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Technical Report

Experiment and Numerical Simulation of Japanese Heavy Oil Recovery

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Heavy oil production depends on reservoir characteristics like permeability, reservoir pressure and oil viscosity. Heavy oil is difficult to produce because of its high viscosity. To reduce viscosity, the suitable technology for producing this oil is thermal recovery by using steam. In this study the viscosities of oil were measured and correlated with temperature. Also the effects of reservoir characteristics were then studied by using a commercial reservoir simulator. The simulation results showed that oil viscosity and permeability play significant roles in heavy oil production whereas pressure difference has less effect on oil production.

1. Introduction

Heavy oil production is gaining more interest because of the current oil prices and huge amount of heavy oil reserves[1]. However, heavy oil is difficult to produce because of its high viscosity. Viscosities of heavy oil need to be closely examined because this property plays a significant role in efficient operation of heavy oil production processes. The key to produce it is to reduce oil viscosity. With this condition, thermal recovery, such as steam injection, is needed to make the heavy oil flow easily. Steam injection is an increasingly common method of extracting heavy oil. It is considered as an enhanced oil recovery (EOR) technology to produce more oil.

Other than oil, emulsion of crude oil also plays a major part for oil production as well. Emulsions of crude oil and water can be encountered at many stages during drilling, producing, transporting and processing of crude oils and in many locations such as in hydrocarbon reservoirs, well bores, surface facilities, transportation systems and refineries. A good knowledge of petroleum emulsions is necessary for controlling and improving processes at all stages. Many studies have been carried out in the last 40 years and have led to a better understanding of these complex systems. However there are still many unsolved questions related to the peculiar behavior of these emulsions. The complexity comes mostly from the oil composition, in particular from the surface-active molecules contained in the crude. These molecules cover a large range of chemical structures, molecular weights, and HLB (Hydrophilic-Lypophilic Balance) values; they can interact between themselves and/or reorganize at the water/oil interface. To make the system even more complex these petroleum emulsions may also contain solids and gases[2].

Crude oils, especially the heavy oils, contain large quantities of asphaltenes (high molecular weight polar components) that act as natural emulsifiers. Other crude oil components are also surface active: resins, fatty acids such as naphthenic acids, porphyrins, wax crystals, etc[3].

Therefore, this study is intended to measure the viscosity of heavy oil and its emulsions at the reservoir characteristics and to correlate the oil viscosities with temperature. This will be used to investigate the effects of the reservoir characteristics such as permeability, reservoir pressure and oil viscosity on heavy oil recovery by simulating with a commercial reservoir simulator. The field-scale simulation of the process is based on the laboratory-scale data of the process experimentally and numerically. This would provide realistic data needed for simulation and, therefore, increase the accuracy of modeling studies.

2. Experimental

An accurate description of physical properties of crude oils is of a considerable importance in the solution of petroleum reservoir engineering problems. Oil viscosity is of primary interest in oil production especially with steam injection. To obtain the reliable data, experiments are needed to measure the viscosity of heavy oils and their emulsions with the effect of temperature. Viscosity data are usually determined by laboratory experiments performed on samples of actual reservoir fluids. The samples come from Japanese heavy oil as well as their emulsions from the mixture of steam at 6.58 and 3.20 oil/water ratio. The measurement temperature ranges from 15 to 180 °C.

2.1 Equipment and measurement procedure

2.1.1 Equipment for viscosity measurement at low temperature

The viscosity measurement at low temperature was carried out by Brookfield cone/plate programmable viscometer Model DV-ΠI, using a cone spindle with various numbers. Measurement of viscosity was performed within the temperature ranging from 15 to 60 ºC with the accuracy of ± 1.0 ºC. The accuracy of viscosity measurement is ± 1.0% accuracy of full scale range for a specific spindle running at a specific speed.

Experimental procedure

Initially, warm up the equipment for 10 mins. Before reading, the viscometer must be autozeroed. The various sizes or numbers of spindle were selected to fit with the viscosity range of sample. Then attach to equipment and place fluid in proper position. Allow enough time for sample to reach equilibrium. Each sample can be measured 3 times. Calibration can be done with standard solution supplied by Brookfield.

