Effect of Impure CO_2 Injection on Physical Properties of Crude Oil

He Tang[1, a, *], Hao Chen[1, b], Xiansong Zhang[2, c], Baozhen Li[2, d]

[1]*State Key Laboratory of Petroleum Resources and engineering, China University of Petroleum, Beijing 102249, China*

[2]*State Key Laboratory of Offshore Oil Exploitation, Beijing 100027, China*

[a] *291290331@qq.com*, [b] *chenhao@cup.edu.cn* , [c] *zhangxs@cnooc.com.cn*, [d] *libzh2@cnooc.com.cn*

Keywords: impure CO_2; gas oil ratio; expansion; viscosity reduction;

Abstract: CO_2 has been studied for many years as a displacement agent for reservoir enhanced oil recovery. However, due to the difficulty of purification of CO_2 and high purification costs, the use of impure CO_2 flooding is often implemented in the field. Therefore, in this paper, to study the change of crude oil properties by injecting gas with different purity of CO_2, based on the oil and gas of QHD29-2E oilfields, expansion tests and simulations were conducted to determine and simulate the saturated pressure, swelling factor, gas oil ratio(GOR), density and viscosity of CO_2-crude oil under pure/impure conditions. Results show that under the same pressure, with the decrease of CO_2 purity, the solubility of the injected gas decreases, the swelling factor decreases, and the viscosity reduction effect becomes worse. The intermediate component (C_2-C_6) in the impure CO_2 can improve the dissolution, swelling and viscosity reduction of the crude oil by impure CO_2 injection to some extent.

1. Introduction

In order to achieve the win-win result of oil and gas production and CO_2 emission reduction, CO_2 gas injection into the reservoir to enhanced oil recovery has become one of the important ways of CO_2 resource utilization[1]. In the process of CO_2 gas injection, there may be a variety of oil displacement mechanisms, which are closely related to the phase behaviors. CO_2 miscible flooding has been studied abroad for many years, and has been greatly welcomed in comparison with natural gas, flue gas or N_2 [2-4].

CO_2 injection changes the physical and chemical properties of crude oil, such as viscosity, density, Swelling factor, interfacial tension, saturated pressure [5-7]. The study of fluid phase in gas injection process is the basis of other reservoir engineering research, and the results can provide the basis for gas injection process development, reservoir design and dynamic analysis. In the same oil field, due to the different fluid types, the swelling capacity, viscosity decrease degree and the interfacial tension of oil and gas are different when the gas is injected [8-9]. In 1998, J.L.Creek and

J.M.Sheffleid [10] conducted CO_2 flooding experiments on different crude oils in the Permian Basin. The viscosity, density and interfacial tension of the CO_2-crude oil system were calculated in detail. T.G Monger and A.Khakoo [11] have studied the influence of contamiant gas (5-10 mol% N_2, CH_4, H_2S or SO_2) in CO_2 on the swelling factor of crude oil.

However, at present, most domestic and foreign researches focus on the influence of pure CO_2 injection on the physical properties of crude oil, or the influence of impure CO_2 on the single physical properties of crude oil. The research on the typical phase characteristics of impure CO_2-crude oil system has rarely been published.

In this article，the saturated pressure, swelling factor, gas oil ratio, density, viscosity and other physical parameters of CO_2-crude oil system under pure/impure conditions were measured by PVT cell of gas injection expansion experiment. Experimental parameters and numerical simulation of PVTi module in Eclipse software were fitted. According to the data obtained from simulation, the influence of injection gas with different purity of CO_2 on the physical properties of crude oil was obtained from the aspects of dissolution capacity, swelling capacity and viscosity reduction capacity.

2. Experiment

The gas injection expansion experiment under different CO_2 purity were carried out at the formation temperature. After many times gas injection, the effects of different CO_2 purity gas on viscosity, density, swelling factor, saturated pressure and dissolved gas oil ratio of crude oil were determined.

2.1 Equipment Apparatus

The experiment was performed in RUSKA-3000 high pressure high temperature visual PVT apparatus and high precision gasometer flask produced by Ruska Company (USA). Fig.1 illustrates the PVT system. The entire assembly was enclosed in a heated bath to maintain the required temperature.

2.2 Reservoir Fluids and Injected Gas

The crude oil used in the experiment was configured according to the reservoir fluids components and GOR datas of QHD29-2E oilfield. Tab. 1 shows the components of the reservoir fluids. In order to obtain the influence of the contamiant gas in the injection gas, the injection gas with CO_2 purity of 100% and 40% was selected for comparison. Tab. 2 shows the components of CO_2 purity of 40% injection gas. Reservoir temperature and reservoir pressure are 112.1℃ and 31.96 MPa.

