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The Effect of Montmorillonite on Water-in-Oil Emulsion of Omani Heavy Oil in a Steam Injection EOR Process

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Abstract: Understanding the behaviors of clays containing in the oil in the reservoir is important to design a process of enhance the oil recovery, especially steam flooding (Steam-EOR). The objective of this paper is to investigate the effects of montmorillonite clay on physical and rheological characteristics of heavy oil and its emulsion during Steam-EOR. The experiments were carried out using Omani heavy oil (21.5 °API at 15 °C) containing montmorillonite particles by changing their mass ratio in the oil. The measured results showed that the montmorillonite has no effect on the rheology of the original oil. The effect of montmorillonite on emulsion (water-in-oil) formed by steam injection was also studied by changing montmorillonite mass ratio in the oil. It has been cleared that the montmorillonite in the oil has a function to reduce the emulsion viscosity by contacting condensed water. The viscosity of the emulsion was 7 times less and 4 times less at temperatures of 40℃ and 50℃, respectively. Those results show that the highly polar components in the heavy oil could be absorbed on montmorillonite particles by changing salinity due to the condensed water.

Keywords: *Steam Injection EOR, Montmorillonite, Heavy Oil, Emulsion, Rheological*

Introduction:

Clay minerals have an important role on enhanced oil recovery (EOR) and improved oil recovery (IOR) (Das and Medhi, 2015). Clay minerals are present in the reservoir rocks and also mixed with the oil as they can be found in the produced oil, in the process plant, in the tanks, and in the pipelines as shown in Fig. 1.

Fig. 1 Examples of clays observed in the production tanks and pipelines

An emulsion can be performed in almost all oil production operations: inside the reservoir during EOR processes, well bores and well head, during transportation through the pipelines, crude storage and during petroleum processing (Kokal, 2005). During steam injection process the injected fluid has low salinity and could reduce the reservoir brine salinity. The oil in the reservoir contains a water-sensitive clay such as montmorillonite, the clay particles may disperse and migrate in the reservoir and affect the oil characteristics (Baptist and Land, 1966; Wilson et al., 2014). One of the sources of fresh water with low salinity and high temperature in the reservoir is the condensed water from the steam injection EOR especially when the reservoir is very deep. This hot water acts as a waterflood with low salinity (Terry, 2001). Also the pH gradient of the condensed water will decrease as a result of an increase in temperature (Aksulu et al., 2012). Austad et al. (2010) reported that the adsorption capacity of the montmorillonite increase as the pH decrease. The oil must contain polar component. The heavy polar components in the oil adsorbed into the montmorillonite particles (Clementz, 1976; Cosultchi et al., 2005). Montmorillonite has a high cation exchange capacity and plays a major role when it reacts with reservoir components in low-salinity enhanced oil recovery (Underwood et al., 2015). It swells when it contact with low salinity water (Tiab and Erle C., 2015). Thus, this paper discusses the emulsion formed as a result of the enhanced extraction process by steam injection EOR for Omani a heavy oil containing montmorillonite clay. This paper focuses on the emulsion viscosity, rheological and flow behavior formed in the reservoir in the existence and absence of montmorillonite in the oil. It also discusses about the effect of clay concentration in the viscosity of the emulsion. This work is helpful to highlight the effect of montmorillonite presence in the heavy oil on the emulsion mobility and its rheological behaviors during steam injection EOR process.

Materials and Methods for Experiments:

Crude oil and clay

The crude oil used in this study is a heavy crude oil with an API° gravity of (21.5 at 15 °C) from an Omani heavy oil field. The clay used is dry powder montmorillonite. The characteristics of the crude oil is presented in Table 1.

Table 1. Properties of the Omani heavy oil

Properties	Value
BS&W (v/v %)	0.40
Free H2O (v/v %)	0.30
Emulsion (v/v %)	0.10
Salt (Kg/M^3)	0.015
Density (g/cm^3 @ 20 °C)	0.9215
API (°API)	21.5
Viscosity (cP @ 30 °C)	1455

Montmorillonite – Oil mixing method:
The crude oil was heated to 50°C in autoclave oven for 30 minutes to reduce the viscosity for better mixing with montmorillonite. Then, the heated crude oil was taken to the stirrer. The stirrer had a temperature controller that was set to 50°C to maintain the reservoir temperature. The montmorillonite was added gradually to the oil while mixing at 400 rpm speed and then was kept for 30 minutes to mix properly. Different montmorillonite concentrations were added to the oil to check the quantity effect on the measurements. The montmorillonite ratios were 0%, 2 %, 10 % and 20 % (w/w). The rheological measurements were done for all these different four samples to check the effect of the montmorillonite on heavy oil before the injection of steam.

