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XANTHAN GUM AND SILICA OXIDE NANOPARTICLE SYNERGIZATION EFFECTS ON OIL RECOVERY

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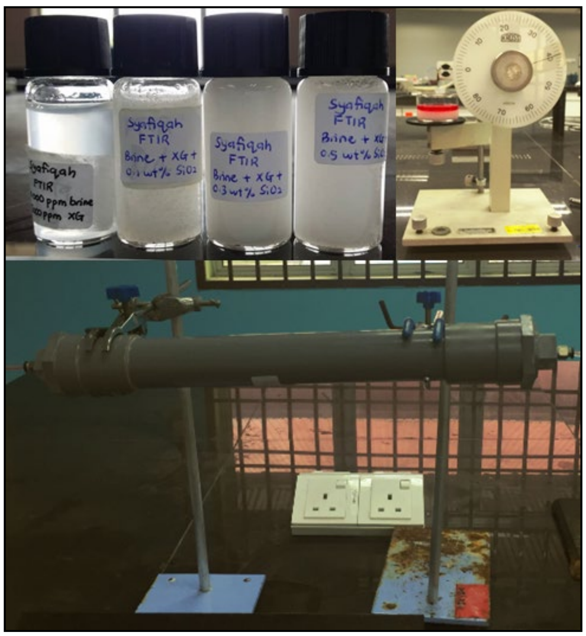
Graphical abstract



Abstract

This study aims to evaluate the capability of synergised XG and SiO2 nanoparticles solutions to improve the solution viscosity, IFT reduction and analyse the effects on the recovery factor. Samples were prepared with 4000 ppm XG and five concentrations of SiO2 (1000, 3000, 5000, 7000, 9000 ppm). The samples were tested for viscosity and IFT reduction to determine the optimum concentration of the synergised solution. Then, a flooding test was conducted using a sand pack to measure oil recovery factors when different slug ratios of polymer and brine were injected. Results show viscosity of the solution increased with increasing SiO2 concentrations. The synergy has shown IFT reduction from 75.5 mN/m to 55 mN/m with increasing concentrations of the SiO2 added into the polymer solution. Thus, 4000 ppm of XG synergised with 3000 ppm SiO2 nanoparticles was chosen as the optimum concentration as the IFT reduction is achieved and can be correlated with the viscosity result. A slight viscosity difference is observed when 5000 ppm SiO2 nanoparticles were added to 3000 ppm SiO2 nanoparticles. Oil recovery increased from 27.5% to 56% using 4000 ppm XG, while the oil recovery was increased to 57.5% using the synergised solution with a similar slug ratio. Maximum oil recovery was 66.3%, using an optimum synergised solution with the highest slug ratio of 0.5:0.5 PV polymer flooding to water slug. These prove that SiO2 nanoparticles can help polymer flooding improve sweep and displacement efficiency by viscosity increment and IFT reduction to increase the oil recovery.

Keywords: Enhanced oil Recovery, Interfacial tension, Silica Oxide Nanoparticles, Viscosity, Xanthan Gum

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1.0 INTRODUCTION

Oil and gas production are lessening from time to time, and this causes an increase in cost (S. J. Kulkarni, 2017)[13]. Efficient oil exploration is crucial in the petroleum and refining industry 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 trapped in the reservoir after primary and secondary recovery due to unfavourable 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 A et al, 2018) [5]. EOR activities can be divided into chemical, thermal, gas and microbial. Polymer flooding is one of the chemicals enhanced oil recovery (EOR) methods. The polymer flooding has been proved to be suitable for EOR application in Malaysia. 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 et al. 2018)[30]. Their small size causing them to be able to access into the pore spaces where the conventional recovery methods cannot do so (Negin et al., 2016)[17]. 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)[5]. Negin et al. (2016)[17] 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 (SiO2), while the metal oxides nanoparticles are aluminium oxide (Al2O3), TiO2 and iron oxide (Fe2O3/Fe3O4). Polymer nanoparticles and polymer-coated nanoparticles are examples for non-silica nanoparticles.

Xanthan gum is widely used in the industry, including food, clothes and the oil and gas industry. According to S. Ghoumrassi-Barr et al. (2015)[7], Xanthan gum is an extracellular polysaccharide formed by the xanthomonas campestris. Its primary structure comprises the backbone of glucose monomers or cellulose-like chain and trisaccharide side chain. Silica nanoparticles, for instance, are cheap and easy to control their chemical behaviour by using surface modification technique (Youssif et al., 2018)[30]. 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 et al. (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.et al., 2018)[23]. 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.

