Bulgarian Chemical Communications, Volume 47, Number 3 (pp. 945 – 948) 2015

Determination of CO_2/crude oil system interfacial tension and dynamic interfacial tension by ADSA method

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Submitted May 4, 2014

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 visuality. 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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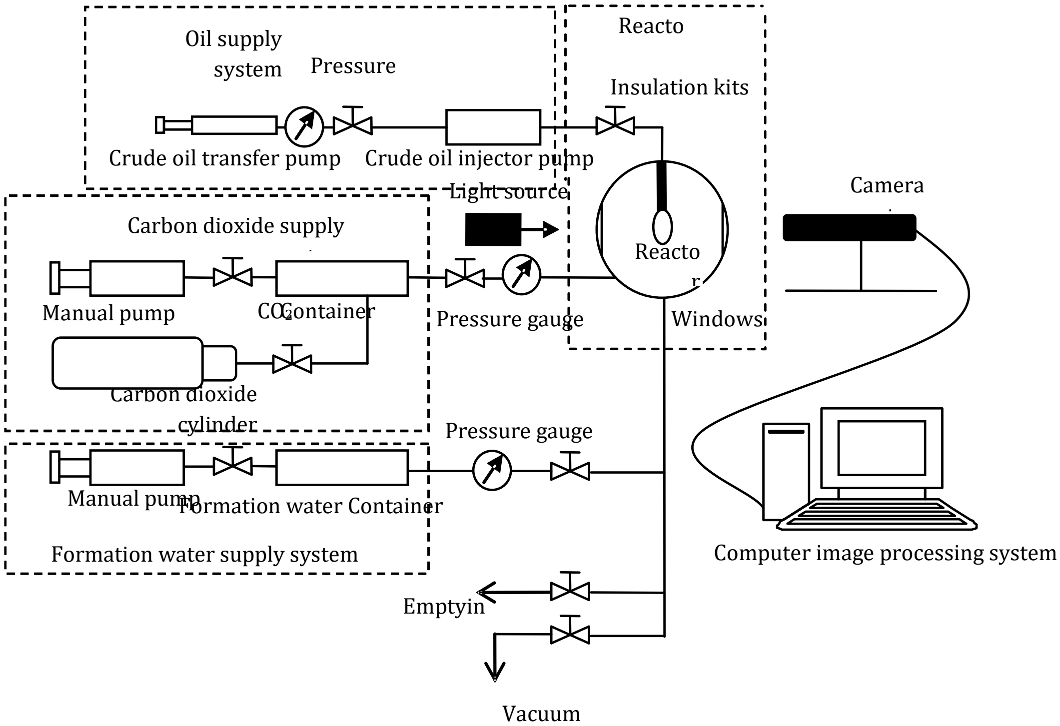

Fig.1 The schematic for the determination of interfacial tension by the pendant drop method

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_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_2 from the reactor on the condition that the experimental pressure is higher than the bubble point pressure [16-18]. CO_2 is constantly dissolved into the oil droplets, and the light group of oil droplets is spread to CO_2 [19-22]. At the beginning of the contact between oil and CO_2, the reaction is much stronger, and the light component of crude oil is constantly dissolved by supercritical CO_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_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.

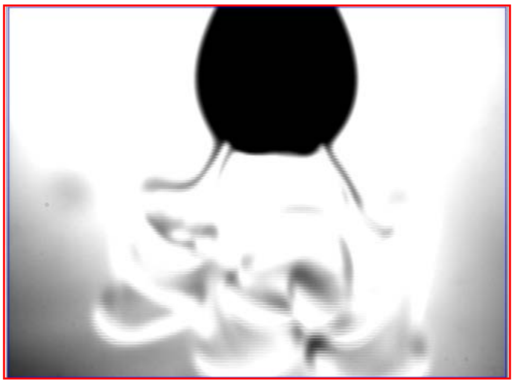

Fig. 2. Initial phase.

Fig. 3. Equilibrium phase.

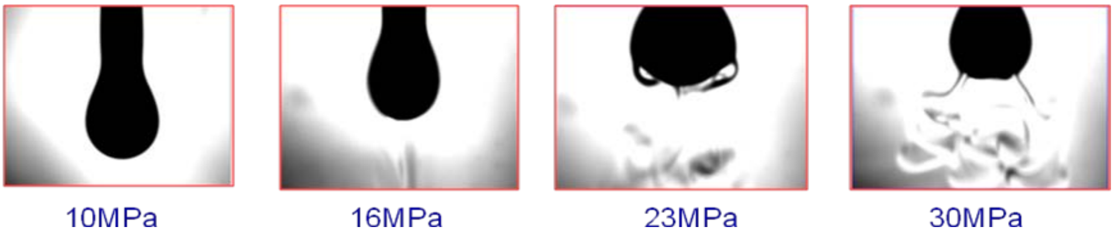

Fig. 4. Images of the pendant oil drop in CO_2/crude oil system under different pressures.

