THE EFFECT OF SALINITY ON POLYMER SELECTION AND OIL RECOVERY BY POLYMER FLOODING

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Dedicated to:

My beloved parents, wife and children.

To all my friends who have always support me.

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ABSTRACT

Polymer flooding is one of the most promising EOR methods and has frequently been applied in EOR operations. In this process, water-soluble polymers increase the viscosity of the flood water and thus improve the water / oil mobility ratio. The incremental oil production is a result of improved vertical and areal sweep efficiency. The effect salinity on polymer solution viscosity determination and selection of suitable and optimum polymer type and concentration for different brine concentration present in the reservoir is important for polymer flooding success. In this work, cores were designed and developed and considered as pores medium. These cores were saturated with light and low-viscosity oil samples from Malaysian crude oil and then flooded by 0.4 PV polymer slug in low-pressure and low-temperature conditions. In this study the effect of two polymer types, polyacrylamide and xanthan, were utilized to inspect the effects of polymer type, concentration and salinity on polymer solution viscosity. The result of the optimum polymer type and concentration was used to make the polymer flooding using core saturated with four different brine concentration of $CaCl_2$ (5000, 15000, 25000, and 45000 ppm).The results of experiments illustrated that the salinity effects on polyacrylamide viscosity is more comparing to xanthan gum and concentration of 1500 ppm xanthan gum is most suitable for good polymer flooding with favourable mobility ratio. The study shows that polymer flooding with low salinity brine is more beneficial compare to high saline. Finally, compared with waterflooding, polymer flooding resulted in a considerable growth in ultimate oil recovery.

ABSTRAK

Kaedah pembanjiran polimer adalah satu kaedah yang berkesan dan sering digunakan dalam operasi EOR. Dalam operasi EOR, polimer larut air dapat meningkatkan kelikatan air dan menambah-baik mobiliti nisbah air/minyak. Peningkatan Pengeluaran minyak ialah hasil daripada pembaikan tegak dan kecekapan areal sapu. kesan Kemasinan pada penentuan kelikatan larutan polimer dan pemilihan jenis polimer yang sesuai dan optimum dan penumpuan untuk air masin yang berbeza kepekatan di dalam takungan penting untuk kejaygan polimer kebanjiran. Dalam tugas ini, teras - teras telah direka bentuk dan dibangunkan dan dianggap sebagai media yang berliang. Teras – teras ini ditepukan dengan cahaya dan sampel minyak kelikatan rendah dari minyak mentah Malaysia dan kemudian dibanjiri oleh 0.4 PV polimer pata keadaan tekanan dan suhu rendah. Dalam kajian ini kesan dua jenis polimer, poliakrilamida dan xantan, digunakan untuk memeriksa kesan jenis polimer, tumpuan dan kemasinan pada kelikatan larutan polimer. Keputusan jenis dan tumpuan polimer yang optimum digunakan untuk membuat pembanjiran polimer menggunakan teras tepu dengan empat air masin berbeza kepekatan $CaCl_2$ (5000, 15000, 25000 , dan 45000 ppm).Keputusan eksperimen menjelaskan bahawa kesan kemasinan pada kelikatan poliakrilamida adalah lebih banyak berbanding dengan gam xantan dan kepekatan 1500 ppm gam xantan paling sesuai untuk pembanjiran polimer dengan nisbah mobiliti yans baik. Kajian menunjukkan pembanjiran polimer dengan kemasinan rendah air masin lebih bermanfaat berbanding dengan masin yang tinggi. Akhirnya, dibandingkan dengan pembanjiran, pembanjiran polimer menghgaikan satu pertumbuhan yang besar pemulihan minyak muktamad.

