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Study on the Interaction of Interfacial Tension Between Water and Oil Surfaces In The Presence of Aluminium Coated With Polyvinylpyrrolidone (PVP) Nanoparticles

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ABSTRACT

Applications of nanotechnology are frequently used in the oil and gas sector. However, nanoparticles boost sand consolidation, lower interfacial tension between water and oil, and improve the mobility of trapped oil to increase crude oil recovery in enhanced petroleum recovery (EOR). Using aluminium PVP-coated low-porosity sand packing, the effects of nanoparticles on interfacial tension and water-oil surface contact were examined in this study. The horizontal column was filled with low-porosity sand, and the nanopowders were suspended in deionized water. The four distinct nanoparticle suspension pore volumes (PV) used in this experiment are 0.25, 0.5, 0.75, and 1.0 PV. At the column's output, the sample is then deposited, and the effluent is analysed and contrasted using IFT and viscosity with a solid viscometer. In this investigation, it was discovered that the water target zone had a very limited pore volume and only received 0.52 PV of injected nanoparticles. The better the oil can be extracted, the lower the viscosity and IFT value. The removal of the oil droplet and increased oil output for EOR could result from the transport of PVP nanoparticles coated with aluminium.

Keywords: *Nanoparticles; Interfacial tension; Enhanced oil recovery; Viscosity; Pore Volume*

1. INTRODUCTION

The oil and gas industry as well as all other industries have used nanoparticles. Applications of nanotechnology to the oil and gas sector are not new; in fact, drilling muds have successfully utilised nanoparticles in the past. Due to the anticipated growth in demand for oil and gas, increased oil recovery is the application of nanoparticles that is most crucial for this industry [1]. With the alteration of wettability, changes in fluid properties, improved oil mobility that is trapped, strengthened sand consolidation and aids in lowering the interfacial tension between water and oil, the addition of nanoparticles to injection solution can improve enhanced oil recovery [2]. As a result, the production of crude oil in enhanced oil recovery will increase. It is important to note that more research needs to be done before we can determine whether nanoparticles can reduce oil viscosity, boost mobility ratios, and alter reservoir permeability.

1.1 Research Literature

In previous studies, nanoparticles have been used for control of mobility, which indicates results in decreasing water cut excellently, improved sweep efficiency, and recovery of oil [3]. Furthermore, nanoparticles can reduce the capillary force and water relative permeability and change the flow of a water path in porous media [4]. These nanoparticles have a scale of 1nm to 100nm and are smaller than the throat of a reservoir medium. They can enter pore spaces where they are already utilised and can increase sweep efficiencies. Usually, about 15%–30% of the initial oil in place can be produced by conventional recovery methods. By using EOR methods, large quantities of oil in unswept reserves can be produced [5].

Surface-coated nanoparticles [6] have a unique application in that they are specially used as stabilisers, CO2 foams, and emulsions with cheap, low-molecular-weight hydrocarbons that can improve mobility under harsh reservoir conditions and are formulated as an “intelligent” additive for drilling, cementing, and other downhole applications. Next, the second application can be as a detection instrument of the fluid and rock properties of the producing reservoir zone because nanoparticles can flow easily long-distance deep in the reservoir. Nanoparticles have extraordinary mechanical strength, and electrical, and thermal conductivity, which can be applied to enhance the performance, reliability, and durability of structural materials used by the oil industry in upstream activities [7].

Laboratory tests are the first step in measuring the quality of nanoparticles in recovery before they are used on a larger scale. The analysis made in this study was to determine the effects of coated metal oxide [8] nanoparticles flooding on oil recovery. Nanoparticles are typically less expensive than chemicals, lowering injection costs and allowing them to be widely used for EORs at oilfields. In field applications, the process is relatively cheap, does not pollute the environment, has higher oil recovery, does not corrode well equipment, and is easier to handle as compared to EOR methods that are alternative means for heavy oil recoveries [9].