2.1.2. Equipment for viscosity measurement at high temperature

Brookfield Digital Viscometer: Model DV-I Prime with Brookfield thermosel is used for viscosity measurement at elevated temperature up to 300 ºC with the chamber (Model HT-2) and temperature probe (HT-60DP). Spindle is model SC4-18 with viscosity range 3-10K (mPa.s). Temperature is controlled by programmable temperature controller (Brookfield Model 106) ranging from 40 to 300 ºC with accuracy ± 1.0 ºC from 40 to 150 ºC and ± 2.0 ºC from +151 to 300 ºC and with resolution of 0.1 ºC.

Experimental procedure

At first, turn on, level and autozero the viscometer. The level is adjusted using the three feet on the bottom of the base. Later, at the desired temperature, attach the spindle to the lower shaft and insert the spindle in the test material until the fluid's level is at the immersion groove in the spindle's shaft. Allow time for the indicated reading to stabilize. Record the reading and relevant test parameters. Each sample can be measured 3 times.

3. Experimental Results

Firstly, original heavy oil from Japan and its emulsions were measured at temperatures from 15-180 °C as presented in Figure 1. From the results, it is obvious that the viscosity of the heavy oils decreased as the temperature increased because thermal energy transferred to molecules of oil and emulsion and made the bonds less stronger. The viscosities of the mixture of oil and steam or emulsions from Japanese oil with 6.58 and 3.20 oil/water ratio (O/W) were higher than the original Japanese oil for the whole concentration range.

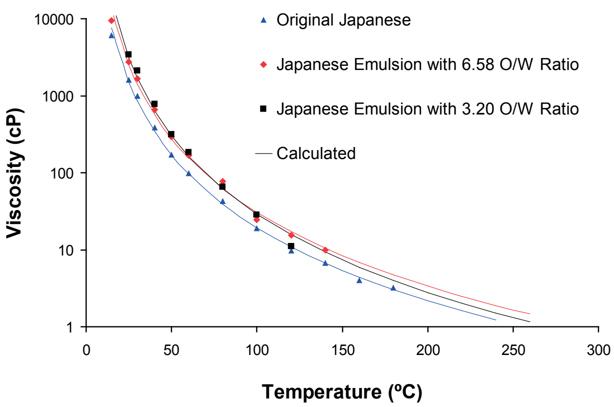

Fig. 1 Effect of temperature on viscosities of Japanese oil and its emulsions.

These phenomena can be explained by the fact that crude oils, especially the heavy oils, contain large quantities of asphaltenes (high molecular weight polar components) that act as natural emulsifiers. Other crude oil components are also surface active: resins, fatty acids such as naphthenic acids, wax crystals, etc. These substances contain hydrogen bonds in the heavy oil molecule. When steam is present in heavy oil, hydrogen bonds are formed following interactions between components and water. Hydrogen bonds can create irregular properties deviated from mixing rules such as maximum or minimum peak for viscosity of mixture. The appearance of such phenomena has been reported in the literatures[4,5] for systems of less polar molecules such as the ethanol-water system.

4. Correlation for Viscosity Measurement

Viscosity data usually come from experiments of actual reservoir fluids. If such laboratory data are not available, engineers may refer to published correlations, which usually vary in complexity and accuracy depending upon the available data on the crude oil. Therefore, from the Figure 1 and Table 1 and 2, the calculated results were calculated with the extrapolation by using correlation. This correlation was in the form as shown below:

$$\mu = A\,T^{-B} \qquad (1)$$

Where μ = viscosity (cP),
T = temperature (°C)
A and B = coefficients

This correlation was developed based on the ones from the literatures such correlations from Glaso[6], Bennisonl[7], and Kartoatmodjo[8]. In addition, the average absolute deviations (AADs) between experimental and calculated values were estimated from the following equation:

$$\%AAD = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{P_{exp}-P_{cal}}{P_{exp}}\right| \qquad (2)$$

where n is the number of data points.

From the measured results and calculation, the average absolute deviation (%AAD) for this correlation is 12.92%. Therefore, this correlation can be acceptable to predict the viscosity of heavy oil.

