THE EFFECTS OF SYNERGY BETWEEN XANTHAN GUM AND SILICA OXIDE NANOPARTICLE ON OIL RECOVERY FACTOR

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ABSTRACT

The oil production has kept depleting due to several factors including the limitations of the conventional methods to recover the oil. This leads to the first problem statement on how to overcome the limitations of typical polymer flooding. Recently, nanoparticles have gained attention for their potential in accessing pores restricted for typical methods and lower down interfacial tension (IFT), which generate a stable emulsion as well as wettability alteration. Besides, the performance of Xanthan Gum (XG) in polymer flooding to enhance the oil recovery is believed to be improved with the presence of Silica Oxide (SiO_2) nanoparticles. However, the effect of this synergy injection on the oil recovery has to be studied. Therefore, the objectives of this study are to evaluate the capability of the synergised XG and SiO_2 nanoparticles solutions to improve the solution viscosity, IFT reduction and to analyse the effectiveness of the synergy on recovery factor improvement. The samples were being prepared with 4000 ppm XG and five different concentrations of SiO_2 nanoparticles (1000, 3000, 5000, 7000 and 9000 ppm). The samples were tested for viscosity and IFT reduction to determine the optimum concentration of the synergized solution. Lastly, the flooding test was conducted by using a sand pack to measure the oil recovery factors when different slug ratios of the polymer and brine were injected. All tests were conducted at 27°C. Based on the results obtained, the viscosity of the solution is increased with the increasing SiO_2 concentrations. The viscosity of the solution is increased from 27.185 up to 145.87 cp when 9000 ppm SiO_2 nanoparticles were added. The synergy has shown the IFT reduction from 75.5 mN/m to 55 mN/m with the increasing concentrations of the SiO_2 added into polymer solution. Thus, 4000 ppm of XG synergised with 3000 ppm SiO_2 nanoparticles was chosen as the optimum concentration as the IFT reduction is achieved and can be correlated with the viscosity result. There is only a slight viscosity difference is observed when 5000 ppm SiO_2 nanoparticles were added as compared to 3000 ppm SiO_2 nanoparticles. The oil recovery was increased from 27.5% to 56% by using 4000 ppm XG while, the oil recovery was increased to 57.5% by using the synergized solution with similar slug ratio. The maximum oil recovery was 66.3% by using optimum synergized solution with the highest slug ratio of 50:50 polymer flooding to water slug. In conclusion, these results have proven that SiO_2 nanoparticle is able to helps polymer flooding to improve both sweep and displacement efficiency by viscosity increment and IFT reduction in order to increase the oil recovery.

ABSTRAK

Pengeluaran minyak telah disimpan semakin berkurangan disebabkan oleh beberapa faktor termasuk batasan kaedah konvensional untuk mendapatkan semula minyak. Ini membawa kepada pernyataan masalah yang pertama mengenai cara untuk mengatasi batasan polimer banjir biasa. Baru-baru ini, nanopartikel telah mendapat perhatian untuk potensi mereka dalam mengakses liang terhad untuk kaedah yang biasa dan menurunkan ketegangan antara muka (IFT), yang menghasilkan kestabilan emulsi serta pengubahan kebolehbasahan. Selain itu, prestasi Xanthan Gum (XG) dalam polimer banjir untuk meningkatkan pemulihan minyak itu dipercayai dipertingkatkan dengan kehadiran silika oksida (SiO_2) nanopartikel. Walau bagaimanapun, kesan suntikan sinergi ini kepada pemulihan minyak perlu dikaji. Oleh itu, objektif kajian ini adalah untuk menilai keupayaan XG dan SiO_2 nanopartikel penyelesaian bersinergi untuk meningkatkan kelikatan penyelesaian, pengurangan IFT dan untuk menganalisis keberkesanan sinergi pada peningkatan faktor pemulihan. Sampel disediakan dengan 4000 ppm XG dan lima kepekatan yang berbeza nanopartikel SiO_2 (1000, 3000, 5000, 7000 dan 9000 ppm). Sampel telah diuji untuk kelikatan dan pengurangan IFT untuk menentukan kepekatan optimum penyelesaian disinergikan. Akhir sekali, ujian banjir telah dijalankan dengan menggunakan pek pasir untuk mengukur faktor pemulihan minyak apabila nisbah slug berbeza daripada polimer dan air garam telah disuntik. Semua ujian telah dijalankan pada 27°C. Berdasarkan keputusan yang diperolehi, kelikatan penyelesaian meningkat dengan kepekatan SiO_2 yang semakin meningkat. sinergi telah menunjukkan pengurangan IFT dari 75.5 mN / m kepada 55 mN / m dengan kepekatan meningkat daripada SiO_2 ditambahkan ke dalam larutan polimer. Oleh itu, 4000 ppm XG bersinergi dengan 3000 nanopartikel ppm SiO_2 dipilih sebagai kepekatan optimum pengurangan IFT dicapai dan boleh dikaitkan dengan keputusan kelikatan. Hanya ada perbezaan kelikatan sedikit diperhatikan apabila 5000 nanopartikel ppm SiO_2 ditambah berbanding 3000 nanopartikel ppm SiO_2. Faktor pemulihan meningkat daripada 27.5% kepada 56% dengan menggunakan 4000 ppm XG semasa, faktor perolehan meningkat kepada 57.50% dengan menggunakan penyelesaian disinergikan menggunakan nisbah slug yang sama. Faktor-faktor pemulihan maksimum adalah 66,3% dengan menggunakan penyelesaian optimum yang disinergikan dengan nisbah slug tertinggi 50:50 polimer banjir untuk slug air. Kesimpulannya, keputusan ini telah membuktikan bahawa SiO_2 nanopartikel mampu meningkatkan potensi banjir polimer untuk meningkatkan kedua-dua menyapu dan kecekapan anjakan oleh kenaikan kelikatan dan pengurangan IFT untuk meningkatkan faktor penemuan minyak.