Due to the expected rise in energy consumption worldwide in the future, the oil and gas industry is challenged regarding materials and harmless environmental operations. In the following phases of primary and secondary recovery, a huge amount of the original oil quantity is trapped in the rock. It is needed that improved techniques in oil recovery [10] be used to recover the oil that is trapped in the reservoir. Nanoparticles with nanosized dimensions in the range of 1 to 100nm are suitable for EOR because of their strong particle surface interaction with solvents [11]. Although the critical adsorption of nanoparticles into the reservoir is caused by the enormous specific surface area of permeable media and nanoparticles, this factor is crucial for EOR because it can change the wettability of the rock [12–14], reduce interfacial tension with the addition of surfactants, and reduce oil viscosity [15]. Even though the oil and gas industry faces a big challenge with the application of these nanoparticles because of the high production cost of these nanoparticles compared to conventional materials, some major oil and gas companies and service companies are working vigorously on developing practical applications.

1.2 Research Significance and Motivation

Numerous metal oxides have been tested, and there is a need to fill the research gap by applying a layer of Polyvinylpyrrolidone to these aluminium nanoparticles. This will greatly contribute to the improvement of nanofluids for enhancing oil recovery. Therefore, it is crucial to showcase a detailed experimental procedure to observe the impact of our modified nanofluids on interfacial tensions in sand packs and flow capabilities.

1.3 Research Objectives

The objective of this research is to study the effect of nanoparticles on interaction tension and interfacial between water and oil surfaces on a sand pack test in the presence of aluminium coated with PVP nanoparticles to select the optimum injection of pore volume (PV) for enhanced oil recovery (EOR) oil production. Investigating the interfacial tension of aluminium coated with PVP (Polyvinylpyrrolidone) nanoparticles (oil and water-based) by using a solid viscometer to measure viscosity to determine the effect and behaviour of Aluminium coated with PVP (Polyvinylpyrrolidone) nanoparticles on interaction tension and interfacial between the water/oil surface and rocks in the reservoir by using the sand pack test before and after injection to select a sand screen to maximise or minimise hydrocarbon production. The study also examined the oil displacement efficiency on interaction tension and interfacial between water and oil surfaces using aluminium coated with PVP (Polyvinylpyrrolidone) nanoparticles to increase the tertiary phase oil production of EOR.

2. METHODOLOGY

The methodology of the study is given as mentioned below, along with the purchase of nanoparticles and steps needed to achieve the experimental study.

2.1. Raw Materials

Coated metal oxide nanoparticles, distilled water, paraffin oil, and brine solution were the raw materials used in this experiment. The nanoparticles used in this analysis, aluminium coated with PVP nanopowder with a purity of 99.5%, were purchased from a well-known supplier. The sand was collected from Pantai Kempadang, Kuantan, for set-up sand pack experiments. The paraffin oil and chemicals used for the preparation of synthetic brine water were obtained from the UMP analytical chemical laboratory.

2.1.1 Brine Solution

The transport of nanoparticles in the presence of synthetic brines containing salinity levels at 40°C to 90°C and 1 atm will be determined in this analysis using brine solution. Table 1 lists the compounds contained in brine water solutions.

Table 1 Salinity formation water compounds synthetic brine solutions

Compound	Normal salinity formation water (ppm)	High salinity formation water (ppm)
Sodium Chloride	132,000	132,000
Magnesium Chloride	35,625	35,625
Calcium Chloride	25,677	110,045
Sodium Chloride	482	482
Strontium Chloride	1,521	3,347

2.1.2 Paraffin Oil

Paraffin oil, also known as liquid paraffin oil, is made from crude oil distillation. It is a colourless, odourless oil that can be used for a wide range of applications. In certain cases, the words paraffin oil and mineral oil are interchangeable. Liquid paraffin oil is a mineral oil formed as a by-product of crude oil distillation. It is a clear, odourless, tasteless oil made up of high-boiling alkane derivatives. Paraffin oil has a wide range of applications in modern times, including industrial, medicinal, beauty, and manufacturing. High-boiling liquid paraffin oil and low-boiling liquid paraffin oil are the two most common types of liquid paraffin oil. However, paraffin oil, when inhaled or swallowed, as well as when exposed to the skin repeatedly or for a prolonged period, may be detrimental to one's health.

