Study of the effect of heavy oil composition and temperature on wettability of reservoir rocks

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ABSTRACT

Wettability of reservoir rocks is a major factor that influences mobility and distribution of reservoir fluids (oil and water) within micro-pores. Also it has a significant impact on the determination of capillary pressure, relative permeability water flood behavior and simulated EOR. This paper presents a series of laboratory tests concerning the effects of heavy oil composition and temperature on rock wettability. Amott (imbibition and forced displacement) method was used to determine the wettability of reservoir rock in the presence of heavy oil (from Shengli Oilfield) and heavy oil + kerosene at temperatures of 40, 55, 70 and 80℃. The results show that the water-wet exponent of the rock tends to increase with the increase in kerosene composition. One possible explanation for this phenomenon may be that increase in the amount of kerosene results in a decrease in the fraction of polar compositions to be absorbed on the surface of rock. The experiments also showed that rock wettability in the presence of a fixed oil/kerosene ratio tends to shift to be water-wet as temperature increased from 40 to 80℃. This may be due to the aggravation of Brownian motion at higher temperatures, which results in less polar compositions to be adsorbed on rock surfaces. Besides, a sharp variation trend was demonstrated in rock wettability in the presence of different fractions of kerosene at a temperature of 40℃, whereas such variation at temperatures of 70 and 80℃ exhibited a more subtle trend. It is suggested that a sensitive temperature may exist at which the amount of absorbed and desorbed polar components on the surface of reservoir rocks are balanced due to Brownian motion, making the change in wettability hardly to occur.

INTRODUCTION

As is known to all, rock wettability has significant effect on the recovery properties including capillary pressure[6], residual oil saturation[5,10], and so on. An accurate understanding of rock wettability is crucial to determine the most efficient means of oil recovery, especially in the process of secondary and tertiary recovery. Generally speaking, both Amott and the USBM are the most widely used quantitative methods to measure the rock wettability, the results of which represent the average core wettability.

The Amott method[4,6,9] is widely applied to evaluate the rock wettability, which is a process of spontaneous imbibition depending on capillary pressure as a driving force. It is

remarkable that this method may arise some problems when the spontaneous imbibition is low, near neutral wettability. However, the USBM method has the advantage of quantifying wettability around intermediate wettability, while its disadvantage is that this method could only be used for a slug size core which is placed in centrifuge. Besides, the USBM method is also inaccurate for distinguishing intermediate wettability, such as mixed and fractional wettability.

Some studies indicate that wettability index is prominent reduced at lower initial water saturation. To eliminate the problem of saturation dependencies, the dynamic adsorption as an improved method is presented by Torske and Skauge[2], Holbrook and Bernard[1], et.al to measure rock wettability, which should preferably be performed with only one liquid phase present in the core. And n-heptanol and methylene blue are regarded relatively as the best choice to determine of the rock wettability for oil wet fraction and water wet fraction, respectively. Whereas the result by different methods (Amott, USBM, Dynamic adsorption) is possibly different, which may be caused by the different conditions of core, such as physical properties, mineralogy.

The disadvantages for the Amott and the USBM method include time-consuming, high cost and not suitable for monitoring the change of rock wettability as a function of time or other experimental parameters. To overcome these disadvantages, the nuclear magnetic resonance (NMR) method[12-17] is more widely applied to provide information of rock wettability at arbitrary saturation (water or oil). Since NMR method was firstly presented by Brown and Fatt[16], it has been gradually improved including data processing, computation formula and experimental reagents. And it is found that most of the previous studies were conducted by using refined or pure hydrocarbons on artificial unconsolidated formations, while it may neglect the effect of oil composition. This is not reasonable due to the fact that some polar components are well known to attach on the surface of rock and can change the rock wettability.