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LIST OF ABBREVIATIONS

EOR	Enhanced oil recovery
S_{or}	Residual oil saturation
S_{oi}	Initial oil saturation
E_A	Areal sweep efficiency
E_I	Volumetric sweep efficiency
E	Efficiency
E_D	Displacement efficiency
E_V	Sweep Efficiency
nm	Nanomicron
SiO_2	Silica oxide
CNT	Carbon nanotube
Al_2O_3	Aluminium oxide
TiO_2	Titanium dioxide
Fe_2O_3/Fe_3O_4	Iron oxide
PEG	Polyethylene glycol
IFT	Interfacial tension
HTHP	High temperature high pressure
OOIP	Original oil in place
Pc	Capillary pressure
Ca	Capillary effects
RF	Recovery factor
M	Mobility ratio
WAG	Water alternating gas
ILs	Imidazolium and lactam based ionic liquids
SDS	Sodium Dodecyl Sulfate
LHP	Lipophobic And Hydrophilic nanoparticles

HLP	Hydrophobic And Lipophilic nanoparticle
ZrO_2	Zirconium Dioxide
PNP	Polymer-coated nanoparticles
WF	Water flooding
NF	Nanofluid floodings
NaCl	Sodium Chloride
NaOH	Sodium Hydroxide
UV-Vis	Ultraviolet-visible Spectrophotometer
XG	Xanthan Gum

LIST OF SYMBOLS

μ	Fluid viscosity
υ	Interstitial velocity
γ	Interfacial tension

CHAPTER 1

INTRODUCTION

1.1 Research Background

S. J. Kulkarni (2017) reported in his study that the oil and gas production are lessening from time to time and this causes an increase in cost. Efficient oil exploration is very crucial in the petroleum and refining industry in order to support the increasing demands for petroleum. There are several factors contributing to the declining of the oil production. Firstly, there are bypassed or residual oil that has been trapped in the pores after primary and secondary recovery. This is because of an improper mobility ratio of the injectant which prone to viscous fingering and resistance of oil to flow. Secondly, the oil is trapped because of the high capillary forces across the interface between water and oil or pressure declining the reservoir and also because of the heterogeneities present in the reservoir (Gbadamosi, Junin, Manan, Yakeen, Agi, Oseh, 2018). The reservoir pressure decline happened because of inadequate water injection or poor injection quality during primary and secondary recovery. The unrecovered oil can be existed in a pore of either swept zone or unswept zone. The oil left in a swept zone due to capillary forces is called as residual oil saturation (S_{or}). While the oil left in a pore in an unswept zone is called as bypassed oil. Therefore, several techniques are used to recover the remaining oil from the reservoir.

Gbadamosi et al (2018) explained in their study that the recovery of crude oil is categorised into three stages, which are primary recovery, secondary recovery and tertiary recovery. First, primary recovery uses the number of reserves recovered without injected fluid pressure support or in another words, it uses the natural drive energy. The natural energy sources include rock and fluid expansion, solution gas, water influx, gas cap and gravity drainage. Second, the recovery of oil by injection of external fluids such as water and/or gas is called as secondary recovery or also known as Recovery Improvement process. It aims to maintain the pressure and increase the volumetric efficiency. Last but not least, the increased cost and depleting resources have established the enhanced oil recovery (EOR) activities or tertiary recovery. It is used after secondary recovery is no longer economical. It is characterized by the injection of special fluids such as chemical, microbial, miscible gases and/or injection of thermal energy. In some situations, it might be applied after primary recovery along with waterflooding (Green & Willhite, 1998).