2.1.3 Porous Media Preparations

The sand was obtained from Pantai Kempadang in Kuantan and washed with clean water to remove any remaining mineral salts. The sand is then sieved using sieves with a

500-micrometre mesh scale. The columns were made of transparent polyvinyl chloride pipe (PVC) so that the sample processing and measuring process could be seen directly. The columns are 35cm long and have a 6.6cm inner diameter. Furthermore, sand may be compressed into columns and agitated to facilitate sand compaction. Meanwhile, the porosity caused by grain stacking can be reduced by agitating the samples. The columns are estimated to have a porosity of 30-40%. Two fine mesh wires were placed at the inlet and exit of the column to keep the sand particles from flowing out with the solutions.

2.1.4 Aluminium Coated with PVP Nanoparticles Suspension Preparation

The concentration of aluminium coated with PVP nanoparticles used in this analysis was 80 mg/L. The first step in making nanoparticle suspensions was measuring 8g of aluminium coated with PVP powder in a measuring crucible using a weight balance. Next, to make nanofluids, the aluminium coated with PVP nanopowder was combined with 1 litre of deionized water (DIW). Besides, DIW was used as the dispersion [16, 17] medium to avoid the effects of solution chemistry (i.e., ionic concentration and pH) on nanoparticle stabilisation and transport. After that, the mixture was mixed at room temperature for 1 hour with a magnetic stirrer. The mixture can be ultrasonicated for 6 hours in an ultrasonic bath to achieve homogeneous suspensions. The magnetic stirring helps disperse the nanopowders in the base fluid [18] evenly, but the energy is inadequate to break any nanoparticle agglomeration. Because of that less energy is used in an ultrasonic bath to break up the agglomerations of nanoparticles.

2.1.5 Viscosity Test Analysis

In this test analysis, the viscosity of the mixed brine, paraffin oil, and aluminium coated with PVP nanoparticle fluids can be determined. This viscosity test was done by laboratories at CARIFF Laboratory, UMP Gambang. A viscometer machine named “Brookfield RSt CC" was used to test three different samples of brine + nanoparticles, brine + paraffin oil, and brine + nanoparticles + paraffin oil, respectively. So, from the viscometer, testing was collected and showed some data on viscosity from the sample fluids stated below.

2.2. Experimental Setup

The laboratory setup used in this analysis is depicted schematically in Figure 1 below. The nanoparticle suspensions were weighted and moved to a 250-mL measurement cylinder, which was injected into the column using a peristaltic pump with a volumetric flow rate of 45 mL/min. After that, the column effluent was collected in a beaker installed at the column outlet.

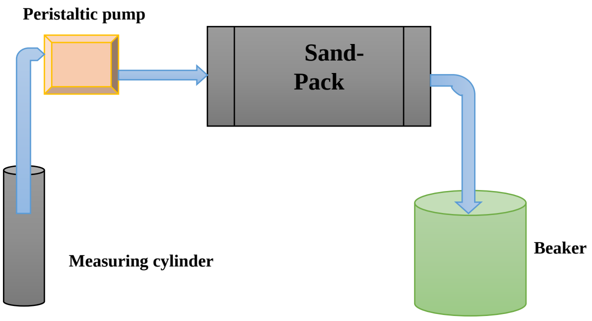

Figure 1. Sand Pack test set up to observe the flow effect between nanoparticles, brine and oil such as real reservoir for enhanced oil recovery.

