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Effect of Temperature on the Rheological Properties of Eastern Ogun Oil sand Slurries Formed with Water or Diesel

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Abstract

Slurries are formed during the flooding of oil sand in the subsurface and the formation of these slurries between injected fluid and heavier oil in the oil sand will create both in situ separation of oil from the grains of the oil sand and an increase in the mobility of the oil for production purpose. The increasing mobility is due to density and viscosity reduction as a result of increased temperature. This research studied the rheological properties of the slurries obtainable when tropical oil sand deposits are either flooded with hot water for enhanced production or when diesel is injected into the oil sand formation in preparation for an in-situ combustion. The main focus is the analysis of the rheological properties of the slurries formed as indication of mobility of the oilsand slurries during future development of the long-abandoned Nigerian oil sand deposits. Obtaining an optimum slurry mixture will result in optimize flow rate during production. The optimum mixing ratio of the oil sand and the injected fluids were obtained through series of mixing ratios until the resultant slurry formed was homogenous mixture, for both the diesel and the hot water. This gives approximate volume of the hot water or the diesel to be injected per unit volume of the oil sand with special consideration to the top layer temperature of the oil sand reservoir. Moreover, the knowledge of the rheological properties obtained in the research will help in the design of the surface equipment (Annudeep 2012; Brookfield 2016) required for the heavy oil production. The unprocessed oil sand used in this research was mechanically mined, at Imeri-Ogun, Nigeria, in order to simulate probable in-situ slurry obtainable for hot water flooding of the oil sand for heavy oil production or for in situ combustions of the oil sand with diesel. It was concluded that the reduction in the gel strength of oil sand-water slurry with increasing temperature will result in less sand grain production during the flooding of the oil sand with hot water. It was discovered that at a slurry temperature beyond 60^{o}C, slurries formed will be too viscous for effective flow because of higher solubility between the oilsand and the solvents.

Keyword: oil sand; rheological property; slurry; drilling mud; viscosity; in situ flooding.

1. Introduction

This research evaluated the rheological properties of oil sand slurry that could be formed during in situ production with hot water and in situ combustions with diesel. In most cases, heat is the primary element used for in situ heavy oil recovery and hot water is widely used as flooding material for this in situ production. The injected water will form a slurry with the oil sand and slurry will be forced to flow upward to the surface through the production well. Diesel can also be used to enhance the production of heavy crude from oil sand through the process of in situ combustions. As the diesel is injected and just before combustion, a slurry is formed between the diesel and the oil sand.

Nigeria currently produces no heavy oil from its oil sand but it has a 30 billion barrels of deposit and approximately 3.5 billion barrels of recoverable reserve (Tarsands world, accessed 2017). The deposit is shallow and open cast mining would have been the cheapest option but due to environmental factor, hot water flooding or in-situ combustion is preferred production technique. Oil shales are one of the major energy sources for the world and has world-wide distributed deposits (Altun et al, 2016). There is much presence of surface water in the oil sand reservoirs in Nigeria and the rocks are appropriately assumed to be water wet since the water was in place before the upward migration of the oil from deeper formation to form oil sand. The wettability of a rock affects the fluid production from the rock (Mohammed 2008; Toth 2001). As long as the rocks are water wet, the production of oil from the oil sand is expected to give higher yield that when the rock is oil wet as the flooding will be drainage pattern.

In-situ heavy oil production from oil sand is a function of the mobility of the oil. Enhancing the mobility of the oil will either makes the production easier or create an increase production rate. Mobility is given by:

$$\lambda = {}^{K}/_{\mu}$$

Based on the equation above, the best way to increase mobility or production rate of heavy oil is either to reduce the viscosity of the oil or increase the permeability of the oil sand reservoir. It is easier to manipulate the oil viscosity, through heat injection, than to alter the formation permeability. For flooding, mobility ratio is considered. The mobility ratio is the ratio of the viscosities of the defending fluid to that of invading fluid (Santos et al, 2014) and is expected to be less than 1 in order for the flooding to be a success Green and Willhite, 1998)

Siy, Robert et al (2011) obtained a USA patent on oil sand slurry solid reduction process for extracting bitumen from oil sand ores having low bitumen content and/or high fines content. They suggested that the following process steps are followed:

- mixing of the problematic oil sand ore with heated water to produce an oil sand slurry
- conditioning the oil sand slurry for a period of time sufficient to substantially disperse oil sand lumps and promote the release and coalescence of bitumen flecks from the sand grains
- removing a sufficient amount of solids from the conditioned oil sand slurry in a de-sander circuit
- Subjecting the solids-reduced oil sand slurry to gravity separation in a bitumen separation vessel, to allow the bitumen to float to the top of the vessel to form clean bitumen froth.

