Determination of CO$_2$/crude oil system interfacial tension and dynamic interfacial tension by ADSA method

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ADSA was used to measure the interfacial tension of CO$_2$/crude oil system under simulated-formation conditions of temperature of 355.65K and pressure ranging from 7MPa to 23MPa. The test results indicated that the equilibrium interfacial tension of CO$_2$/crude oil system decreased as the systematic pressure increased. Intense mutual diffusion happened when CO$_2$ was in contact with crude oil. CO$_2$ extracted the light components of crude oil and was constantly dissolved in the crude oil, both processes ultimately achieving homeostasis. The dynamic interfacial tension between CO$_2$ and crude oil was large at the initial contact. After that, the interfacial tension gradually decreased, and finally reached dynamic balance. In addition, the interfacial tension of the CO$_2$/crude oil system decreased greatly with time as the systematic pressure increased.

Key words: ADSA; diffusion; equilibrium interfacial tension; CO$_2$/crude oil system; dynamic interfacial tension

INTRODUCTION

Miscible flooding technology is considered as one of the most cost-effective methods of EOR [1,2]. There is a variety of gases that can be injected; CO$_2$ for its wide sources and good flooding effect has been widely put into practical application in oil fields. The key for miscible flooding technology is to determine the minimum miscibility pressure between injection agent and crude oil [3-7]. The common experimental methods are slim-tube displacement test [8-12], rising bubble and vanishing interfacial tension (VIT) technique [13-15]. The latter technique has many advantages, e.g., ease of operation and visibility. ADSA was used to measure the relationship between the equilibrium interfacial tension and pressure of CO$_2$/crude oil system under the conditions of the stratum temperature, make sure how the interfacial tension changes with time, and get the variation of the dynamic interfacial tension with pressure.

EXPERIMENTAL

Experimental apparatus

High temperature and pressure interfacial tension meter, made by the French production company ST, was used in the experiments. The core of the device is a reactor with a window, operating at a temperature of 0 ~ 200 K, and a maximum working pressure of 70MPa. The needle used in the experiments was 0.81mm. ADSA is the most accurate method to measure the interfacial tension under high temperature and high pressure conditions. At first use the pump to form droplets on the stainless steel needle department, then take photographs of the droplets shape by an amplifying camera system, after that use the computer image processing system to get the outer contour of the oil droplets. Using the data of the needle diameter corrected by image magnification and the density of light phase and heavy phase, ultimately calculate the interfacial tension. The experimental apparatus is shown in Fig. 1.

Experimental samples

Crude oil was provided by Zhongyuan oilfield, formation temperature 355.65 K. CO$_2$ gas produced by Beijing Hua Yuan Co., purity of 99.995%, and petroleum ether produced by Sinopharm Chemical Reagent Company were used.

Experimental procedure

The experimental steps are as follows:

(1) Wash the whole experimental system with petroleum ether, and use hot nitrogen to remove residual petroleum ether.
(2) Do vacuum.
(3) Pump the oil sample into the injector with a manual pump.
(4) Start heating when both reactor and oil injector pump reach the set temperature (355.65K), then introduce CO$_2$ into the reactor pressurized with a manual pump. Shut valve until the reactor pressure stabilizes.
(5) Push oil slowly into the reactor through the oil injection pump, the formed small droplets around

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the probe are maintained for a period of time. Photograph the images of droplets by the camera system. Each droplet holds no less than 15 minutes, and each pressure point refers to at least three droplets. Finally, get the interfacial tension according to the shape of droplets.

(6) Adjust the experimental pressure and repeat step (5) and step (6) until the end of the experiment.

EXPERIMENTAL PHENOMENA AND RESULTS ANALYSIS

CO\textsubscript{2}/Crude oil equilibrium interfacial tension

Experimental Phenomena. (1) Dissolution and Extraction Effect. During the experiment, there is a medium exchange as the oil drop from the tip of the needle interacts with CO\textsubscript{2} from the reactor on the condition that the experimental pressure is higher than the bubble point pressure [16-18]. CO\textsubscript{2} is constantly dissolved into the oil droplets, and the light group of oil droplets is spread to CO\textsubscript{2} [19-22]. At the beginning of the contact between oil and CO\textsubscript{2}, the reaction is much stronger, and the light component of crude oil is constantly dissolved by supercritical CO\textsubscript{2} [23-25], as shown in Figure 2. After some dissolution and extraction, the heavy component of crude oil will be left behind, and the crude oil and CO\textsubscript{2} will eventually reach equilibrium state as shown in Figure 3. The interfacial tension at this moment can be considered as the equilibrium interfacial tension.
Effect of Pressure on the Dissolution and Extraction. It can be seen from the experiment that, as the pressure increases, the extraction of crude oil increases, and the interface between CO\textsubscript{2} and crude oil becomes unstable. A small amount of light components can be extracted out at a pressure of 16MPa, but the extraction effect becomes more significant when the pressure reaches 30MPa, as shown in Figure 4.