Xanthan gum has been proved that viscosity is affected by various parameters such as salinity, pH, temperature and hardness. This research is proposed with the objectives to evaluate the capability of the synergised nanoparticle of Xanthan Gum and SiO2 nanoparticle solution to improve the solution viscosity and IFT reduction and to measure the effectiveness of synergy of Xanthan Gum and SiO2 nanoparticle in improving oil recovery factor.

2.0 METHODOLOGY

2.1 Materials

Xanthan gum – silica nanoparticles solution

A Firstly, Xanthan Gum that was obtained from Sigma Aldrich Chemical Pvt. Ltd., India with concentration of 2000 – 6000 ppm was mixed in 20,000 ppm brine and continued to stir for 3 hours to prevent agglomeration. SiO2 nanoparticles were slowly mixed with the polymer solutions in order to get 1000 – 9000 ppm of polymer-silica nanoparticles solutions and stirred for 12 hours to ensure the solutions were evenly dispersed. After that, a clear and transparent nanofluid without any precipitation of nanoparticles was achieved.

Sand pack

The sand pack was designed with 1 ½" internal diameter (ID) and 1 ft long. The materials needed are glass beads with an average particle size of 150 - 250 µm. The sand pack was prepared as wet pack where sand and water were filled into the pipe alternately

2.2 Viscosity Test

This test was conducted by using a rheometer (Anton Paar Physica MCR 301). The sample's viscosity was measured using various shear rates (1/s) from 0 to 100 to avoid pore blocking. This test aims to determine the most optimum viscosity of the polymer solution when different concentrations of SiO2 are added to the solution. 50 ml of polymer solutions (2000, 3000, 4000, 5000 and 6000 ppm of XG) were filled into rheometer and tested for 10 minutes at 27°C. The test was conducted for all polymer solutions with and without SiO2 nanoparticles (1000, 3000, 5000, 7000 and 9000 ppm), and the results obtained were recorded.

2.3 Interfacial Tension Test

This test was done to investigate the capability of reducing the oil-water interfacial tensions using the different concentration of SiO2 (1000, 3000, 5000, 7000 and 9000 ppm) synergised with an optimal concentration of Xanthan Gum nanofluid.solution (4000 ppm). The polymer-silica nanofluid sample was placed in Kruss tensiometer followed by injection of paraffin oil in the middle of the solution at room temperature. The ring was slowly pulled out of the solution until it is fully separated from the solution. IFT values were determined and recorded. The test was repeated for each concentration of SiO2. The temperature was at 27°C.

2.4 Recovery Test

After the porous medium characterisation test has been done, the water flooding proceeded until the oil cut is less than 1% or oil is no longer producing more than water. Then, 4000 ppm XG solution synergised with 3000 ppm SiO2 nanoparticles injection was commenced at the same constant flow rate of 2 mL/min for 0.1:0.9 PV slug ratio between polymer flooding and water slug. The flooding was continued until no more oil could be produced. The test procedures were repeated for four other different slug ratios of SiO2 (0.2:0.8, 0.3:0.7, 0.4:0.6 and 0.5:0.5 PV). The nanofluid solution was tested for different slugs to determine the best injection rate, thus lowering the chemical requirement. The cumulative oil recovery was calculated by using Equation 1.

$$Cumulative\ Oil\ Recovery(\%) = \frac{Produced\ Oil\ (mL)}{OIP\ (mL)} \times 100 \quad (1)$$

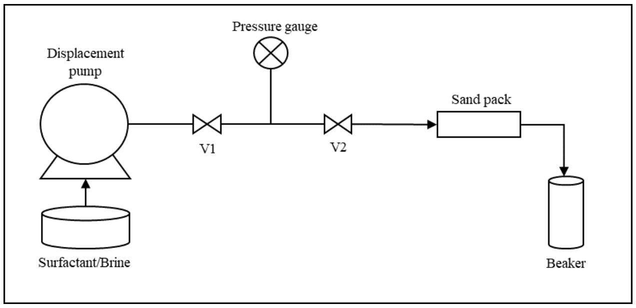

Figure 1 Schematic diagram of oil recovery experimental setup

3.0 RESULTS AND DISCUSSION

3.1 Viscosity Test

Based on Table 1, the viscosity of the solution with varying polymer concentrations was increased with increasing concentration of the polymer until the highest concentration (6000 ppm). Besides, Figure 1 indicates an increase in viscosity when SiO2 nanoparticle was added. The viscosity increased as the concentration of SiO2 increased to the highest concentration of 9000 ppm from 44.2 cp to 3272.7 when the shear rate was 1 s-1. The polymer solutions' viscosity enhancement is because of the adsorption of the polymer on the SiO2 particle surface driven by a hydrogen-bonding based interaction. Secondly, it is because of the interaction between polymer and nanoparticles through electrostatic and van der Waals and hydrophobic interaction.