This patent actually utilized processes that were already in existence for either oil sand production or drilling mud desilting and de-sanding.

Syncrude applied warm water extraction method in one of their facilities, Mildred Lake facility, to separates the bitumen from the in a process involving oil sand and oil sand slurry from the North mine and Aurora froth. The process involves mixing the oil sand with hot water and caustic soda in tumblers for a formation of slurry and then conditioned it for bitumen separation. It is then discharged onto vibrating screens where large material component is rejected and the blended slurry is fed into four primary separation vessels causing the bitumen froth floating to the top, while the sand sinks and settles at the bottom. It was discovered that the slurry transport from the mine to the plant naturally causes over 90% recovery of the bitumen and this bitumen froth is then upgraded to synthetic crude oil.

The Saskatchewan Research Council's two-layer model was used to interpret several operating data from numerous slurry pipelines in the Alberta oil sand industry (Sanders and Jason, 2004). It was discovered that the friction in the pipelines are usually larger than those predicted by the model due to the effect of large particles with a diameter greater than 50mm and this is critical when there is upward bend section in the pipelines.

This research examines the flow properties of the slurry formed between injected hot water and oil sand and also between injected diesel and oil sand. The oil sand used is a representation of oil sand with very small sand grains. The research represented the expected flow parameters of the slurry that will be formed during hot water flooding of oil sand deposits and also the flow parameters of the oil sand-diesel slurry that will form prior to in-situ combustions when diesel is injected into oil sand for in-situ combustion enhanced production.

Equipment used include Hamilton Beach Mixer, Electric grinding machine, Weighing Balance, Mud balance, Thermometer, Rotary Viscometer and Fluid Heater. Density of the oil sand was obtained through water displacement method and this was found to be 2.5893g/cm^3 or 21.57ppg in field unit.

2. Methodology

The methodology followed in the course of this experiment is as follows:

- Oil sand was obtained from Imeri Village in Ijebu-Imushin, Ogun State, Nigeria.
- The density of oil sand was obtained by using the displacement method. The specific density of the oil sand was found to be 2.5893 as 290g of the oil sand displaced 112cm^3 of water.
- Oil sand-water slurry was prepared as follows:
    1. Oil sand sample was prepared together with large volume of 80°C water. 80^{o}C is assumed to be the expected average temperature of the hot water when it comes into contact with the oil sand reservoir due to expected heat loss in casing/tubing and also to surrounding reservoir layers during the hot water injection.

2. Various mixtures of oil sand - hot water samples were prepared, using the Hamilton Beach Mixer, with increasing water content to form homogenous slurry. Most of these slurries were too viscous and non-homogenous until a homogenous slurry consisting of 400g oil sand and 350ml of 80°C water was obtained.
3. The homogenous oil sand slurry obtained was cooled by natural convection.

- Oil sand-diesel slurry was also similarly prepared as follows:
    1. Various samples of Oil sand - diesel slurries were prepared by trial and error method. This is because oil sand and diesel mixtures gives very viscous mixture and the diesel easily settles out of the mixture.
    2. The diesel ratio was increased until a good homogenous slurry sample consisting of 400g oil sand and 303.5ml of diesel was obtained.
- Minimal homogenous Slurry formed:
    1. Sample A: 400g of oil sand and 350ml of water (1 : 2.2657 ml/ml)
    2. Sample B: 400g of oil sand and 303.5ml of diesel (1 : 1.9642 ml/ml)

- Mud balance was calibrated with fresh water.
- Densities of the slurry samples were measured
- Viscosities of the samples were measured at various temperatures using viscometer
- Gel strength of the samples were measured at different temperatures with the viscometer.