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LIST OF ABBREVIATIONS

API	-	American Petroleum Institute
ASTM	-	American society for testing and materials
$CaCl_2$	-	Calcium Chloride
CMC	-	Carboxyl methyl cellulose
CMHEC	-	Carboxymethyl Hydroxyethyl Cellulose
CO_2	-	Carbon Dioxide
CSE	-	Cellulos sulphate esters
EOR	-	Enhanced Oil Recovery
FR	-	Resistance Factor
FRR	-	Residual Resistance Factor
HC	-	Hydrocarbon
HCPV	-	Hydrocarbon Pore Volume
HEC	-	Hydroxyethylcellulose
HPAM	-	Hydrolyzed Polyacrylamide
IFT	-	Interfacial Tension
IOR	-	Improved Oil Recovery
IUPAC	-	International Union of Pure and Applied Chemistry
KCL	-	Potassium Chloride
KOH	-	Potassium hydroxide
MW	-	Molecular weight
NaCl	-	Sodium Chloride
NaOH	-	Sodium Hydroxide
OOIP	-	Original Oil in Place
PAM	-	Polyacrylamide
PHPAM	-	Partially Hydrolyzed Polyacrylamide

ppm	-	Part per million
PV	-	Pore Volume
PVP	-	Polyvinylpyrrolidones
SG	-	Specific Gravity
SPE	-	Society of Petroleum Engineering
TDS	-	Total Dissolved Solids
XC	-	Xanthan Gum Biopolymer

LIST OF SYMBOLS

A	-	Area
Q	-	Flow rate
T	-	Time
R	-	Radius
D	-	Diameter
V	-	Volume
V_b	-	Bulk Volume
V_p	-	Pore Volume
K	-	Permeability
K_{ro}	-	Oil Relative Permeability
K_{rw}	-	Water Relative Permeability
L	-	Length
S_{or}	-	Residual Oil Saturation
S_{wi}	-	Residual Water Saturation
S_{oi}	-	Initial Oil Saturation
S_{wc}	-	Connate Water Saturation
μ	-	Viscosity
P	-	Pressure
Ø	-	Porosity
M_p	-	Polymer Mobility
M_{w-o}	-	Water Oil Mobility Ratio
K_p	-	Polymer Permeability
K_w	-	Water Permeability
M_w	-	Water Mobility
M_o	-	Oil Mobility

μ_p	-	Polymer Viscosity
μ_w	-	Water Viscosity
τ	-	Degree of Hydrolysis
F_r	-	Resistance factor
F_{rr}	-	Residual resistance factor
λ_w	-	Water Mobility
f_o	-	Fractional Flow

LIST OF SYMBOLS

A	-	Area
Q	-	Flow rate
T	-	Time
R	-	Radius
D	-	Diameter
V	-	Volume
V_b	-	Bulk Volume
V_p	-	Pore Volume
K	-	Permeability
K_{ro}	-	Oil Relative Permeability
K_{rw}	-	Water Relative Permeability
L	-	Length
S_{or}	-	Residual Oil Saturation
S_{wi}	-	Residual Water Saturation
S_{oi}	-	Initial Oil Saturation
S_{wc}	-	Connate Water Saturation
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M_{w-o}	-	Water Oil Mobility Ratio
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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Enhanced oil recovery is generally considered as the third, or last phase of useful oil production, sometimes called tertiary production. The first, or primary, phase of oil production begins with the discovery of an oilfield using the natural stored energy to move the oil to the wells by expansion of volatile components and/or pumping of individual wells to assist the natural drive. When this energy is depleted, production declines and a secondary phase of oil production begin when supplemental energy is added to the reservoir by injection of water. As the water to oil production ratio of the field approaches an economic limit of operation, when the net profit diminishes because the difference between the value or the produced oil and the cost of water treatment and injection becomes too narrow, the tertiary period of production begins.

Up to 80 % of the original oil in place is typically left behind in the reservoir after primary oil recovery. Primary oil recovery uses the energy of the reservoir to produce oil. Examples of primary oil recovery include natural flow and artificial lift. Secondary oil recovery strives to recover more of what’s left behind of primary oil recovery. Secondary oil recovery involves pressure maintenance of the reservoir for addition oil recovery. Water flood and gas injection are examples of secondary oil recovery. Primary and secondary recovery methods are considered conventional oil recovery.

Enhanced oil recovery is a process that recovers oil not produced by conventional primary and secondary methods. The goal of enhanced oil recovery is to improve sweep efficiency in the reservoir by the injection of artificial materials in order to reduce the remaining oil saturation. Enhanced oil recovery processes target trapped oil in the flooded areas by capillary forces, also known as, residual oil. Oil in areas not flooded by the injected fluid, or bypassed oil, is also targeted by enhanced oil recovery processes.