2.3 Procedure

All measurements were done using the PVT device. Injected gas was added into crude oil according to four gas injection volumes. Based on formation crude oil, the mole fractions of injected gas and formation crude oil were 15%, 30%, 45% and 60%, respectively. After complete dissolution, the parameters were determined, and the highest dissolved gas pressure was 40 MPa.

3. Simulation

Due to experiment taked a long time and the process was tedious, in this article, the numerical simulation software ECLIPSE was used to simulate the expansion experiment.

3.1 Compositional Model

The compositional model was established through the PVTi module of ECLIPSE software, and the model was fitted with PVT high pressure physical parameters of QHD29-2E oilfield crude oil. By regression calculation, the saturated pressure is 18.01 MPa at the reservoir temperature of 112.1℃, and the actual saturated pressure is 17.92 MPa, with an error of 0.50%. The calculated density is 0.6833 g/cm^3 at saturated pressure, and the actual density is 0.6798 g/cm^3, with an error of 0.51%. According to the fitting effect, the difference between the simulated value of crude oil and the actual experimental value is small. The componsitional model conforms to the actual nature of crude oil and can be used for the simulation experiment of gas injection expansion.

3.2 Simulation of Expansion Experiment

Based on the compositional model, the simulation experiment of gas injection expansion was conducted. Respectively, the molar ratios of gas injection were 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55% and 60%. The injection gas samples were set as CO_2 with purity of 100%, 70%, 40% and CH_4 with a purity of 100%. Physical parameters such as saturated pressure, GOR, density, swelling factor and viscosity were obtained by simulation.

4. Results and discussions

Fig. 2 to Fig. 7. show the comparison of simulation results and the experimental results.The real laws of the experiment are reflected through the simulation. The dissolving capacity of injected gas is reflected by GOR and saturated pressure. The swelling capacity is mainly reflected by the swelling factor and the density of crude oil, and the viscosity reducing capacity is mainly reflected by the viscosity of crude oil.

4.1 Dissolving Capacity

As shown in Fig. 2, with the increase of injected gas volume, saturated pressure of the oil and gas system raises. After twelve gas injection, the GOR of oil and gas system is 220.28 m^3/m^3. When the contamiant gas is mixed into CO_2, the pressure required to dissolve the same volume of injected gas increases slightly. Obviously, the lower the purity of CO_2, the higher the saturated pressure, the more difficult it is to dissolve the gas into the crude oil.

Fig. 3 shows the relationship of the saturated pressure and GOR of the gas-oil system. Compared with CH_4, the dissolving capacity of impure CO_2 injection gas is stronger and closer to the dissolving capacity of pure CO_2 under the same saturated pressure. Due to the poor dissolving capacity of CH_4 and N_2 in the contamiant gas, under the same saturated pressure, compared with the pure CO_2， the injection gas with CO_2 purity of 40% and 70% have lower GOR, but the difference is not big. The analysis shows that although the content of the intermediate hydrocarbon components (C_2-C_6) is only 9% of the contamiant gas, its solubility in crude oil is stronger than that of CO_2. Therefore, the solubility of impure CO_2 injection gas in crude oil is improved to a certain extent.

4.2 Swelling Capacity

Fig. 4 shows the relationship of the swelling factor and GOR of the gas-oil system. Apparently, the swelling factor is linearly proportional to GOR. The slope of the curve for pure CO_2 is 0.003, higher than that of CO_2 with the purity of 70% and 40%, which are 0.0028 and 0.0025, respectively. It means that under the same GOR, pure CO_2 can expend more crude oil than the impure CO_2.In fact, with the decrease of CO_2 purity, the dissolving capacity of the injected gas decreases, leading to the decrease of the swelling factor. In contrast, CH_4 has the lowest swelling factor, and only a small amount of gas can be dissolved under the same saturated pressure. Therefore, the expansion of crude oil is limited.

Fig. 5 is the relationship of injected gas volume and oil density. As the volume of injected gas increases, density of crude oil decreases. There are two reasons for the decrease in density, on the one hand， the injected gas is dissolved in crude oil, resulting in volume expansion, on the other hand, due to pure CO_2 is supercritical state under high temperature and high pressure, the density is closer to the liquid density than the gas phase, as a result, after the injection of dissolved gas into crude oil, the decrease of crude oil density is smaller than that of injection gas with CO_2 purity of 70% and 40%. Under the condition of formation, the injected gas and crude oil have less difference in density. Compared with pure CO_2 and impure CO_2, pure CH_4 has the smallest decrease in crude oil density, and has the worst swelling capacity.