3. Results

The data obtained for the initial and final gel strength, densities and calculated apparent viscosities are as presented in Tables 1 to 4 in the appendix, while the graphical representation of data is presented in Figures 1-4 below. As expected, the viscosity of the oil sand-water slurry reduces with increasing temperature but the oil sand-diesel mixture has an unexpected viscosity profile. This implies that hot water may be used to produce the oil sand through flooding but diesel will not be applicable for the in situ flooding of the oil sand. This was confirmed with the yield point for the oil sand-diesel in Fig.2. Table 1 presented the measured densities for the minimal homogenous oil sand slurries while Table 2 presented the calculated apparent viscosities for the oil sand slurries from the data obtained with the viscometer. The initial (10secs) and final (10mins) gel strength of the oil sand slurries are presented in Table.2 and figures 3 and 4, while Table 3 is the table of calculated plastic viscosities and yield points for the oil sand-diesel Slurry. The gel strength of the oil sand-water slurry reduces with temperature which is good for production of heavy oil from the oil sand as the slurry will not be able to carry the sand grains in the oil sand with it during the flooding process.

4. Conclusion.

The oil sand-water slurry has a very small viscosity which reduces with increasing temperature for all temperature range while the oil sand-diesel slurry has gradually increasing viscosity with increasing temperature until 50^{o}C after which it increases radically. The initial gel strength of the oil sand-diesel slurry followed the same pattern as that of viscosity with increasing temperature while that of the oil sand-water slurry follow its viscosity pattern as it decreases with increasing temperature. As shown in fig.4 above, the final gel strength of the oil sand-diesel slurry deteriorated rapidly with increasing temperature while that of the oil sand-water was almost constant until after the 50^{o}C, after which it reduced by about 5% to the 60^{o}C temperature.

After series of trial mixing proportions, in this research, with increasing ratio of the continuous phase, it was discovered that the minimum ratio of the oil sand to hot water that will cause the slurry formed to be homogenous in mixing and have low viscosity for optimum effective flow during production is 1ml to 2.2657ml of oil sand and water respectively. It was also discovered that the minimum combination for a homogenous oil sand-diesel slurry is 1ml to 1.9642ml of oil sand and diesel volumes respectively. Below these ratios, the slurry formed will be very inhomogeneous in nature and flow will be distorted. Moreover, it was discovered that the oil sand-water slurry is a more stable slurry than the oil sand-diesel slurry over the temperature range of 30^{o}C to 60^{o}C. This is the average temperature range for shallow subsurface oil sand deposit.

These are indications that while the oil sand-water slurry is slightly stable over the temperature range of 30 to 60^{o}C, the oil sand-diesel slurry is very unstable and will need a gelling additive to enhance its gel strength as temperature increases. The oil sand- diesel slurry also requires a thinner, viscosity reducer or any other viscosity control additive, in order to maintain its highly unstable viscosity as temperature increases. Hence, diesel cannot serve as a flooding injector for oil sand but can still be used for in-situ combustion of the oil sand.

In conclusion, the oil sand-water slurry is a more stable slurry than the oil sand-diesel slurry over the temperature range of 30°C and 60°C which is a representation of very shallow subsurface depth. Hence, the oil sand can be produced through in-situ water flooding at the temperature range and then process at the surface to separate the oil sand – water slurry to its different components using gravity method.

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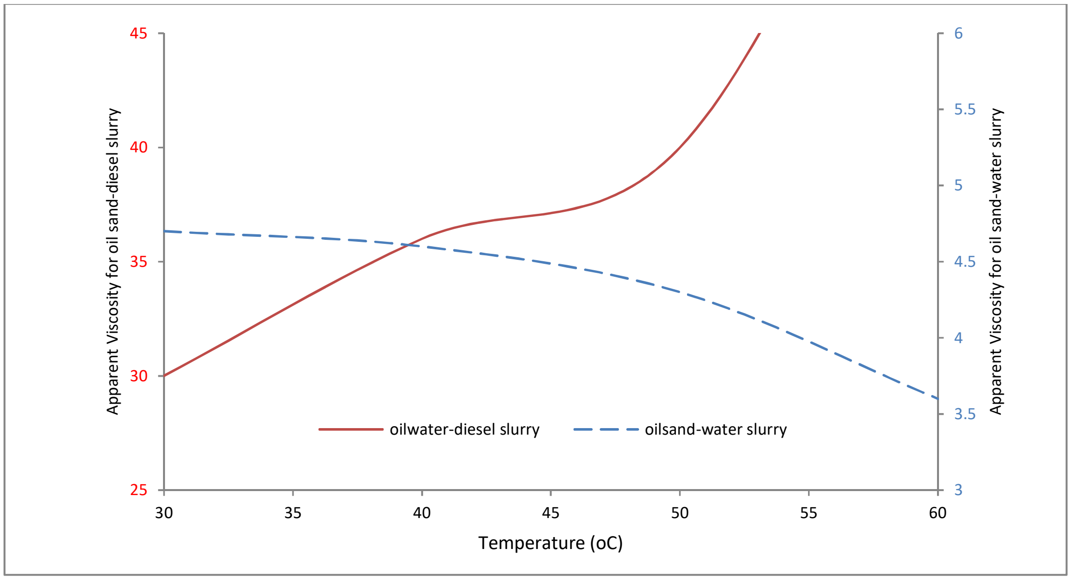