Water-in-montmorillonite/oil emulsification method:
In order to have the emulsion formed by the condensed water from steam injection close to a reservoir conditions, we used a High Pressure Microreactor MMJ-50 provided with a temperature controller and a motor with agitator equipment as shown in Fig. 2.

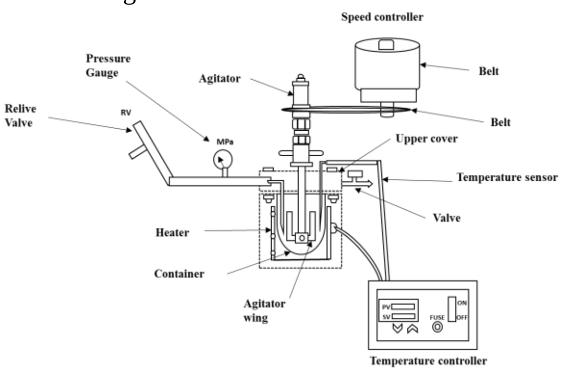

Fig. 2 High pressure microreactor MMJ-50

The water ratio was kept constant at 40 % (w/w) based on the water oil ratio from the subjected field data after secondary EOR method by waterflooding. The water used in the study was distilled water. The 40 % (w/w) water was poured into the container of the reactor and then 60 % (w/w) from the prepared mixed montmorillonite-oil by the stirrer was poured into the same container. As mentioned earlier, different concentrations (w/w) of montmorillonite were used in the oil to investigate the effect of different quantities on the rheological behaviors (0%, 2 %, 10 % and 20 %). The reactor temperature was set at 150℃ (to make sure that all the water in the emulsion converted into the vapor phase) while keeping the agitator wing rotation at 1000 rpm and the pressure at 0.4 MPa. The reactor kept running under this condition for one hour to form the emulsion. Then the temperature was decreased gradually until it reached 60~70℃ to allow the pressure decrease for safely handling the emulsion. The rheological measurements and microscopic analysis was immediately carried out on the formed emulsion.

Results and Discussion:
Rheological properties of montmorillonite-in-heavy oil:
Fig. 3 shows the viscosity vs. temperature for the different concentrations of montmorillonite-in-oil and the oil without montmorillonite (0 %). As can be observed in the figure, as the quantity of montmorillonite increase the viscosity of the oil also increase. This happened at lower temperature i.e. 50℃ and below. Fig. 4 shows the viscosity measurements for different montmorillonite concentrations at constant temperature 50℃. At temperature 50℃ and above the viscosity of montmorillonite-in-oil for all concentrations tended to have the same viscosity of the oil without montmorillonite (0%). This could be due to the increasing in temperature that affects the collision frequency between particles (García-García et al., 2009). When the particles collision frequency increases, their mobility in the oil increases as well and therefore the viscosity decreases faster. Furthermore the highly polar components in the heavy oil would be absorbed by the montmorillonite particles as can be shown in the microscopic image in Fig. 5. This modifies the clay surface charge and increases the clay particles size due the interaction between the highly polar components molecules in the oil adsorbed by the clay particles (Jada et al., 2006).

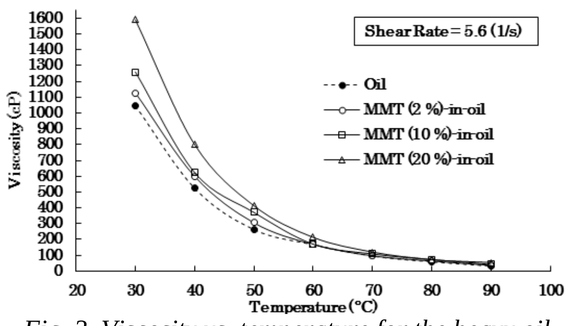

Fig. 3. Viscosity vs. temperature for the heavy oil with different montmorillonite concentrations of 0 %, 2 %, 10 % and 20 % (w/w %) at constant shear rate of 5.6 (1/s). The measurement was carried from low to high temperature.