4.3 Viscosity Reducting Capacity

Fig. 6 shows the influence of injected gas with different CO_2 purity on viscosity of crude oil under different saturated pressures. It can be seen that as saturated pressure increases in the oil, the viscosity of dissolved gas oil decreases. Obviously, the viscosity reduction effect of injection gas containing CO_2 is superior to that of pure CH_4. Approximately, the relationship between the saturated pressure and viscosity of pure CH_4 is linear. When the saturated pressure increased by 10 MPa, the viscosity of crude oil decreased by 0.2 cP after injecting CH_4.In addition, with the decrease of CO_2 purity, the solubility of CO_2 in crude oil decreased, the GOR decreased, and the viscosity reduction effect became worse. However, under high saturation pressure, the viscosity reduction effect of pure CO_2 and impure CO_2 is almost the same.This is due to physical properties of the CO_2 and oil begin to be closer under higher conditions. The viscosity reduction effect of impure CO_2 on crude oil is obviously better than that of CH_4 because of the presence of certain intermediate hydrocarbon components (C_2-C_6).

As is shown in Fig. 7, as gas dissolves in the oil, GOR increases and viscosity decreases. The original oil viscosity is 0.85 cP. After twelve gas injection, for pure CH_4, the viscosity decreases by 59.8%, for pure CO_2, the viscosity decreases by 77.1%, for CO_2 with purity of 70%, the viscosity decreases by 76.1%, for CO_2 with purity of 40%, the viscosity decreases by 73.8%. The viscosity reduction effect of the injection gas with CO_2 purity of 100% is obviously better than that of the impure CO_2. On the one hand, the solubility of CO_2 gas is stronger, and the viscosity reduction effect is better; on the other hand, the saturated pressure required to dissolve the same injection gas is lower, therefore, the viscosity of crude oil is decreased more obviously.

5. Conclusion

Based on the oil and gas of QHD29-2E oilfields, physical properties of the different purity CO_2 and crude oil system was investigated. The saturated pressure, GOR swelling factor, density and viscosity of CO_2 and crude oil system under pure / impure conditions were measured and simulated by gas injection expansion test and simulation. From the point of dissolving capacity, swelling capacity and viscosity reducing capacity, the effect of injectied gas with different purity of CO_2 on the physical properties of crude oil was obtained.

Results show that with the decrease of CO_2 purity, under the same pressure, the solubility of the injected gas decreases obviously, the swelling capacity decreases, and the viscosity reducting capacity becomes worse. The intermediate component in the impurity gas can improve the dissolvting capacity, swelling capacity and viscosity reducing capacity of the impure CO_2 injection to a certain extent. Therefore, the optimization adjustment of the component in the injected gas is one of the potential means to control the CO_2 flooding in the target block.

TABLE I. Components of the reservoir fluids

Component	Mol (%)
C_1+N_2	42.92
CO_2+C_2-C_{10}	27.33
C_{11}	29.75
Total	100

TABLE II. Components of CO2 purity of 40% injection gas.

Component	Mol (%)
CO_2	40
C_1+N_2	54.6
C_2-C_6	5.4
Total	100

References

[1] Hara, S.K.,Chrisman, P.G. *Investigation of the cyclic countercurrent light-oil/CO_2 immiscible process. SPE/ODE symposium on enhanced oil recovery. Society of Petroleum Engineers, 1990.*
[2] *Burger J E, Mohanty K K. Mass Transfer From Bypassed Zones During Gas Injection. SPE Reservoir Engineering, vol. 12, 1997, pp.124-130.*
[3] *Stalkup F I. Carbon Dioxide Miscible Flooding: Past, Present, and Outlook for the Future. Journal of Petroleum Technology, vol.30, 1978, pp. 1102-1112.*
[4] *Jeong M S, Lee K S. Simulation Study on Miscibility Effect of CO_2/Solvent Injection for Enhanced Oil Recovery at Nonisothermal Conditions. Mathematical Problems in Engineering, vol. 12, 2016, pp.1-9.*
[5] *Dong M, Huang S S, Srivastava R. A laboratory study on near-miscible CO_2 injection in steelman reservoir . Journal of Canadian Petroleum Technology, vol. 40, 2001, pp. 53-60.*
[6] *Shen P, Huang L. Flow mechanisms of multi-phase multi-component CO_2-crude oil system in porous media. Acta Petrolei Sinica, vol .30, 2009, pp. 247-251.*
[7] *D. S. Ma, K. Zhang, J. S. Qin. Flow Properties of CO_2/Crude Oil in Miscible Phase Flooding. Petroleum Science & Technology, vol. 28, 2010, pp. 1427-1433.*
[8] *Shokir E M E M. CO_2–oil minimum miscibility pressure model for impure and pure CO_2 streams. Journal of Petroleum Science and Engineering, vol. 58, 2007, pp. 173-185.*
[9] *Orr F M, Jensen C M. Interpretation of pressure-composition phase diagrams for CO_2-crude oil systems. Society of Petroleum Engineers Journal, vol. 24, 1984, pp. 485-497.*
[10] *Orr F M, Silva M K. Equilibrium phase compositions of CO_2 hydrocarbon mixtures-part 1: Measurement by a continuous multiple contact experiment. Society of Petroleum Engineers Journal, vol. 23, 1982, pp. 272-280.*
[11] *T.G Monger, A.Khakoo. The Phase Behavior of CO_2-Appalachian Oil Systems. 56^{th} Annual Fall Technical Conference and Exhibition of the SPE of AIME, San Antonio, Texas, October 5-7, 1981.*

