Lower limit of CO_2 content for production gas re-injection in an offshore oilfield

Xiansong Zhang[1,2], Hao Chen[*1,2], Bowen Li[2], Bao Zhen Li[1] and He Tang[2]

[1]State Key Laboratory of Offshore Oil Exploitation, Beijing, People's Republic of China, 100027;

[2]Key Lab of Petroleum Eng. of MOE, China University of Petroleum, Beijing, P. R. China, 102249;

Keywords: offshore oilfield, production gas re-injection, lower limit of CO_2 content.

Abstract. The discovery of the natural gases with varying CO_2 content (24-90%) on top of the oil reservoir provides big potential for gas flooding in Qinhuangdao oilfield. However, the contamination of the gases, which is mainly methane, greatly limits the promotion of miscible flooding. In this paper, near-miscible flooding was proposed considering the comparative recovery effect as increasingly lab tests and field tests indicated. In this paper, the effect of impurity content in the production gas on the near-miscible interval are studied. The lower limit of CO_2 content for production gas re-injection in the targeted well are determined. It is concluded that CO_2 content higher than 50% can achieve near-miscible flooding.

1. Introduction

QHD 29-2 block is a newly discovery offshore oilfield of China. Due to the low water injectivity, conventional water flooding is not suitable. However, the big natural gas sources with varying CO_2 content on top of the oil layer provides big potential for the development of the oilfield with gas flooding. The original pressure and temperature are 36.53 MPa and 122.5 ^oC, respectively. The CO_2 content in the production gas varies from 24 to 90 mol%, MMP enhanced with the mixing of the natural gas (mostly CH_4). Besides, the high wax content and high pour point of the reservoir fluids further increase the difficulty to achieve miscible flooding. Thus, re-injection of the production natural gas with varying CO_2 content is proposed recently.

In 1994, Thomas et al. presents a new opinion that many successfully miscible flooding would be better described as near-miscible, depending on the evaluation techniques. In addition, laboratory tests and some field tests have fully verified that near-miscible injection can obtain a comparable recovery as miscible flooding (Shyeh-Yung and Stadler, 1995) [1]. Moreover, from both economic and operational points of view, near-miscible flooding sounds very attractive. The cost of injection gas volume and compression reduce with the decrease of the pressure. Also, the reduction of the gas mobility improves the sweep efficiency. To some extent, it obtained a certain degree of mobility control effect.

Theoretically, near-miscible flooding refers to the gas injection of close but not complete miscibility with the oil (Sohrabi et al., 2007) [2]. It is much more complicated because both of the upper and lower boundaries of the near-miscible region in the vicinity of MMP has to be determined. Reservoir temperature, oil composition, and the purity of injected CO_2 are considered to be the main factors of MMP. Typically, the contaminants are methane, nitrogen, or intermediate hydrocarbons, such as ethane, propane, butane, and H_2S. In general, the presence of CH_4 or N_2 in CO_2 can greatly increase the CO_2 MMP, while the presence of H_2S, C_2H_6, or intermediate hydrocarbons (such as C_3, C_4) can decrease the CO_2 MMP [3].

In view of the potential gas sources and significant costs of gas separation, production gas re-injection, if near-miscibility could be achieved, is a practical method to develop QHD offshore oilfield. The contaminants of the production gases is one of the main factors for assessing the feasibility to implement near-miscible flooding. In other words, the lower limit of CO_2 content in the production gas needs to be determined.

So far, study on near-miscible flooding is very limited. To begin with, no reliable method to determine the pressure region of near-miscible injection, especially for the gas sources with varying contaminants. Besides, the effect of mixing gas on miscibility degree is still not very clear. In this paper, taken the well QHD 29-2E-4 as an example, pressure regions of near-miscible flooding under different CO_2 content are determined according to the slim tube simulation results fitted with the data of PVT test. On this basis, the lower limit of the CO_2 content for the oil in well QHD 29-2E-4 to implement near-miscible flooding under reservoir conditions (36.53 MPa , 122.5 ^oC) is predicted.

