similar results at the Sixth Biennial Secondary Recovery Symposium in May, 1964, at Wichita Falls, Texas.

THEORETICAL CONSIDERATIONS

It is well established that the success of a waterflood is largely dependent upon the mobility ratio of the flowing fluids. The mobility ratio can be altered by changing the viscosity of the flowing fluids. The effect of a change in the viscosity of the flowing fluids can be seen from the development of the reduced Buckley-Leverett[5] fractional flow relationship as follows:

$$(1)\quad f_w = \frac{1}{1 + \frac{K_o}{K_w}\,\frac{U_w}{U_o}}$$

$$(2)\quad \frac{K_o}{K_w}\,\frac{U_w}{U_o} = \frac{1 - f_w}{f_w}$$

Let $f_w = 1 - f_o$ and $f_o = \dfrac{q_o}{q_o + q_w}$

Substituting and solving, mobility ratio is defined as follows:

$$(3)\quad \frac{K_w}{K_o}\,\frac{U_o}{U_w} = \frac{q_w}{q_o} = \text{WOR}$$

The assumptions in equation No. 3 are as follows:

(1) Gravity and capillary effects are negligible.

(2) Pressures in the oil and water phases are the same.

(3) Viscosity ratio is some fixed value.

It will be noted from Equation No. 3 that the producing water-oil ratio or mobility ratio is a function of the product of the effective permeability ratio of the flowing fluids and the viscosity ratio. Since the effective permeability is primarily a function of the fluid saturation in a core,[6] any change in the mobility ratio of the flowing fluids will be a result of a change in the viscosity ratio. A reduction in the water-oil ratio or mobility ratio at a particular saturation can be anticipated from an increase in the water viscosity or a decrease in the oil viscosity.

Aronofsky[7] found that the area sweep efficiency of a waterflood on a direct line drive pattern is dependent upon the mobility ratio of the flowing fluids. For mobility ratios expressed as the mobility of water to that of oil as in Equation No. 3, it was found that the area sweep efficiencies to breakthrough were 61.0 percent, 70.8 percent, and 86.6 percent for mobility ratios of 10, 1, and 0.10, respectively.

Dyes, Caudle, and Erickson[8] studied the effect of mobility ratios upon area sweep efficiency after breakthrough of the displacing medium. They investigated several different flood patterns and found that the mobility ratio has a greater effect on area sweep efficiency at breakthrough and at low fractions of water produced than at higher fractions of water produced. Therefore, a favorable change in the mobility ratio of the flowing fluids should result in a greater percent of the oil being recovered at lower fractions of water produced.

RESULTS OF LABORATORY INVESTIGATION

The viscosities of Separan NP10, NP20, MGL, and AP30 ionic polymer solutions were measured in ostwald viscometers at 25°C. These polymers were mixed with a 50,000 ppm brine solution in concentrations varying from 0.05 percent to 1.0 percent by weight. A comparison of the measured viscosities of these polymer solutions at various percent concentrations by weight is presented in Figure 1. The measured viscosities of the polymer solutions ranged as high as 171 cp at 1.0 percent concentration by weight and as low as 1.22 cp at 0.05 percent concentration by weight. It will be noted that the viscosities of NP10, NP20, and AP30 polymer solutions fell within a narrow range at higher concentrations; whereas the viscosity of MGL polymer solution was considerably lower at most concentrations.

The polymer solutions were stirred at varying rates and for different periods of time. It was found that the viscosity of

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these polymer solutions decreased as the rate of stirring and the period of stirring was increased. The measured viscosities of AP30 polymer solutions at different stirring conditions are presented in Fig. 2. From Fig. 2, the measured viscosity of a one percent AP30 polymer solution decreased from 165 cp to 71 cp when stirred at an increased rate and for a longer period of time. The reduction in viscosity suggests that the polymers degrade or lose their effectiveness as a water thickener when stirred at increasing rates and for a prolonged period of time.

A conventional waterflood and an AP30 polymerflood were conducted through three cores approximately 4 inches long and 1.5 inches in diameter. The absolute permeabilities of these cores ranged from 1242 md. to 118 md. The polymerflood solution consisted of 0.05 percent concentration of AP30 polymer added to a 50,000 ppm brine solution. Viscosity of the AP30 polymer solution was 1.75 cp as measured at 25°C. Polymerfloods were conducted by injecting from 0.6 to 2 porevolumes of polymer solution followed with a 50,000 ppm brine solution. Viscosity of the displaced medium, oil, was 71 cp as measured at 25°C. Properties of the cores and flood behavior are presented in Table 1. Also, graphs of the water-oil ratio and cumulative oil produced are presented in Fig. Nos. 3 through 8.