Table 1 Coefficients of viscosity correlation for heavy oils and their emulsions

Sample	A	B
Original Japanese	3.819E+07	3.148
Japanese Emulsion with 6.58 O/W Ratio	7.162E+07	3.184
Japanese Emulsion with 3.20 O/W Ratio	1.649E+08	3.378

5. Numerical Simulation

All simulation studies were performed using the CMG-STARS (steam, thermal, and advanced processes reservoir simulator) commercial simulator (CMG). Heavy oil production can be simulated in term of cumulated oil production, cumulated water injection and steam oil ratio (SOR). The well pattern used for this study is inverted 5-spot pattern which has an injection well at the center and 4 production wells at the corners. The configuration of wells proven to use in commercial nowadays was shown in Figure 2[9]. The operating parameters used for this simulation have been presented in Table 2. Three main parameters, permeability, viscosity and pressure difference were investigated for their effects on heavy oil production. Furthermore, viscosities derived from experiments were used in this simulation as well.

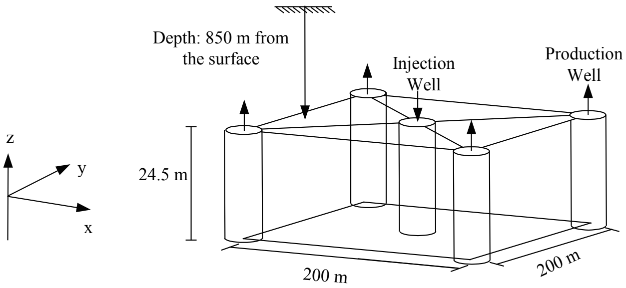

Fig. 2 Schematic diagram of 5-spot pattern and oil well.

6. Simulation Results

6.1 Effect of permeability on heavy oil production

One of the important parameters, permeability, played a significant role in heavy oil production because the higher permeability, the greater amount of fluid can flow. Practically, permeability of the well can be varied from low to high. However, at this point to investigate the effect of permeability, permeability of well was assumed at 1000, 5000 and 25000 mD which is the average of permeability of the field data.

Table 1 Operating parameters for simulation

Operating conditions	Values
Depth from surface (m)	850
Depth of well (m)	24.5
Reservoir pressure (MPa)	8
Pressure difference (MPa)	0.5-1.5
Permeability (mD)	1000-20,000
Porosity (%)	29-37
Oil Viscosity (cP) at 25 °C	1611.3-3444.2
Age of well (year)	20
Well distance (m)	200
Steam injection flow rate (m^3/day)	60
Number of perforation	8

The effects of permeability were shown in Figure 3 on the cumulative oil production and cumulative steam oil ratio of 3 permeability values. It is relatively clear that at high permeability, the production was higher compared to that at low permeability because fluids can flow easily and steam injection rate can be reduced. This condition is conducive to heavy oil production.

SOR can be reduced significantly as permeability increased especially from 5000 mD to 25000 mD. This means that less amount of steam was needed to produce heavy oil.

Compared to 5000 mD, the cumulative oil productions at 1000 and 25000 mD were 8.19% lower and 26.59% higher, respectively and steam/oil ratio used were 6.47% higher for low permeability and 19.64% lower for high permeability.

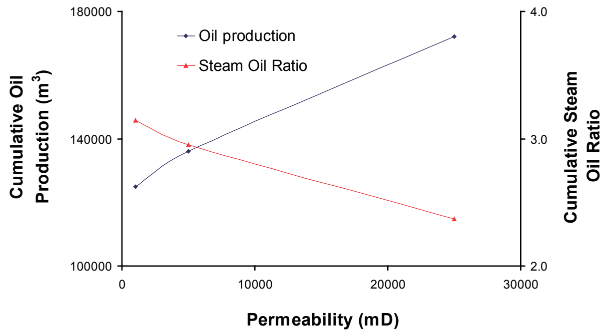

Fig. 3 Effect of permeability on cumulated oil production and steam oil ratio.

6.2 Effect of viscosity on heavy oil production

From the experimental results and correlation, the viscosities of heavy oil have been estimated to use in simulation at different conditions. The viscosities at 25 °C were selected as representatives to mention about the effect of viscosity on heavy oil production. As shown in Figure 1, these viscosities were 1611.3, 2764.5 and 3444.2 cP for original Japanese and its emulsions with 6.58 and 3.20 oil/water ratios, respectively.

The simulation results of effects of viscosity were presented in Figure 4 the effect of heavy oil viscosities on oil production and SOR used, respectively. It is clear that the production rate can be increased with the decrease of viscosity and SOR increased as viscosity increased because low viscosity fluid tends to move easier than viscous fluids. Therefore, at low viscosity, less amount of steam is required and steam/oil ratio becomes lower.