Table 1 Table of Viscosity Result when Various Concentrations of Xanthan Gum Solution at Shear Rate of 1 s-1

XG Concentration, ppm	Viscosity, cp
2000	22
3000	27
4000	44
5000	67
6000	134

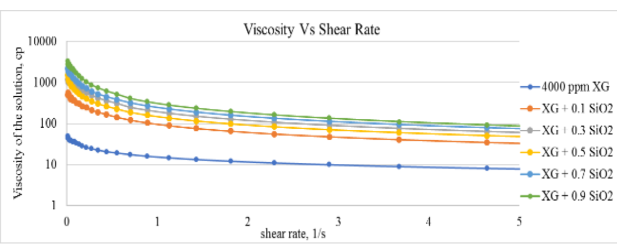

Figure 2 Graph of Viscosity Vs Shear rates when 4000 ppm Xanthan Gum synergised with different concentrations of SiO2 nanoparticles (1000, 3000, 5000, 7000 and 9000 ppm)

The shear stress increases as the viscosity increases as shown in Figure 2. This is due to the resistance for the fluid to flow increasing as the solution becomes more viscous. Figure 3 shows that all the fluids behaved as shear thinning solutions as the shear stress increased with increasing shear rates. This can result in an increment of the residual resistance factor, thus improving the sweep efficiency.

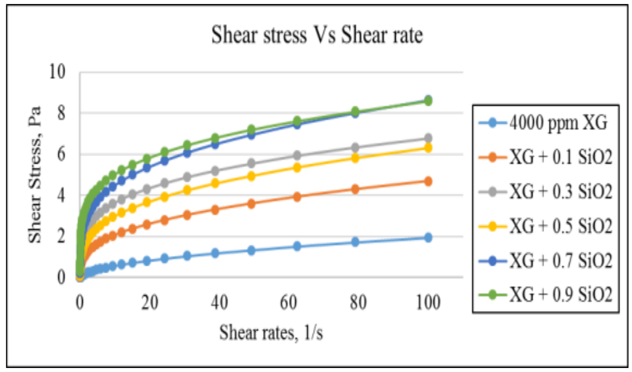

Figure 3 Graph of shear stress vs shear rate shows the behaviour of the polymer-silica nanoparticles solution as a shear-thinning polymer solution

Meanwhile, for an optimum concentration of SiO2 nanoparticles, only a slight viscosity difference was observed in Figure 4 when 5000 ppm SiO2 nanoparticles were added compared to 3000 ppm SiO2 nanoparticles. Other than that, the optimum concentration can be correlated with the IFT results.

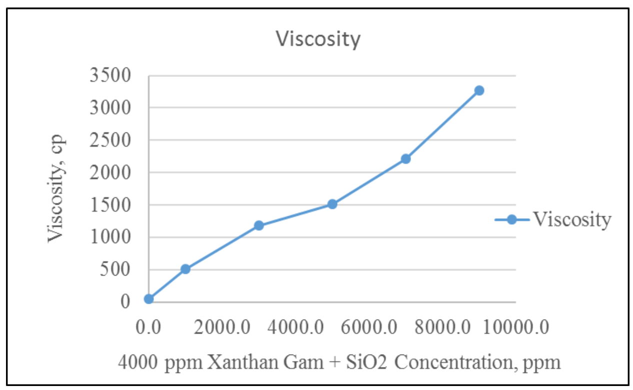

Figure 4 Viscosity behaviour of 4000 ppm XG + SiO2 nanoparticles (SiO2 concentrations of 1000, 3000, 5000, 7000 and 9000 ppm)

3.3 Interfacial Tension Test

Based on Figure 5, although the IFT reduction for the first three concentrations is only slightly reduced with 1.0 mN/m for each concentration, however, the reduction has been increased to 4 mN/m reductions for polymer solution synergised with 7000 and increased by 14 Nm/m for 9000 ppm SiO2 when the solutions become more viscous.