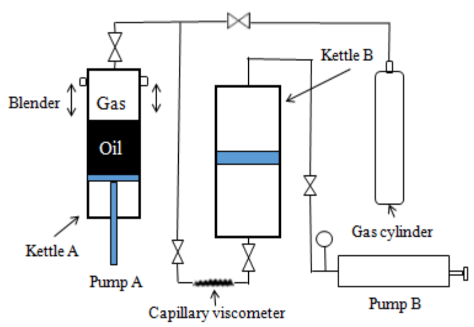

Figure1. Schematic of PVT cell.

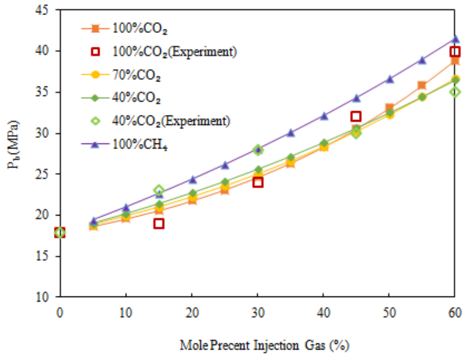

Figure2. Mole precent injection gas versus P_b

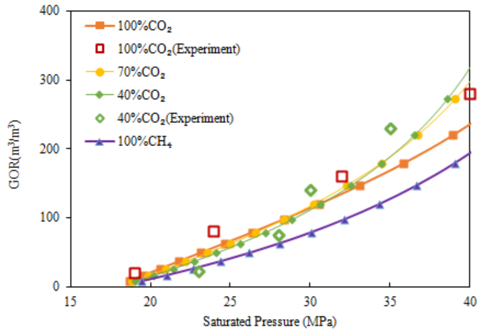

Figure 3. GOR versus P_b

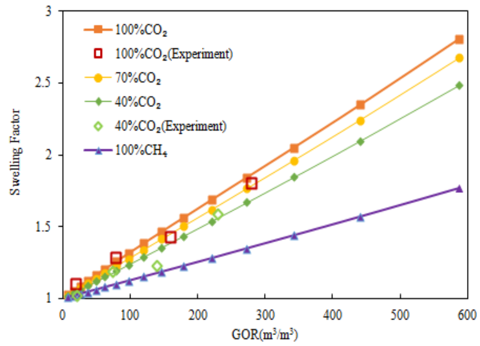

Figure 4. GOR versus swelling factor

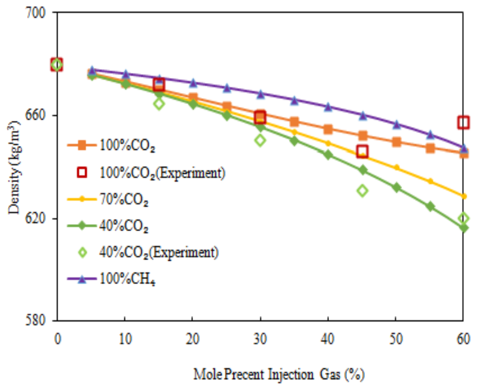

Figure 5. Mole precent injection gas versus denesity

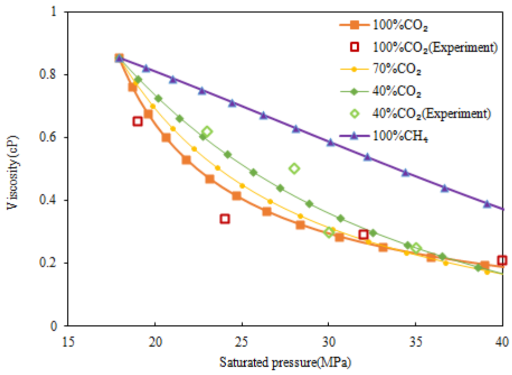

Figure 6. Viscosity versus P_b

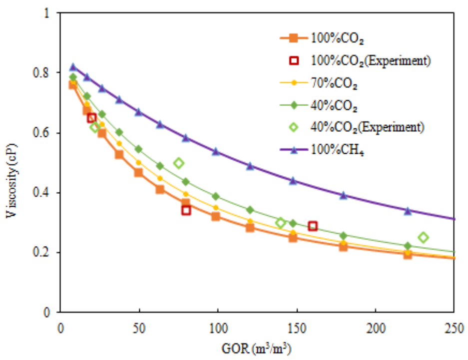

Figure 7. Viscosity versus GOR