Compared to original Japanese oil at 1611.3 cP, the cumulative oil productions for viscosities at 2764.5 and 3444.2 cP were 6.12% and 7.99% lower and steam/oil ratio used were 6.49% and 8.52% higher, respectively.

6.3 Effect of pressure difference on heavy oil production

Pressure difference is the difference between injection pressure and production pressure used as a driving force for oil production. Pressure differences for this investigation were 0.5, 1.0 and 1.5 MPa. The results of pressure difference on oil production presented in Figure 4 showed the cumulative oil production and cumulative steam oil ratio (SOR), respectively.

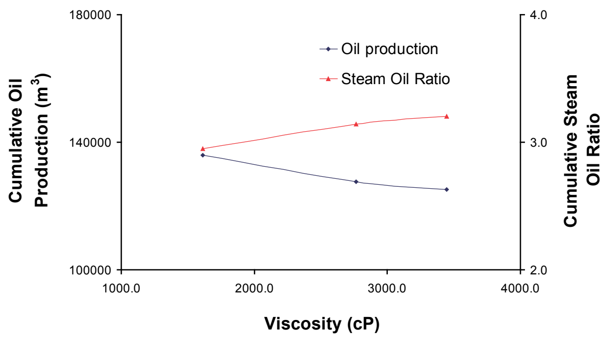

Fig. 4 Effect of viscosity on cumulated oil production and steam oil ratio.

Compared with 1.0 MPa pressure difference, cumulative oil production improved for 0.03% as pressure difference decreased to 0.5 MPa and increased less than 0.01% when pressure difference increased to 1.5 MPa. However, cumulative steam oil ratio will reduce 0.16% at 0.5 MPa pressure difference and increase 0.01% for higher one. It can be concluded that pressure difference has less effect in term of oil production because the flow of fluid depended mainly on viscosity and temperature of injected steam. However, lower pressure difference is more practical and favorable for optimization because it uses less steam and is good for equipment. If we use at higher pressure, equipment can be damaged and it affects maintenance cost in the future.

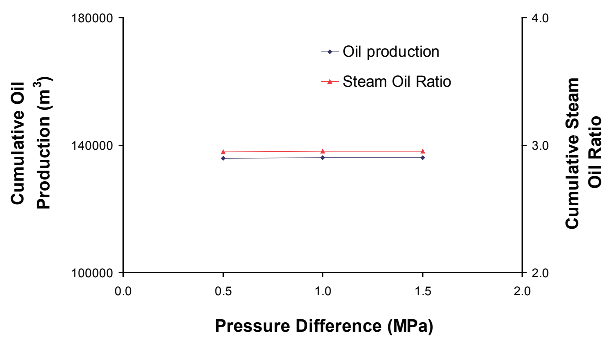

Fig. 5 Effect of pressure difference on cumulated oil production and steam oil ratio.

7. Conclusions

The viscosities of Japanese oil and its emulsions were measured and correlated. These data play a significant role in the heavy oil production, in addition to their future role in estimating the production from simulation. The viscosities were measured over the entire temperatures ranging from 15 to 180 °C. When steam was used, emulsion was formed and effect of hydrogen bonds on the viscosity has been explained. Moreover, the experimental data were correlated as a function of temperature based on the form in literature. The average absolute deviations were found to be 12.92%. Therefore, the correlation was suitable to represent the experimental data of viscosity of heavy oils and their emulsions.

For simulation, fluid properties and reservoir conditions are required to perform calculations and simulation. These properties and conditions are permeability, viscosities, porosity, depth or pressure, temperature, and so on. These parameters are essentially needed for investigation of their effects on heavy oil production. Most of them come from field data and later they are modified for sensitivity study. Furthermore, five-spot pattern is selected for simulation because it is effective and economical method for heavy oil production.

From the simulation results, heavy oil viscosity and permeability of reservoir played a key role for heavy oil production. Heavy production rate increased as permeability increased and heavy oil viscosity decreased. Furthermore, steam/oil ratio would be reduced if oil viscosity was lowered with high permeability reservoirs.

In addition, pressure difference has less effect for oil production but lower pressure difference is more practical and favorable for optimization because it provides little less oil, use less steam and good for equipment. If we use at higher pressure, equipment can be damaged and it affects maintenance cost in the future.

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