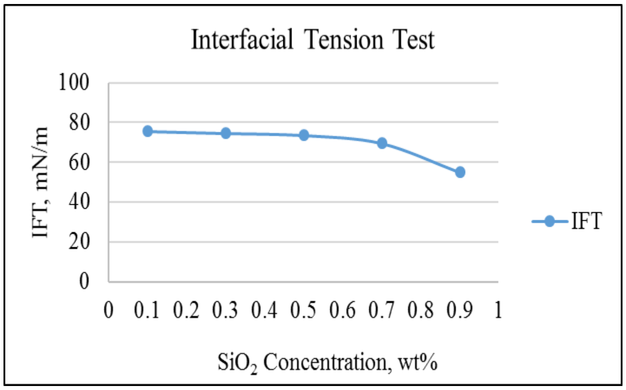

Figure 5 Result obtained for IFT reduction test when 4000 ppm Xanthan Gum is synergised with different concentrations of SiO2 (1000, 3000, 5000, 7000 and 9000 ppm) solutions

3.3 Recovery Test

Based on the result shown in Figure 6, the recovery factor was increased from 27.5% (recovery after water flooding) to 56% by using 4000 ppm XG. In comparison, the recovery factor was increased to 57.5% by using the synergised solution with a similar slug ratio. However, the oil recovery increased further up to 66.3% when the polymer flooding was injected up to 0.5 PV followed by 0.5 PV water injection. The recovery factor improvement was observed in Figure 7. A few factors explain the improvement of oil recovery, such as the enhancement of polymer viscosity. This increment improves the mobility ratio between oil and water, thus promoting better sweep efficiency. It helps to reduce the chances of viscous fingering occurrence or water channelling.

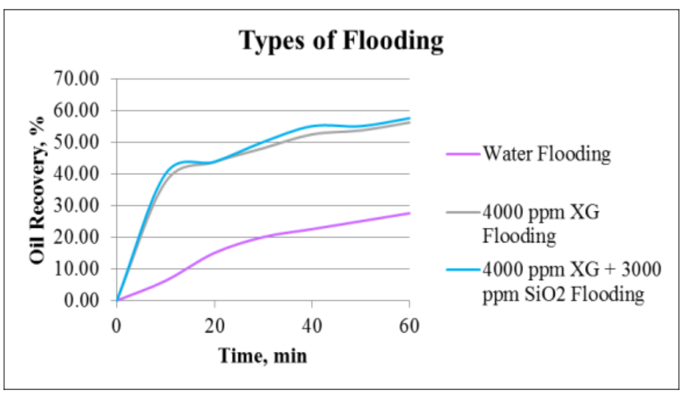

Figure 6 Comparisons of oil recovery after water flooding, polymer flooding and polymer-nanosilica flooding

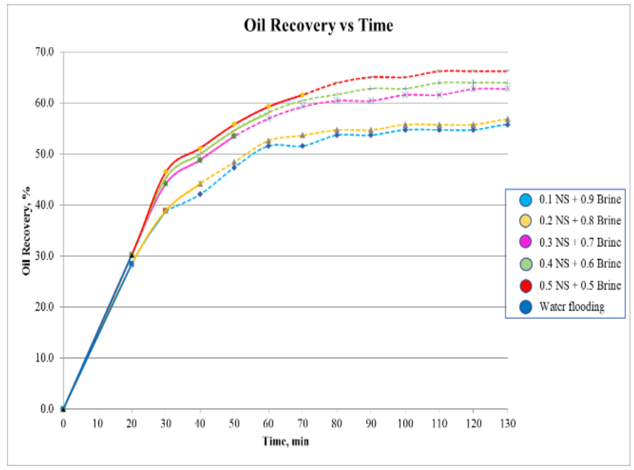

Figure 7 Core flooding result when conducted with optimal XG solution (4000ppm) and 3000 ppm SiO2 nanoparticle for different slug ratio between polymer flooding and water slug (0.1:0.9, 0.2:0.8, 0.3:0.7, 0.4:0.6 and 0.5:0.5 PV). The solid line represents the polymer flooding, and the dotted line represents the water slug.

4.0 CONCLUSION

In conclusion, the results from the tests have proved the effectiveness of the synergy of the silica oxide (SiO2) nanoparticles and Xanthan Gum in improving oil recovery. SiO2 has improved the viscosity of polymer solution, which reduced the mobility ratio between the injected fluids and the oil in the reservoir. This then increased the areal and volumetric sweep efficiency of oil in the reservoir. Moreover, this synergised polymer-nanosilica solution reduced the interfacial tension between the oil and water from 75 mN/m to 55 mN/m, which led to good emulsion stability. This result shows that the polymer solution may reduce the IFT between water and oil with the presence of SiO2. SiO2 has boosted the potential of Xanthan Gum not only in terms of sweep efficiency but also through displacement efficiency. Thus, the recovery of the oil is increased by 30% by using polymer-nanosilica flooding and increased up to 36% when injecting the polymer-nanosilica solution with the highest slug ratio between polymer flooding and water slug (0.5:0.5 PV).

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