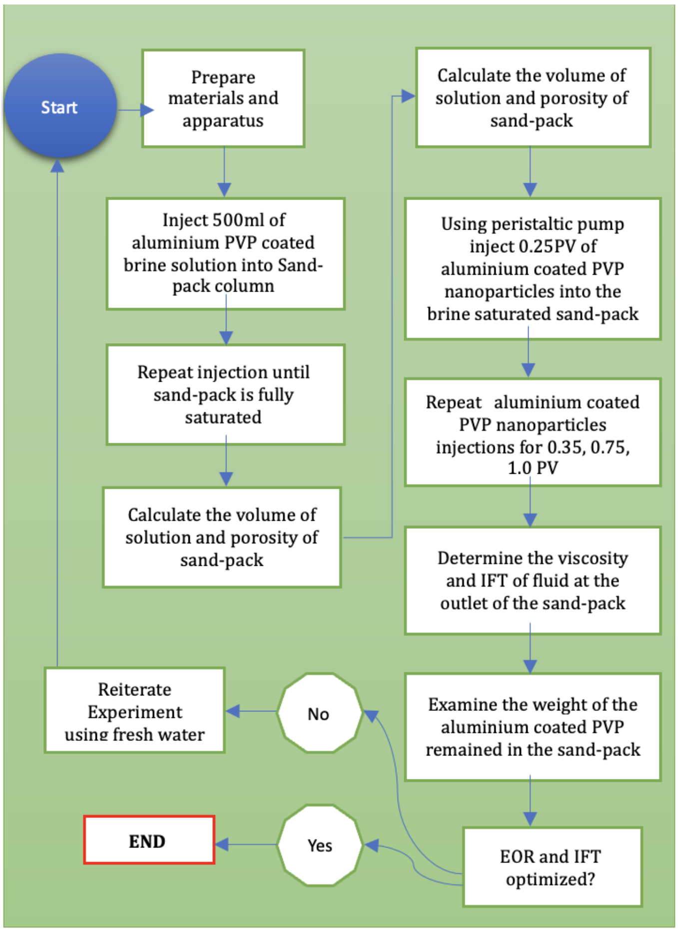

Figure 2. Flowchart for the experiment between Brine, Oil and Al coated with PVP nanoparticle.

3. RESULTS, DISCUSSION AND VALIDATION

3.1 Effect Between Al coated with PVP in Brine and Oil

Sand-pack testing is a common approach for figuring out the ideal display screen aperture. The objective is to develop a sand screen that maximises hydrocarbon output while minimising sand production. This test was performed to determine the optimal number of millilitres (ml) and pore volume (PV) for injection in the EOR phase. This test analysed samples and the results of those samples were compared, and the differences among them were addressed in detail. Moreover, 0.25 PV equals 125 ml, 0.5 PV equals 250 ml, 0.75 PV equals 375 ml, and 1.0 PV equals 500 ml of fluid. Figure 3 summarises the findings of the usual injection without nanoparticles, which consisted completely of brine and oil and ranged from 0.25 PV to 1.0 PV.

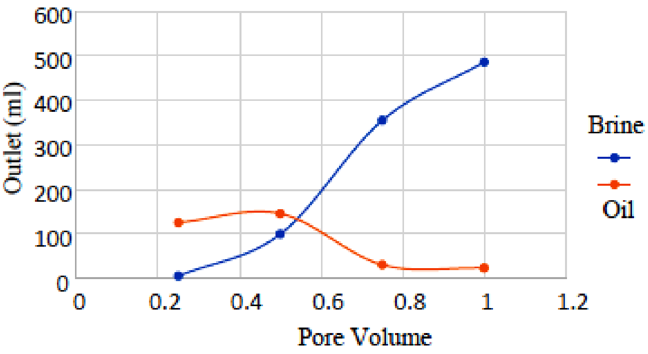

Figure 3. Graph of normal injection of Brine + Oil.

As Figure 3 shows, the volume of brine collected started to increase from 0.5 PV to 1 PV because brine consisted of different minerals such as sodium chloride, magnesium chloride, calcium chloride, and strontium chloride, which are considered ionic compounds. Next, the amount of oil collected started to decrease from 0.5 PV to 1 PV. The optimum Pore Volume (PV) is at the intersection line between brine and oil, which is at 0.54 PV and 130 ml.