It will be noted in Fig. 3 that an increased oil recovery of 10.76 percent, expressed as a percent of original oil, was realized at breakthrough when polymer was added to the flood water. Two pore volumes of polymer solution were injected and followed with a brine solution. After 2.5 pore volumes of fluid were injected, oil recovery was 10.0 percent higher than the conventional waterflood recovery.

The absolute permeability to brine in Torpedo Core No. 1 was reduced from 617 md. to 298 md. or 52 percent as measured before and after the polymerflood; whereas, the absolute permeability to oil was reduced to 464 md. or 25 percent. As a result of the reduced permeability when polymer solution contacts the core, the required injection pressure is increased. The injection pressure during the polymerflood was approximately three times that of the conventional waterflood.

Results of flooding a very high permeability core, Torpedo Core No. 2, are presented in Fig. Nos. 5 and 6. A slug flood was conducted through this core and the Berea core, Fig. Nos. 7 and 8. In both cases, approximately 0.60 pore volume of polymer solution was followed with a 50,000 ppm brine solution. From Fig. 5, it can be seen that oil recovery from Torpedo Core No. 2 was higher than that for a conventional waterflood. Oil recovery at breakthrough was increased by 8.26 percent. After 2.5 pore volumes of fluid were injected, oil recovery was only 4.5 percent higher.

Absolute permeability to water, Torpedo Core No. 2, was reduced from 1242 md. to 692 md. or 44 percent as measured prior to and after polymerflooding. The absolute permeability to oil was reduced to 731 md. or 41 percent. As a result of the reduced permeability, the required injection pressure during the polymerflood was approximately 2.5 times greater than that of the conventional waterflood.

Fig. Nos. 7 and 8 present results from flooding a low permeability core. The Berea core is relatively clean and homogeneous in character; whereas, the Torpedo cores contain a high percentage of iron, limonite, and are less homogeneous in character.

An increased oil recovery of 7.60 percent at breakthrough resulted from polymerflooding the Berea core. However, an increase of only 3.3 percent was apparent after 2.5 pore volumes were injected.

After polymerflooding the Berea core, it was found that the absolute permeability to water had decreased from 118 md. to 4 md. or 96 percent; whereas, the measured permeability to oil remained constant at 118 md. Due to the reduced permeability, the required injection pressure during the polymerflood was approximately 3 times that of the conventional waterflood.

In all of the polymerfloods presented, there was a resultant increase in oil recovery at breakthrough and after several pore volumes of fluid were injected. The increased recovery at breakthrough ranged from 7.60 to 10.76 percent, and the increased recovery after 2.5 pore volumes injected or approximately a 75:1 water-oil ratio was 3.3 to 10 percent greater.

CONCLUSIONS

From the results of the laboratory investigation, the following conclusions were made:

1. The measured viscosity of Separan AP30 polymer solution decreased as the rate of stirring and the period of stirring were increased.
2. When AP30 polymer was added to the flood water, the mobility ratio or water-oil ratio of the flowing fluids decreased. This

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phenomena resulted in increased oil recovery from the polymerfloods at lower producing water-oil ratios when compared with that of a conventional waterflood.

3. A greater oil recovery at breakthrough resulted when AP30 polymer was added to the flood water. The increased recovery ranged from 7.60 to 10.76 percent, expressed as a percent of the original oil.

4. Cumulative oil recovery was increased when AP30 polymer was added to the flood water. Increased oil recovery after 2.5 pore volumes of fluid were injected ranged from 3.3 to 10 percent.

5. The absolute permeability of the cores was reduced in all cases. From this investigation, it was apparent that a greater reduction in permeability to water resulted.

The addition of polymer to the flood water suffices as a water thickener, and the oil to water viscosity ratio is reduced. It is believed that less fingering results and a more piston-like displacement of the flood front occurs. The increased oil recovery and the reduction in mobility ratio in the polymerfloods is attributed to the thickening effect of the polymer additive.