EOR activities can be divided into chemical, thermal, gas and microbial. Thermal EOR uses steam or hot fluids or through in-situ combustion in order to reduce the viscosity of the heavy oil. This method is mainly applied in heavy oil reservoir. Meanwhile, gas or miscible gas EOR such as carbon dioxide (CO_2), nitrogen and hydrocarbon gases is displacing the oil with a fluid that is miscible with the oil at the interface. Microbial EOR however, is an EOR technique that uses microorganisms that lives on the injected nutrition or oil in the reservoir. This microbes will generates several bioproducts such as bio-polymer and bio-surfactant. In contrast, chemical EOR is referring to the process of injecting a specific liquid chemical that changes the physicochemical properties of the displaced/displacing fluid such as IFT.

Polymer flooding is one of the chemical enhanced oil recovery (EOR) methods. The polymer flooding has been proven to be suitable for EOR application in Malaysia. Furthermore, it is useful to extract some heavy oil or more viscous oils. It also promotes a more favourable mobility ratio and improve sweep efficiency by blocking and diverting the flow of displacing fluid where the oil is trapped due to reservoir heterogeneity. However, its effectiveness is affected by the chemical and mechanical degradation (Khalilinezhad et. al., 2017).

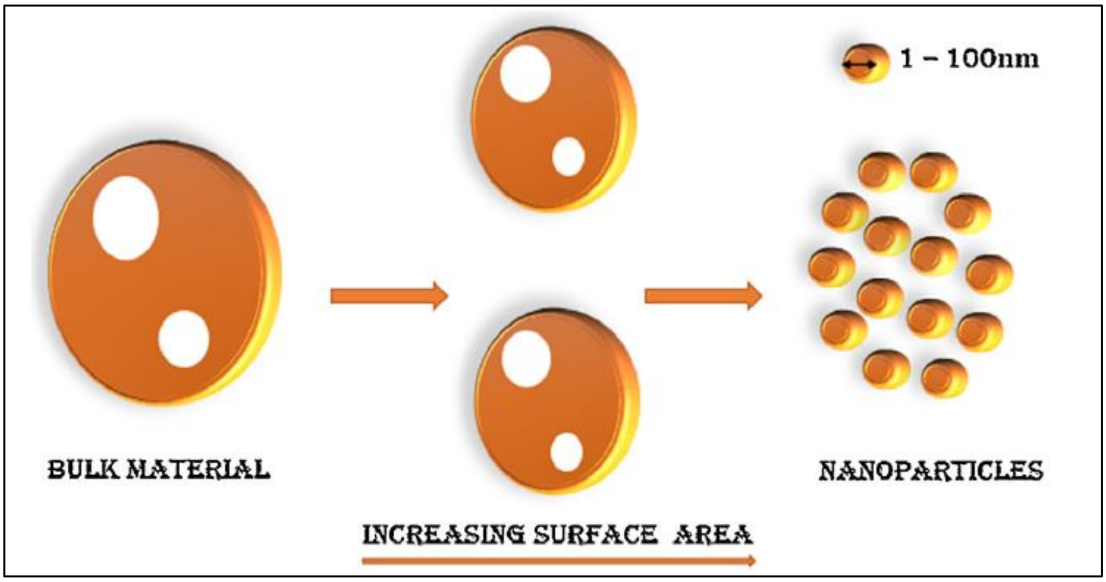

Figure 1.1 Schematic of increase in surface area with decreasing particle size. (A. O. Gbadamosi et al., 2018)

Therefore, there are extensive studies regarding the usage of nanoparticle materials in Enhance Oil Recover (EOR) or tertiary recovery methods including polymer flooding, which helps the conventional methods to increase the oil production. They are small in size, which is in the range of 1 – 100 nm (Youssif, El-Maghraby, Saleh, Elgibaly, 2018). Figure 1.1 illustrates the increment of the surface area of the particles due to their small size. Their small size causing them to be able to access into the pore spaces where the conventional recovery methods cannot do so (Negin, Ali, Xie, 2016). The nanofluid floodings are concluded to have mechanisms of recovery by wettability alteration, interfacial tension reduction, pickering emulsion formation and stability, structural disjoining pressure and oil viscosity reduction (Gbadamosi et al., 2018). Negin et al. (2016) discussed that there are a few types of nanoparticles such as organic, inorganic, metal oxides and non-silica nanoparticles. Organic nanoparticles are carbon nanoparticles and carbon nanotube (CNT) nanoparticles. However, inorganic nanoparticles can be silica oxide (SiO_2), while the metal oxides nanoparticles are aluminium oxide (Al_2O_3), TiO_2 and iron oxide (Fe_2O_3/Fe_3O_4). Polymer nanoparticles and polymer-coated nanoparticles are examples for non-silica nanoparticles.