One of the big challenges that engineers face with water flooding is related to water's tendency to travel very quickly through the reservoir. Because water has such a high mobility, it tends to by-pass large volumes of oil, and "break-through," to the producing well before adequately sweeping the reservoir (Green and Willhite 1998). This problematic characteristic of water flooding ultimately results in only part of the reservoir being contacted for a realistic time frame and injection scheme. Additionally, reservoir heterogeneities will exacerbate the injected water's tendency to only mobilize the oil that resides in high permeability conduits rather than contacting the whole reservoir (Green and Willhite 1998).

When designing a successful pressure maintenance operation, it is not just the mobility of the displacing phase that is important, the relationship between the behaviours of the displacing and displaced phases are also important. The ratio of the oil mobility and water mobility can be used to gain a general understanding about the efficiency of an injection operation. With regards to the phase mobility values, the optimal sweep efficiency occurs when the mobility of the displacing phase is less than or equal to the mobility of the displaced phase. The required reduction in the mobility of the injected phase can be achieved by increasing the viscosity of the injected phase. Undesirable behaviours such as fluid fingering and frontal instabilities can be dampened by adding polymer molecules to the injected phase which cause a decrease in the fluid mobility. Thus far, polymer flooding has been described as an effective pressure maintenance and mobility control process when used on its own, but it also has been found to be successful in conjunction with other processes that require mobility control such as CO2 injection (Green and Willhite 1998).

Polymer is an enhanced oil recovery process that recovers the mobile oil that has been bypassed by earlier water-flooding or an aquifer intrusion, due to reservoir heterogeneity. And due to reservoir heterogeneity, the injected fluids will most likely take the path of the highest permeability, also known as a thief zone. Polymer works to combat reservoir heterogeneity, or thief zones, by filling the higher permeability zones with viscous polymer. This way, the injected fluids can achieve a more uniform sweep. This more uniform sweep will help prevent fast break-through that is detrimental to oil recovery.

Polymer flooding is one of the most promising EOR processes in many reservoirs because of its lower cost. In order to ensure favorable flood, polymer are used to reduce mobility ratio between water and oil. The polymer basically increases the viscosity of the injected water and reduces the porous media permeability, allowing for an increase in the vertical and areal sweep efficiency of the injected water and consequently, increases the oil recovery. Generally, there are two commonly used polymers in EOR applications which are the synthetic material, polyacrylamide in its partially hydrolyzed form (HPAM) and the biopolymer, xanthan.

Injection of a polymer solution to increase fluid viscosity, to aid in displacement of the chemicals through the reservoir and to minimize loss due to dilution and channelling. Finally, the salinity of the injected water following injection of the polymer is gradually increased to the normal concentration of the oilfield fluids.

The objective of polymer flooding is to control water mobility inside the reservoir to favour higher oil recovery. Several design parameters are critical for the success or failure of polymer flooding applications. The salinity of formation water is one of the parameters which impose a limitation on polymer flood applicability.

Even though the cost of operating a polymer flood is relatively inexpensive compared to other forms of enhanced and improved oil recovery, it is still an expensive endeavour and has therefore warranted attention from researchers. The purpose of studying these fluids is to develop an understanding of their intricate behaviours which can then be used for practical field applications.

1.2 Polymer Flooding

On average, primary recovery leaves behind most of the oil in the reservoirs. The recovery for heavy oil reservoirs is usually less than 10%. Heavy oil is oil with high density (10 – 20 °API) and high viscosity (greater than 100 cP). There are estimated 3,396 billion barrels of heavy oil resources worldwide (Chang et al., 2011). High demand for oil and the scarcity of light oil has increased the incentive to recover more heavy oil. One way to retrieve more oil out of the reservoir is to improve the mobility ratio. Mobility ratio describes the mobility relationship between the displacing phase and the displaced phase. When mobility ratio is greater than 1, the displacing phase is likely to cause unstable displacement and fingering. When mobility ratio is less than 1, the displacement is likely to be stable. If polymer is added to the displacing phase to increase its viscosity, mobility ratio decreases. M, k, and μ represent the mobility ratio, permeability, and viscosity respectively.

$$M = \frac{(K/\mu)\text{Displacing fluid}}{(k/\mu)\text{Displaced fluid}} \qquad (1.1)$$

Where k is the effective permeability and μ is the viscosity.