(2) 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_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.

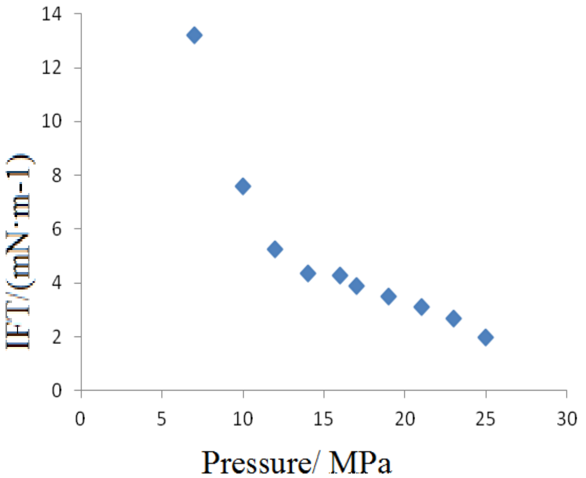

Fig. 5 Interfacial tension of CO_2/crude oil system under different pressures.

The equilibrium interfacial tension between crude oil and CO_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_2

The experiment showed that the interaction between CO_2 and crude oil is strong at the early stage, but with the extraction of light component of crude oil by CO_2, and the dissolution of CO_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_2 was tested.

Figures 6 and 7 compare the curves of CO_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_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_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_2 and oil is stronger, and the change of interfacial tension is bigger at a higher pressure. The actual reservoir CO_2 flooding belongs to multi contact miscible flooding; after the contact of CO_2 and oil, and multiple extraction and dissolution, the oil and CO_2 eventually get miscible. This leads to the interfacial tension between crude oil and CO_2 as an inevitable result of dynamic change.

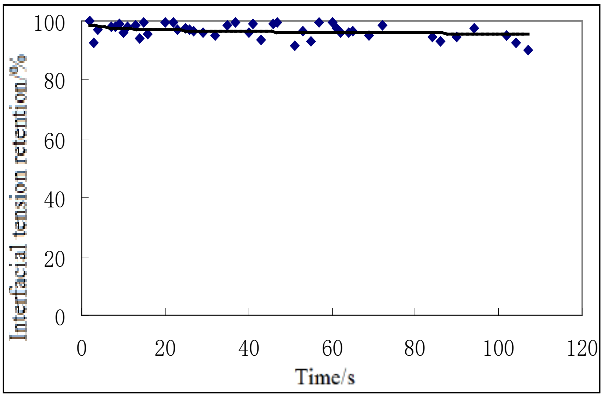

Fig.6. The curve of CO_2/crude oil system interfacial tension change with time under 12MPa.

CONCLUSION

1. Using the ADSA method, the interaction between CO_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_2 and crude oil, and as the pressure goes higher, both dissolution and extraction increase.

2. Experimental determination of CO_2 and crude oil interfacial tension data was performed under the conditions of temperature of 355.65K and pressure ranging from 7MPa to23MPa. Experimental results show that CO_2/crude oil equilibrium interfacial tension decreases with the increase in pressure.

3. The interfacial tension between CO_2 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 CO_2/crude oil interfacial tension change with time.

Acknowledgments. *The authors gratefully acknowledge the support of the Beijing University of Aeronautics and Astronautics and the Guilin University of Aerospace Technology. The work is supported by the project of the Guilin University of Aerospace Technology under Grant No. X12Z002.*

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ОПРЕДЕЛЯНЕ НА РАВНОВЕСНОТО И ДИНАМИЧНОТО МЕЖДУФАЗНО НАПРЕЖЕНИЕ НА СИСТЕМАТА ВЪГЛЕРОДЕН ДИОКСИД/ПЕТРОЛ ПО ADSA-МЕТОДА

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Постъпила на 4 май, 2014 г.

(Резюме)

Използван е ADSA-методът за измерване на междуфазовото напрежение в системата CO_2/суров петрол при симулирани условия на температура от 355.65 K и налягания в интервала от 7MPa до 23MPa. Тестовите резултати показват, че равновесното междуфазово напрежение намалява с нарастване на налягането в системата. Интензивна взаимна дифузия протича когато CO_2 е в контакт със суровия петрол и постоянно се разтваря в петрола, като накрая се достига до устойчиво състояние. Динамичното междуфазно напрежение между фазите е високо при първоначалния контакт. След това то постепенно намалява, като в края на контакта се достига динамично равновесие. Освен това междуфазното напрежение в системата CO_2/суров петрол намалява значително при повишение на налягането.