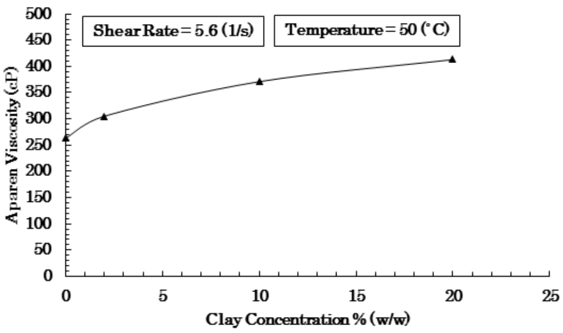

Fig. 4. Viscosity vs. clay concentration of the montmorillonite-in-heavy oil at constant shear rate of 5.6 (1/s) and constant temperature of 50℃.

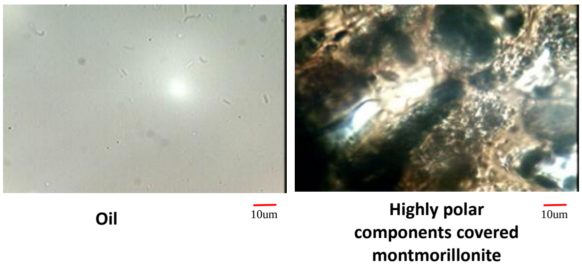

Fig. 5. Photo-microscopic of montmorillonite and montmorillonite-in-oil.

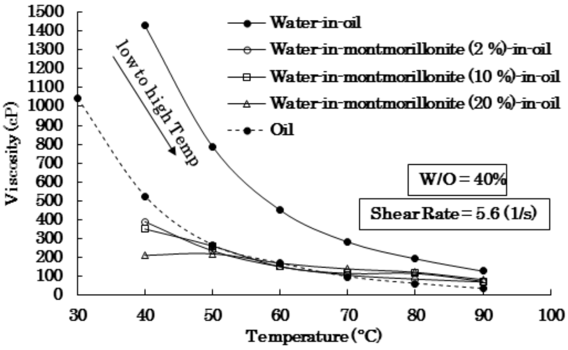

Fig. 6. Viscosity vs temperature for the water-in-montmorillonite-in-oil with different montmorillonite concentrations 0 %, 2 %, 10 % and 20 % (w/w %) at constant shear rate 5.6 (1/s). The measurement was carried from low to high temperature.

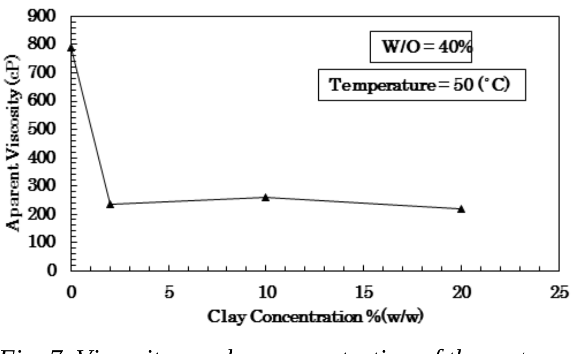

Fig. 7. Viscosity vs. clay concentration of the water-in-montmorillonite-in-oil emulsion at constant shear rate of 5.6 (1/s) and constant temperature of 50℃.

Rheological properties of water-in-montmorillonite-in-heavy oil:

Fig. 6 shows the viscosity vs. temperature for the heavy oil and for the water-in-oil emulsion formed by steam condensed water at different montmorillonite concentrations as discussed earlier. This part of the experiment started by 0 % concentration where only water-in-oil with no clay was tested. Then, gradually montmorillonite were added to form more concentrations (i.e. 2 %, 10 % and 20 %) to form an emulsion of water-in-montmorillonite-in-oil. The emulsion was formed by a High Pressure Microreactor MMJ-50 provided with a temperature controller and a motor with agitator equipment as shown earlier. As can be observed from Fig. 6, adding montmorillonite to the oil results in lowering the water-in-oil emulsion viscosity. The viscosity was 7 times less than the emulsion without montmorillonite at low temperature 40℃ (it was even less than the oil viscosity). Pourabdollah et al. (2011) came up with similar results regarding the effects of montmorillonite on heavy oil viscosity. At high temperature (90℃), the viscosity difference of the emulsion was not as much as in low temperature, but it was still lower with having the montmorillonite in the oil. At temperature 50℃ the viscosity was almost 4 times less. This reduction in viscosity expected to be due to the interactions between the highly polar components in the heavy oil adsorbed by the montmorillonite particles. Which led to increase the particles size and become heavy and settle down. Therefore the oil will contain less highly polar components and become lighter. The montmorillonite concentration does not have a critical effect on the viscosity as shown in Fig. 7.

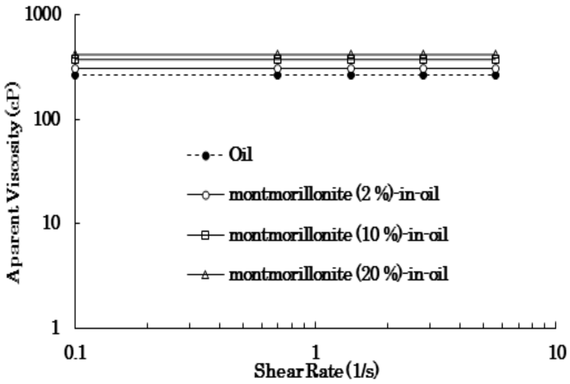

Fig. 8. Viscosity vs shear rate for the heavy oil with different montmorillonite concentrations 0 %, 2 %, 10 % and 20 % (w/w %) at temperature 50℃.

Fluid flow behaviour:

The oil was behaving as Newtonian fluid and the viscosity was the same as the shear rate was increasing even after adding montmorillonite to the oil as shown in Fig. 8. Also the water-in-oil emulsion behaves similar to the oil Newtonian fluid, whereas, the water-in-oil behaviour change when adding montmorillonite to the oil to (thixotropic flow). The viscosity was decreasing as the shear rate increase as shown in Fig.9.

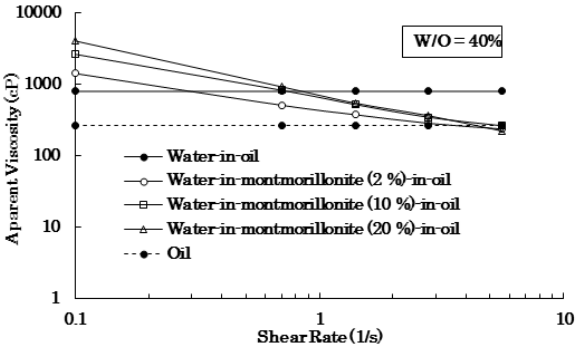

Fig. 9. Viscosity vs shear rate for the water-in-montmorillonite-in-oil emulsion at different montmorillonite concentrations 0 %, 2 %, 10 % and 20 % (w/w %) at temperature 50℃.

Conclusion:

Understanding rheological behaviours of heavy oil and its water-in-oil emulsion (when oil contains clay minerals) is important for steam injection EOR process in heavy-crude oil reservoirs. The presence of montmorillonite containing in heavy oil has an effect on its emulsion expected to be formed during the steam injection process. Several important observations have been made during this study.

The oil viscosity increase when as the quantity of montmorillonite at low temperature, but at high temperature the collision frequency between particles montmorillonite particles increase and led to reduce the viscosity. The viscosity decreases for the emulsion with montmorillonite as it was 7 times less and 4 times less at temperatures of 40℃ and 50℃, respectively. At temperature of 90℃ the viscosity was still lower than the oil without montmorillonite. The montmorillonite concentration does not have a critical effect on the viscosity of the emulsion. Adding montmorillonite to the oil did not change the Newtonian fluid behaviour of the oil. Forming water-in-oil emulsion did not change the flow behaviour of the oil, whereas, it changed when adding montmorillonite to the thixotropic flow characteristic. Furthermore, it was observed that the highly polar components in the heavy oil could be absorbed on montmorillonite particles by changing salinity due to the condensed water.

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