Experimental curve. The relationship between interfacial tension and pressure is shown in Figure 5.

![Fig. 5 Interfacial tension of CO\textsubscript{2}/crude oil system under different pressures.](image)

The equilibrium interfacial tension between crude oil and CO\textsubscript{2} decreases with the increase in pressure. The minimum miscibility pressure of the system calculated by the extrapolation method is 18.97MPa. When the pressure is lower than 18.97MPa, the interfacial tension decreases rapidly; but when the pressure reaches 18.97MPa, the interfacial tension decrease gets slower.

Dynamic interfacial tension between crude oil and CO\textsubscript{2}

The experiment showed that the interaction between CO\textsubscript{2} and crude oil is strong at the early stage, but with the extraction of light component of crude oil by CO\textsubscript{2}, and the dissolution of CO\textsubscript{2} into the oil, the interfacial tension between them changes. In order to study the effect of this process on the interfacial tension, the effect of contact time on the interfacial tension between crude oil and CO\textsubscript{2} was tested.

Figures 6 and 7 compare the curves of CO\textsubscript{2}/crude oil interfacial tension change with time at two different pressures. It can be seen from the figures that the interfacial tension between CO\textsubscript{2} and oil is large at the initial contact; but as the contact is getting longer, the interfacial tension decreases gradually, and eventually reaches dynamic balance. In addition, the higher the pressure, the larger is the magnitude of CO\textsubscript{2}/crude oil interfacial tension. The value of the equilibrium interfacial tension under 12MPa is more than 90% of the initial interfacial tension, but it turns to 80% at a pressure of 21MPa. Obviously, the interaction between CO\textsubscript{2} and oil is stronger, and the change of interfacial tension is bigger at a higher pressure. The actual reservoir CO\textsubscript{2} flooding belongs to multi contact miscible flooding; after the contact of CO\textsubscript{2} and oil, and multiple extraction and dissolution, the oil and CO\textsubscript{2} eventually get miscible. This leads to the interfacial tension between crude oil and CO\textsubscript{2} as an inevitable result of dynamic change.

CONCLUSION

1. Using the ADSA method, the interaction between CO\textsubscript{2} and crude oil can be followed through the reactor under simulated-formation conditions of temperature and pressure. There is a strong mutual diffusion at the beginning of the contact of CO\textsubscript{2} and crude oil, and as the pressure goes higher, both dissolution and extraction increase.
2. Experimental determination of CO₂ and crude oil interfacial tension data was performed under the conditions of temperature of 355.65K and pressure ranging from 7MPa to 23MPa. Experimental results show that CO₂/crude oil equilibrium interfacial tension decreases with the increase in pressure.

3. The interfacial tension between CO₂ and oil is large at the initial contact, then gradually decreases with time, and eventually reaches dynamic balance. Moreover, the higher the pressure, the larger is the magnitude of CO₂/crude oil interfacial tension change with time.

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REFERENCES


ОПРЕДЕЛЕНИЕ НА РАВНОВЕСНОГО И ДИНАМИЧНОГО МЕЖДУФАЗНОГО НАПРЯЖЕНИЯ НА СИСТЕМАТЕ СУРОВЫЙ ПЕТРОЛ - КСИСУДА ПО МЕТОДУ АДСА

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(Резюме)

Изложенная в АДСА-методе для измерения междуфазового напряжения в системе CO₂/суровый нефть при симулировании температуры 355.65 K и насыщенного температуре от 7MPa до 23MPa. Тестовые результаты показывают, что равновесное напряжение междуфазового напряжения изменяется с нараставанием напряжения в системе. Интенсивная взаимная диффузия порога, когда CO₂ в контакте с сырым нефть постоянно увеличивается, и изменяется с нарастанием напряжения между фазами. Мера напряжения может быть использована при повышении насыщенного нефти.

948