Investigations[3,6,8, 10,11]in recent years have been further and better conducted to research on the quantitative relationship between the rock wettability and various factors, such as the crude oil composition[7] and the rock type simultaneously, providing more accurate and convenient result among Amott, USBM and NMR method. However, few studies focus on the subtle change of rock wettability that performed with different oil composition under different temperature. One purpose of this paper is to discuss the effect of oil composition on rock wettability. In addition, the result of series of experiments is presented to indicate the influencing degree of different oil composition on rock wettability at different temperature.

Experiments

If rock wettability is to be determined by core analysis, precautions should be taken to minimize the interference from experimental conditions, such as established routines, apparatus and reagents, and artificial error including volume measurement. This section mainly consists of sample preparation including the properties of rock and crude oil measurement, experimental procedure and the results of the data processing.

Rock and Crude Oil Properties. Solvent extraction procedures are observed to induce invariably changes of wettability when removes crude oil from the core. Therefore, it is not advised to use in core handling whose results are dependent on rock wettability.

Considering this factor and experimental conditions, many standard sintered cores (78mm long cylinders and 25mm diameters, K_g around 1000×10^{-3} μm^2) with similar physical parameters, are used in this paper to eliminate the potential interference.

The heavy crude oil from Shengli Oilfield was used in this paper. The detailed analysis of crude oil including four components and the carbon distribution are shown in **Table 1** and **Fig 1**. Different mass fraction of kerosene was mixed with crude oil to obtain different oil compositions, whose viscosities were shown in **Table 2**.

Table 1: Four components of crude oil

Sample	Saturates, /%	Aromatics, /%	Resin, /%	Asphalt, /%
Cao 13-811 well	35.78	25.46	31.95	3.61

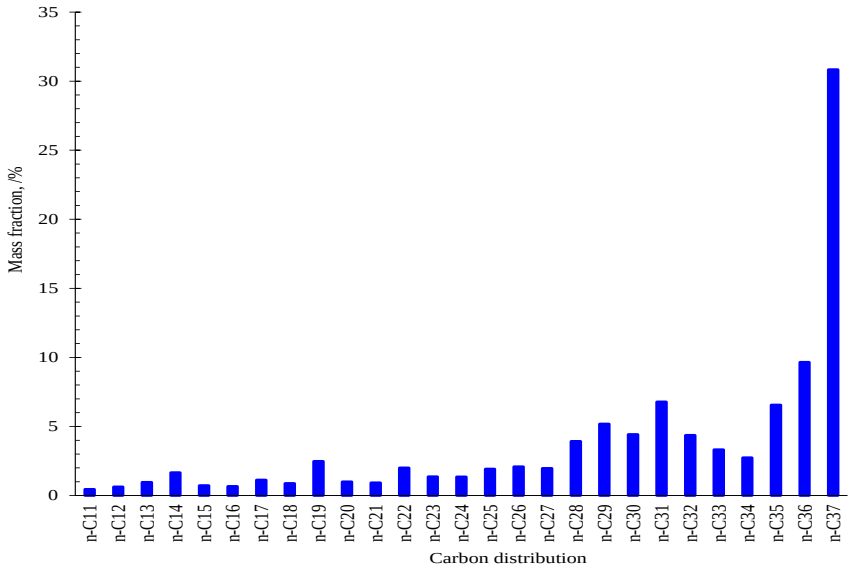

Fig 1: Carbon distribution of crude oil

Table 2: Measured viscosity of different oil composition

Temperature, ℃ / Kerosene, w%	40	55	70	80
0	3622	1100	421	273
20	154.5	81.7	50.2	38.6
30	79.7	48	34	26.4
40	52.6	33.7	26	20
45	40.7	26.2	19	15.6

Note that the unit of above measured viscosity is mPa · s.

Evidence to date demonstrates that the components, especially the higher molecular weight ranges or polar in nature, absorbed on the surface of rock is the most plausible reason for wettability changes. And some studies indicate that the polar component in the light oil ranging from C_{10} to C_{12} may reduce the wettability of a water-wet rock. Therefore, as is shown in Fig 1, polar components that distributed from C_{26} to C_{37} in heavy oil are more crucial for the rock wettability. And different oil composition that primarily relatively different in the mass fraction of polar component in the crude oil were used to conduct this study.