3.2 Effect Between Aluminium Coated with PVP +Brine + Oil

Based on Figure 4, its trend is identical to that of a normal brine injection. However, unlike with normal injection, the increase and drop values are almost the same. Because brine consists of ionic components, it may be useful in the stabilisation of nanoparticles. The rate of the nanoparticles is neutralised more efficiently because the ionic strength will increase, lowering nanoparticle aggregation. After that, the nanofluids were no longer well-dispersed despite being agitated for 1 hour using a magnetic stirrer. That is why the rise and reduction for each were substantial in comparison to a normal injection. The nanoparticles injected into the column started to collect and cluster collectively at 0.25 PV, indicating that they were no longer mixing properly in the brine and oil.

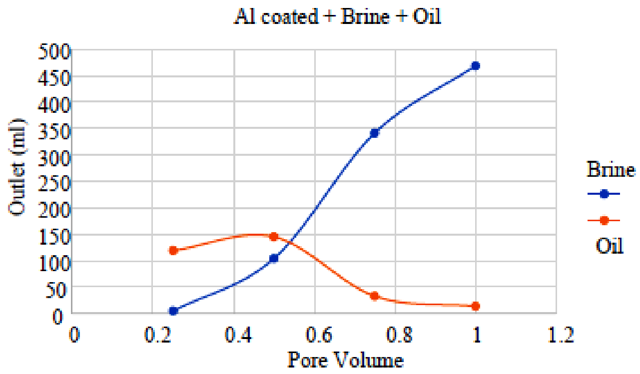

Figure 4. Graph of injection Brine + Aluminium coated with PVP nanoparticle.

When the oil flowed out of the column, the nanoparticles aggregated and moved slowly alongside the column, resulting in a lack of nanoparticles in the brine water at the outlet and a dramatic reduction in the outflow from 0.50 PV to 0.75 PV. The brine level rises gradually, beginning at 0.50 PV, not like in a based injection in Figure 3. In Enhanced Oil Recovery (EOR), however, the intersection line is 0.52 PV, and 140 ml is the optimum pore volume (PV) and volume (ml) for aluminium coated with PVP nanoparticle injection. The brine line indicated a constant growth from 0.50 PV to 1.00 PV based on those graphs above. But for the oil line, there is an indication of a decline from 0.50 PV to 1.00 PV. This suggests the nanoparticles have been stable and flowed with the oil and brine along the sand percentage column.

3.3 Effect on Optimum Weight for Aluminium Coated with PVP Nanoparticles Injection

Figure 5 shows the weight value of nanoparticles used for the injection, which are aluminium coated with PVP when using the optimum PV, which is 0.52 PV based on the graph at 4.32, which is decreasing compared to the initial, which is 0.25 to 1 PV. This is because the amount of optimum PV is enough to lower the interfacial tension of the brine and oil in the reservoir for enhanced oil recovery (EOR).

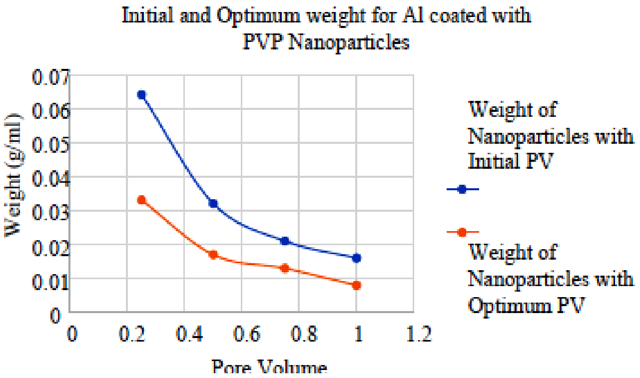

Figure 5. Graph of Initial and Optimum Weight for Aluminium Coated with PVP Nanoparticles.

3.4 Calculated Viscosity and Interfacial Tension of Aluminium Coated with PVP Nanoparticle Injection

The calculation of cylindrical area of the sand pack column was first calculated using Equation 1:

$$A = 2\pi rh + 2\pi r^2 \tag{1}$$

The diameter, d, of the sand pack column is 0.066 m, while the radius, r, is 0.033 m and the length of the sand pack column is 0.35 m. From Equation 1, the area calculated is 0.0794 m^2.