Figure 1.2 Improved permeability due to wettability alteration from oil-wet to water-wet (A.O. Gbadamosi, 2018)

Silica nanoparticles, for instance, are cheap and easy to control their chemical behaviour by using surface modification technique (Youssif et al., 2018). Moreover, these nanoparticles are also environmentally friendly, which is another advantage of using this type of nanoparticles in EOR apart from their ability to improve production. Corredor L.M., Husein M.M. & Maini B.B (2019) stated that Xanthan gum (XG) is a high molecular anionic polysaccharide that is formed by *bacterium Xanthomonas campestris* during the process of cellulosic backbone fermentation. This water-soluble polymer has been commonly used in EOR proving that it is able to improve sweep efficiency by controlling the mobility of water, lowering the permeability of water in the swept zones as well as contacting unswept zones. However, the temperature limit for Xanthan gum was reported around 70°C to 90°C.

In another study, they claimed that by adding hydrophilic Silica NP to the heavy crude oil and Xanthan gum (XG) has improved the emulsion stability at all polymer concentrations. It also reduced the IFT and changed the wettability from oil-wet to water-wet and thus improving the recovery of oil between 18% and 20% at 30 and 70°C (Saha R., Uppaluri RV S., Tiwari P., 2018). The wettability alteration from the oil-wet to more water-wet causing the oil to move/flow easier by lowering the capillary forces which retain the oil in the pores as shown in Figure 1.2. Therefore, in comparison to the previous studies, this research aims to study the effect of the synergy of these nanofluids flooding in terms of viscosity, interfacial tension reduction as well as oil recovery test at room temperature.

1.2 Problem Statement

Nowadays, there are many reports claimed that oil and gas production is decreasing and the conventional ways of recovering and extracting the reserves are no longer applicable or in other words, inefficient. The polymer flooding have always been reported to have several problems such as mechanical and biological degradation, adsorption and high temperature and salinity effects. The problems arise has initiated this study to find the solutions to several questions. One of the questions is how to overcome the limitations of the conventional polymer flooding? Secondly, what are the effect of this synergy of SiO_2 and Xanthan Gum nanoparticles injection on oil recovery? First, this study was proposed to introduce an enhancement material into conventional polymer flooding. It aims to study the effect of injecting a combination of nanoparticles and polymer flooding to the core to recover the bypassed and residual oil trapped, or particularly to enhance the recovery factor. The nanoparticles used in this study are Silica Oxide (SiO_2) nanoparticles. In order to answer the second problem statement, the synergy of these nanoparticles has been tested for their capability in terms of viscosity increment and interfacial tension (IFT) reduction.

1.3 Objectives

This research is proposed with the objectives as followed:

a) To evaluate the capability of the synergised nanoparticle of Xanthan Gum and SiO_2 nanoparticle solution to improve the solution viscosity and IFT reduction.

b) To measure the effectiveness of synergy of Xanthan Gum and SiO_2 nanoparticle in improving oil recovery factor.

1.4 Scope

First and foremost, the research objectives were analysed based on the data obtained from the laboratory experiments. Xanthan Gum and Silica Oxide (SiO_2) nanoparticle were mixed together and injected into a sand pack. The performance of the synergy between the varying concentrations of SiO_2 (1000, 3000, 5000, 7000 and 9000 ppm) and 4000 ppm Xanthan Gum floodings was investigated by studying their ability to increase the viscosity of the displacing fluid (polymer) and minimise the interfacial tension between the phases. Then, the result were calculated and compared to get the optimum concentration of synergised solutions. The optimum solution was tested for flooding test for different slug ratio between polymer injection and water slug (0.1:0.9, 0.2:0.8, 0.3:0.7, 0.4:0.6 and 0.5:0.5 PV). All tests were conducted at room temperature of 27°C and pressure at standard 14.7 psia.

1.5 Significance of Study

The importance of the study is to find a new solution to help improve the existed Enhanced Oil Recovery (EOR) methods. In conjunction with that, this study targets to develop a new method that can enhance the production in an environmentally friendly manner. Moreover, it does not have a significant effect on low temperature. It also has a good resistance to mechanical degradation, temperature and high salinity (Jang et al., 2015). Therefore, it is suitable for this study where it was conducted at temperature of 27 °C with 20, 0000 ppm brine concentration. Nanoparticle prevents the degradation and improves the viscosity of polymer in the presence of salt and temperature (Gbadamosi et al., 2019).

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