Measurement of rock wettability by Amott method. All the core samples were water-saturated by vacuum first, and then oil flooding till the irreducible water saturation. The volume of drained oil by spontaneous imbibition should be recorded as V_{o1} after the core sample immersed 20h in water. Meanwhile, the volume of discharged oil by water driving to residual oil saturation should be recorded as V_{o2}. Then the rock wettability can be calculated by V_{o1} and V_{o2}. Besides, for the rubber containing some polar component in core holder may be affected at higher temperature, the experiment is performed at relative low temperatures, which is absolutely far below the maximum suitable temperature of rubber. The basic experimental parameters are shown in **Table 3** and the water-wet index under different conditions is shown in **Table 4**.

Table 3: Basic experimental parameters

T, ℃ / Kerosene, w%	40			55			70			80		
	S_{wc}	V_{o1}	V_{o2}	S_{wc}	V_{o1}	V_{o2}	S_{wc}	V_{o1}	V_{o2}	S_{wc}	V_{o1}	V_{o2}
0	27.2	2.54	2.44	26.1	2.84	2.42	25.3	3.35	2.23	24.7	3.47	2.22
20	24.8	3.05	2.50	24.2	3.40	2.36	23.1	3.69	2.26	22.4	3.90	2.20
30	24	3.45	2.30	23.1	3.69	2.26	22.3	3.98	2.15	21.8	4.14	2.13
40	23.5	3.77	2.12	22.5	4.02	2.07	21.7	4.12	2.12	21.3	4.31	2.03
45	23	3.94	2.03	22.2	4.18	1.97	21.5	4.35	1.95	21	4.48	1.92

Note that the pore volume of all the experimental cores is around 10 ml (fluctuation range is 0.1ml) and the porosity is about 24%. S_{wc} represents of the initial water saturation.

Table 4: Water-wet index under different conditions

Temperature, ℃ / Kerosene, w%	40	55	70	80	Standard deviation
0	0.51	0.54	0.6	0.61	0.041
20	0.55	0.59	0.62	0.64	0.034
30	0.6	0.62	0.65	0.66	0.024
40	0.64	0.66	0.66	0.68	0.014
45	0.66	0.68	0.69	0.7	0.014
Standard deviation	0.056	0.05	0.031	0.031	

Note that the rock wettability is calculated by $V_{o1} / (V_{o1}+V_{o2})$.

The results shown in **Table 4** indicate that the core wettability range from intermediate wettability to strong water-wet. When the mass fraction of kerosene keeps constant, the water-wet index increases with the increase of temperature. While the different of standard deviation under different kerosene concentrations states that the effect of temperature on wettability conducted at higher concentration is less than at low concentration, for the difference of oil properties at relative high concentration seems subtle. Another possible explanation for this phenomenon is that increasing the amount of kerosene results in a decrease in the fraction of polar compositions to be absorbed on the surface of rock.

When the temperature keeps constant, the water-wet index increases with the increase in mass fraction of kerosene. Besides, rock wettability in the presence of a fixed oil/kerosene ratio tends to shift to be water-wet as temperature increased from 40 to 80℃. This may be due to the aggravation of Brownian motion at higher temperatures, which results in less polar compositions to be adsorbed on rock surfaces. Besides, a sharp variation trend was demonstrated in rock wettability in the presence of different fractions

of kerosene at the temperature of 40℃, whereas such variation at temperatures of 70 and 80℃ exhibited a more subtle trend.

CONCLUSION

1 Various improved measurement and experimental details are conducted in this paper to obtain accurate rock wettability.

2 Temperature and oil composition are demonstrated to impact the rock wettability significantly. A sensitive temperature may exist at which the amount of absorbed and desorbed polar components on the surface of reservoir rocks is balanced due to Brownian motion, making the change in wettability hardly to occur.

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