1.3 Polymers

The chemicals improve the mobility ratio of the process by changing the properties of the water (polymers).

Polymers are used in water flooding to reduce the mobility of the water and thus improve its displacement efficiency. The reduction in mobility is caused by both an increase in the water viscosity and a decrease in the permeability to water. Reduced driving phase mobility results in improvements in the areal and vertical sweep efficiencies.

With the advent of the less expensive synthetic organic polymers, polymer flooding became a reality. Polyacrylamides and xanthan gum are the most common of polymers being used. The polyacrylamides are sometimes partially hydrolyzed; which further increases their molecular weight. Polymer flooding is best suited for reservoirs in which water sweep efficiency is very low owing to an unfavourable mobility ratio (e.g., because of low crude oil gravity) or wide permeability variations.

1.4 Polymer Products and Theory of use

Polymer is a chemical that is compound of a number of individual molecules that are attached in some manner. These units are usually associated in a pattern that repeats itself throughout the length of each polymer. The repeating units are called monomers and the polymer can be homopolymer (One monomer), a dimer (two monomer), etc. Another common term used in polymer chemistry to represent the joining of two different monomer is copolymer(Donaldson et al. 1989).

One published definition to differentiate a large molecule from a polymer is that a polymer should have a molecular weight greater than 200 and at least 8 or more repeating units (Clark and Hoffman 1984).

Polymer flooding operations use high molecular-weight organic chemicals to alter the flow of water in the formation. Molecular weights of flooding polymer may be as high as several millions. These large molecules are soluble in water because of hydrogen bonding between water molecules and the polymer's polar side chains.

1.5 Problem Statement

The increase in recovery is mainly the result of increasing the volume of the reservoir swept. The best method to plan and calculate fluid flow within the reservoir is experiments and numerical simulation.

The brine that saturates the pores of a reservoir besides the oil itself is one of the most important parameters for the selection of a suitable polymer. If the reservoir water is of high salinity the polymer should be salt stable or the reservoir must be reconditioned by a preflush of fresh water.

1.6 Objectives

The study aims to revise the benefits of using polymer for enhancing the recovery. Main specific objectives can be summarized as:

1. Select a suitable polymer solution that can help in control water mobility inside the reservoir to favour higher oil recovery in conditions of particular brine salinity with respect to salinity tolerance.

2. To use the selected polymer type solution and with specific concentration in coreflood experiments with different brine salinities to study the recovery factor

of polymer flooding and to see the effect of different brine salinity ($CaCl_2$ solutions) on polymer flooding efficiency, to evaluate the role of polymer for improving the sweep efficiency over waterflooding in an environment of high salinity $CaCl_2$ brine.

1.7 Scope of Work

In this study the effect of salinity on the viscosity of two polymer types, polyacrylamide and xanthan, were utilized to inspect the effects of polymer type, concentration on polymer solution viscosity.

In order to select to a polymer solution 70 samples has been prepared and tested for seven brine salinity (2500, 5000, 10000, 15000, 2000, 25000, and 35000 ppm) of $CaCl_2$ brine solution which prepared and test for two types of polymer together with five different concentration of the two polymers (500, 1000, 1500, 2000 and 2500 ppm). The material used is polyacrylamide and xanthan gum as polymers. The result of the optimum polymer type and concentration was used to make the polymer flooding using core saturated with four different brine concentration of $Cacl_2$ (5000, 15000, 25000, and 45000 ppm). Polymer solutions were mixed with brine solution using magnetic stirrer. Viscosities measured using Brookfield viscometer. Cores were designed and developed and considered as pores medium. Sand pack size between 250 -355 μm used as porous media to represent the reservoir, the sand pack made of glass pipe with dimensions length 30.5 cm diameter 4.7 cm. These cores were saturated with light and low-viscosity oil samples from Malaysian crude and then flooded by 0.4 pore volume polymer slug in low-pressure and room temperature conditions.

1.8 Assumptions

The laboratory investigations for polymer solutions were sufficient to determine their compatibility for field application. Core experiments can reasonably simulate the behaviour of xanthan gum solution under field conditions.

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