NOMENCLATURE

f_w = Fraction of water in effluent stream, dimensionless.
K_o = Effective permeability to oil, md.
K_w = Effective permeability to water, md.
q_o = Flow rate of oil phase, cc/sec.
q_w = Flow rate of water phase, cc/sec.
U_w = Viscosity of water phase, cp
U_o = Viscosity of oil phase, cp

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Table 1 - SUMMARY OF RESULTS

Description	Perm. Prior to Polymer-flood (md.)	Perm. After Polymer-flood (md.)	No. of Pore Volumes of AP30 Polymer Solution Inj.	Increased Recovery at Breakthrough (Percent)	Increased Recovery After 2.5 Pore Volumes Fluid Injected (Percent)
Torpedo Core No. 1	617	298	2.0	10.76	10.0
Torpedo Core No. 2	1242	629	0.62	8.26	4.5
Berea Core	118	4	0.60	7.60	3.3

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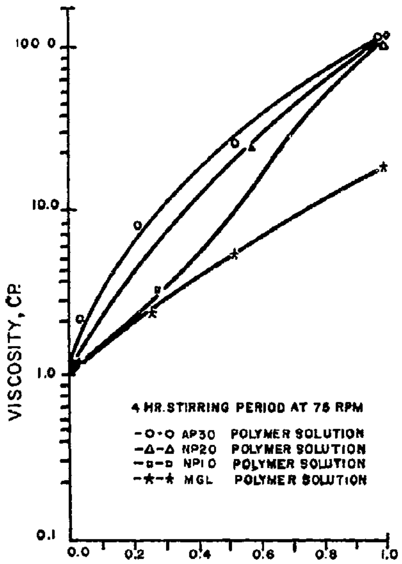

FIG. 1 - MEASURED VISCOSITY AT 25°c OF SEPARAN POLYMER SOLUTIONS VS. PERCENT CONCENTRATION BY WEIGHT

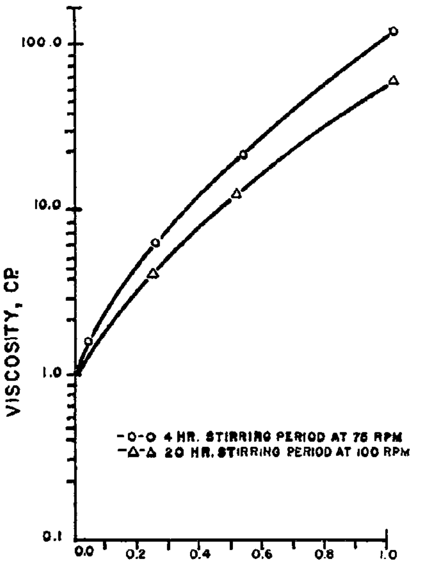

FIG. 2 - MEASURED VISCOSITY AT 25°c OF AP30 POLYMER SOLUTION VS. PERCENT CONCENTRATION BY WEIGHT

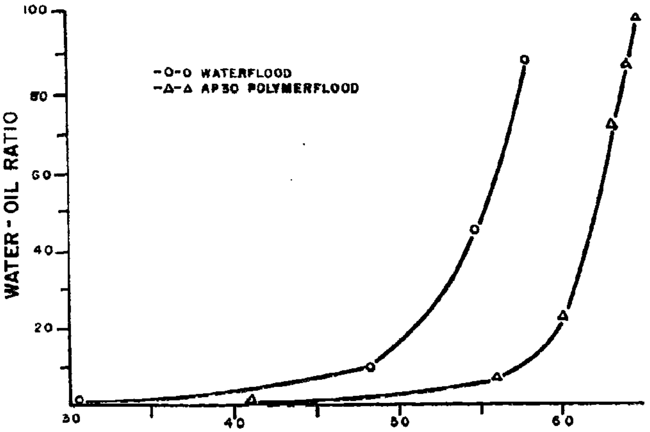

FIG. 3- WATER-OIL RATIO VS. CUMULATIVE OIL PRODUCED (TORPEDO CORE NO. 1)

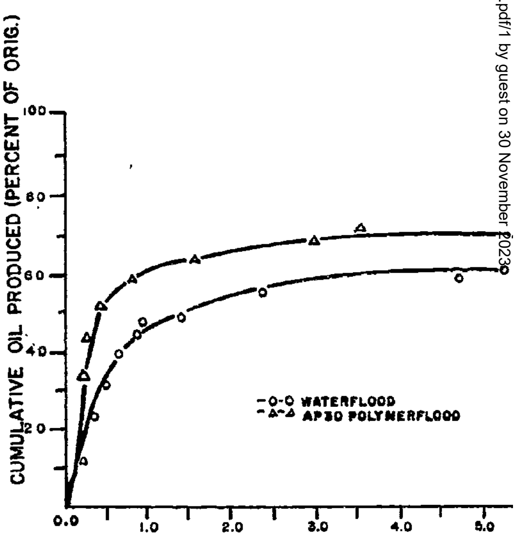

FIG. 4 - CUMULATIVE OIL PRODUCED VS. NUMBER OF PORE VOLUMES INJECTED (TORPEDO CORE NO. 1)