With the viscosity, μ of fluid brine plus oil given as 1.8809 cP and deformation shear rate, u/y is 434.430 s^{-1}. Area cylindrical, A of sand pack column as given above-using Equation 2 below, the calculated liquid force, F given as 64.8793 N.

$$F = \mu A \frac{u}{y} \qquad (2)$$

The Interfacial Tension (IFT), γ of Aluminium coated with PVP Nanoparticles + Brine + Paraffin oil in N/m using the F value that is obtained using Equation 2. Equation 3 is given to determine the IFT:

$$\gamma = \frac{1}{2}\frac{F}{L} \qquad (3)$$

With the length of the sand pack column given as 0.35 m, the IFT is 92.6847 N/m.

Calculated IFT for the aluminium coated with PVP nanoparticles + brine + paraffin oil using the same Equation 3 above with the provided date of viscosity, μ of fluid brine + oil is 1.2554 cP and deformation shear rate, u/y is 434.430s^{-1}. The area of the cylindrical is stated before is 0.0794 m^2. The liquid force for aluminium coated with PVP nanoparticles + brine + paraffin oil is given as 43.3034 N given by Equation 2. With the F given above, the value for IFT calculated is given as 61.862 N/m by Equation 3.

Based on the result of the calculation observed, the difference in force between brine + paraffin oil and aluminium coated with PVP nanoparticles + brine + paraffin oil is 64.8793 N and 43.3034 N, respectively. This is because when only brine is used to extract oil from the reservoir, more force is needed to push the oil out to the outlet column. With the presence of nanoparticles, however, the nanoparticles can help reduce the viscosity of the brine + oil in the reservoir, so less force is needed to extract the oil inside the reservoir. Next, when the force is high, the interfacial tension will also become high, as the results show that the IFT for brine + paraffin oil is 92.6847 N/m, while the IFT for aluminium coated with PVP nanoparticles + brine + paraffin oil is 61.8620 N/m. Based on the results, the presence of nanoparticles helps to lower the interfacial tension of the brine and oil in the reservoir such that the brine and oil are easily mixed and have a steadier flow. This mixture can easily be extracted separately from the reservoir oil.

This present study was validated by the works of Tangparitkul and Yu [19]. Similarly, their investigation considered the PVP-coated Silica nanoparticles in low-salinity brine, while our work on PVP-coated aluminium nanoparticles had a primary objective of enhancing oil recovery. However, the weight and dispersion of these nanoparticles in the presence of brine and oil yielded that Tangparitkul and Yu's experiment had their oil/water interfacial tension in brine lower as compared to Mili-Q water. In a similar effect, by maintaining adequate nanoparticle concentration, the oil/water interfacial tension in brine was still lower than the Mili-Q water. That being said, in the experiment for PVP-coated aluminium nanoparticles interfacial tensions in brine were as well lower as compared to the modified silica.

4. CONCLUSION

The goal of this experiment was to use aluminium coated with PVP (Polyvinylpyrrolidone) nanoparticles to investigate the influence of nanoparticle tension and interfacial between water and oil surface to determine the best pore volume (PV) injection for enhanced oil recovery (EOR) production. Pore volume dropped from 0.50 PV to 1.00 PV in the presence of paraffin oil, while brine increased from 0.50 PV to 1.00 PV. When nanoparticles are put into the sand pack, the numbers for increase and decrease for both graphs are not significant. As a result, the optimum pore volume in EOR for both normal and nanoparticle injection is 0.54 PV for normal injection and 0.52 PV for aluminium coated with PVP (Polyvinylpyrrolidone) nanoparticles injection. The optimum PV was employed to inject the sand pack in an EOR application because the optimum PV was sufficient to reduce the interfacial tension (IFT) between nanoparticles, brine water and oil. So, the lower the viscosity and IFT, the better the oil extraction from the sand pack column. This suggests that nanoparticle transport from the pore throat removes the oil drop by cutting through the oil-solid interface in the presence of nanoparticles.

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