Figure 1: Apparent Viscosity for Oil sand Slurries

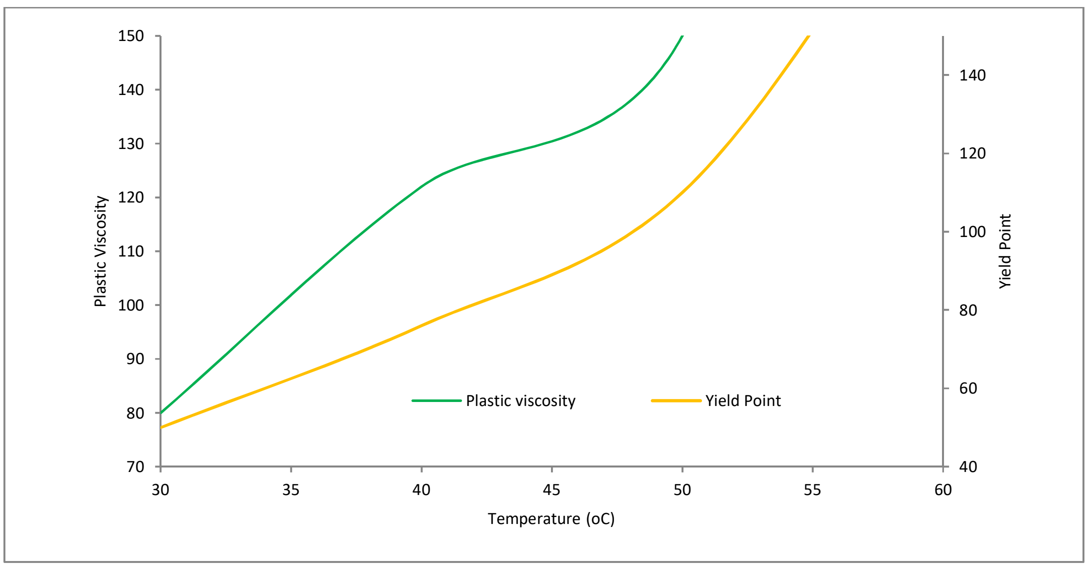

Figure 2: Plastic Viscosity & Yield Point for oil sand-diesel Slurry

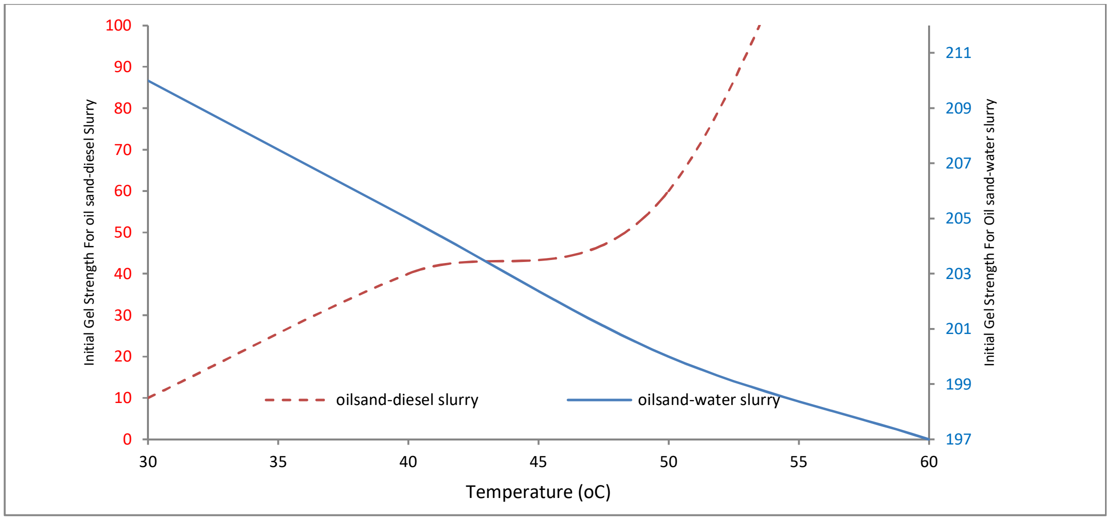

Figure 3: Initial Gel Strength for Oil sand Slurries

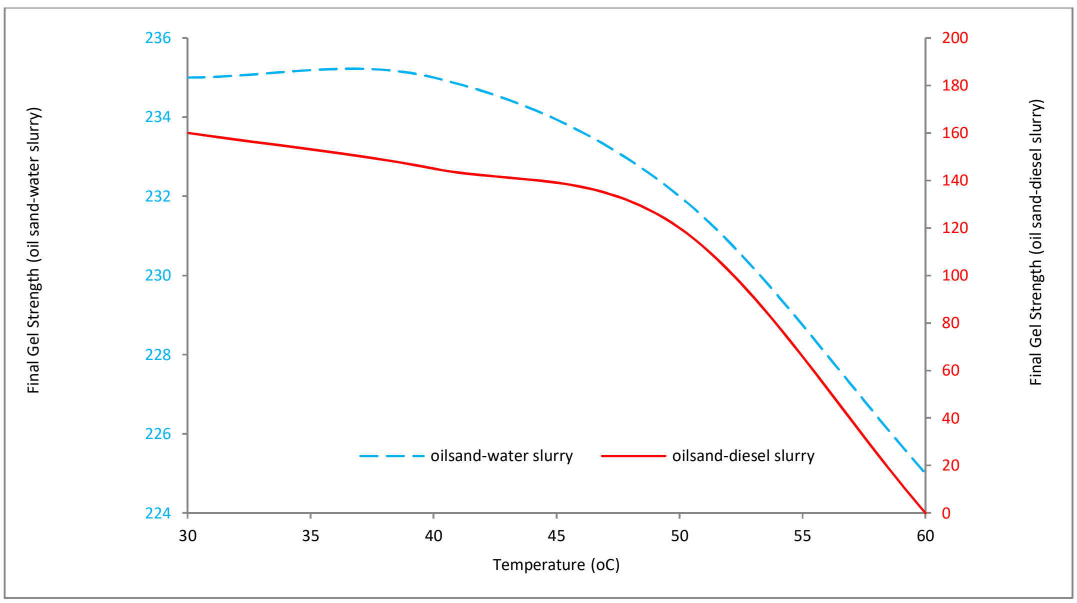

Figure 4: Final Gel Strength for Oil sand Slurries

Table 1: Measured Density of Minimum Homogenous Oil sand Slurry

Sample	Density (ppg)
A	12.436
B	11.987

Table 2: Apparent Viscosity for the Minimal Homogenous Oil sand Slurry

Temperature (°C)	Apparent Viscosity (cP)	
	Oil sand-water slurry	Oil sand-diesel slurry
30	4.7	30
40	4.6	36
50	4.3	40
60	3.6	maximum

Table 3: Initial and Final Gel Strength of Oil sand Slurry

Temperature (°C)	Initial Gel Strength (lb/1000ft2)		Final Gel Strength (lb/1000ft^2)	
	Oil sand-water	Oil sand-diesel	Oil sand-water	Oil sand-diesel
30	210	10	235	160
40	205	40	235	145
50	200	60	232	120
60	197	Max	225	Max

Table 4: Plastic Viscosity & Yield Point for Oil sand-Diesel Slurry

Temperature (°C)	Plastic Viscosity	Yield Point
	Oil sand-diesel	Oil sand-diesel
30	80	50
40	122	76
50	150	110
60	Max	Max