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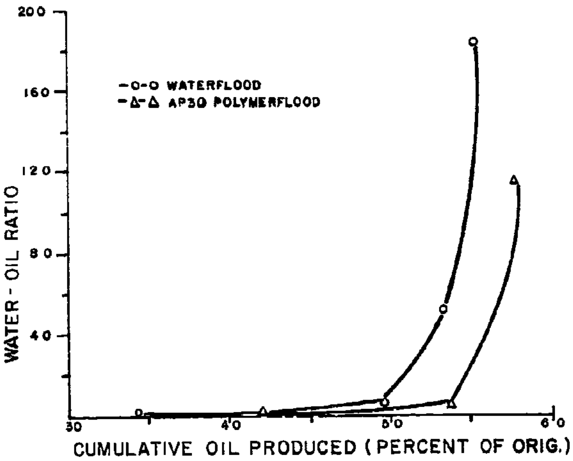

FIG. 5 - WATER-OIL RATIO VS. CUMULATIVE OIL PRODUCED (TORPEDO CORE NO. 2)

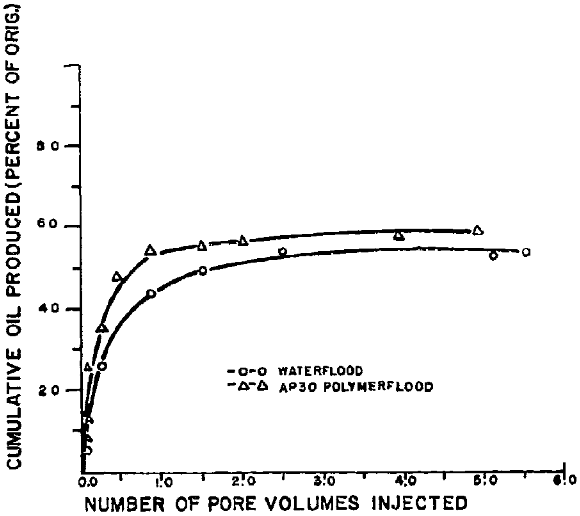

FIG. 6 - CUMULATIVE OIL PRODUCED VS NUMBER PORE VOLUMES INJECTED (TORPEDO CORE NO. 2)

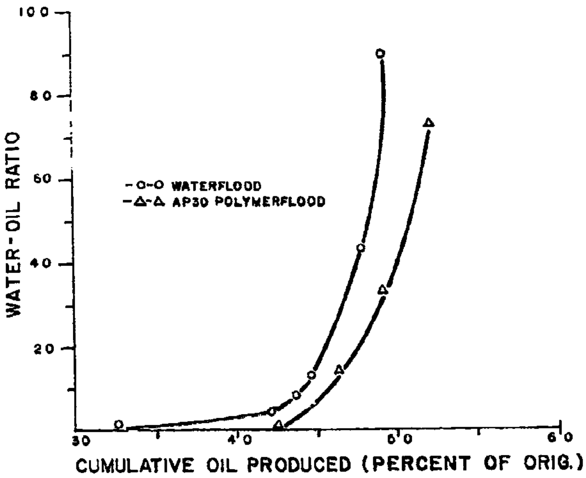

FIG. 7 - WATER-OIL RATIO VS. CUMULATIVE OIL PRODUCED (BEREA CORE)

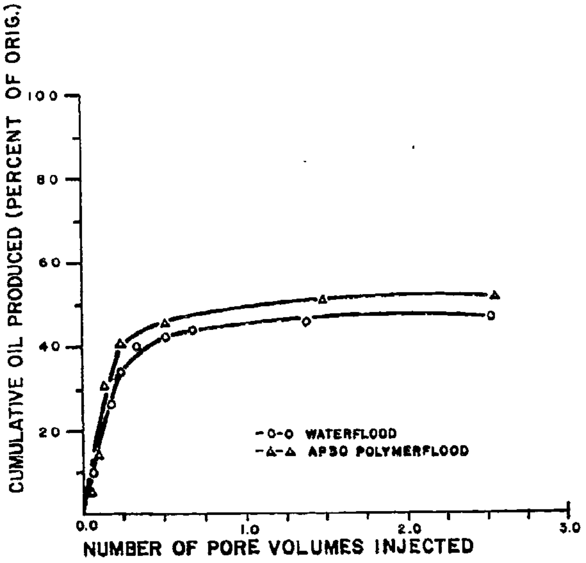

FIG. 8 - CUMULATIVE OIL PRODUCED VS. NUMBER OF PORE VOLUMES INJECTED (BEREA CORE)

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