2. Methodology

2.1 Experimental

The oil and gas samples are collected from the well 29-2E-4 in QHD 29-2 offshore reservoir. Table 1 is the physical properties of the crude oil. The live oil was recombined using RUSKA-2730 high pressure high temperature visual PVT apparatus produced by Ruska Company (Houston, Texas, USA). More details of the operation procedure to conduct PVT test can be found in previous publications (Chen et al., 2016) [4].

Table 1 Physical properties of crude oil

	Parameters	Value	Units
Reservoir condition	Pressure	36.53	MPa
	Temperature	122.5	℃
Fluid properties	Saturation pressure	11.11	MPa
	Gas/oil ratio	64.0	m^3/m^3
	Volume coefficient of the oil	1.224	m^3/m^3
	Oil density (reservoir condition)	0.7352	g/cm^3
	Oil viscosity (reservoir condition)	0.67	mPa/s
	Died oil density	0.8329	g/cm^3
Composition of Well-flow content	C_1+N_2	26.10	%
	CO_2+C_2~C_{10}	37.92	%

2.2 Simulation

A compositional model was built by component lumping technique using PVTi, Eclipse 300. EOS parameters were adjusted to match the PVT data. Molecular weight of the plus fraction was adjusted to fit the oil density. Coefficients of Pedersen viscosity components were adjusted to fit the oil viscosity. Binary interaction coefficients between CO2 and hydrocarbon components as well as CO2 volume shift factor were adjusted to fit saturation pressure. With the compositional model, slim tube simulation was conducted and parameters of displacement efficiency and IFT can be obtained. Based on component chopping technique, 7 pseudo components were divided.

2.3 Empirical Formulas

Several empirical formulas for predicting MMP of CO2 and oil systems based on the specific conditions of crude oil and gases were established in the past decades. On this basis, according to the compositions of crude oil, solution gas, and injection gas, MMP can be calculated and compared with the results of slim tube simulation.

2.4 Results and discussion

The lower and upper boundaries of near-miscible flooding of the oil samples with different CO2 contents were obtained from both slim tube simulation and empirical correlations. Displacement efficiency and IFT are used together to comprehensively determine MNMP and MMP. Also, the effect of contaminant on the degree of miscibility was discussed.

2.5 Slim tube simulation

Slim tube simulation under 5 different CO_2 contents (100%, 85%, 70%, 55%, and 40%) was conducted using Eclipse based on the compositional model fitted with the data of PVT tests. According to the simulation results, the displacement efficiency increase linearly first and then leveled off with the increase of injection pressure. While the IFT decrease sharply and then slows down. However, it is not easy to distinguish the breakpoints from the smooth curves. Thus, the IFT data was transformed to semilog coordinate, where a much more significant breakpoint can be clearly identified to be the lower boundary of near-miscible flooding. In this paper, 0.001 mN/m is regarded as the ultra-low IFT which can be used as the indication of miscibility from the engineering point of view. On this basis, pressure interval of near-miscible flooding with varying CO_2 content were determined. Fig.1 and Fig.2 are the three regions divided by the upper and lower boundaries determined by displacement efficiency and IFT with the CO_2 content of 85%, respectively. Statistically, the lower boundaries are all about (0.8-0.86) to the upper boundaries.

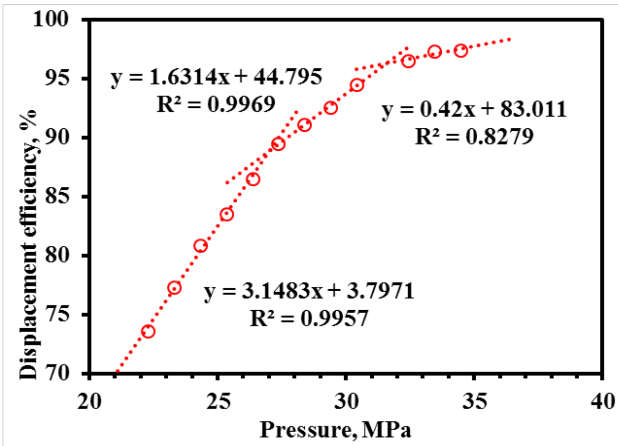

Fig. 1 displacement efficiency VS Pressure

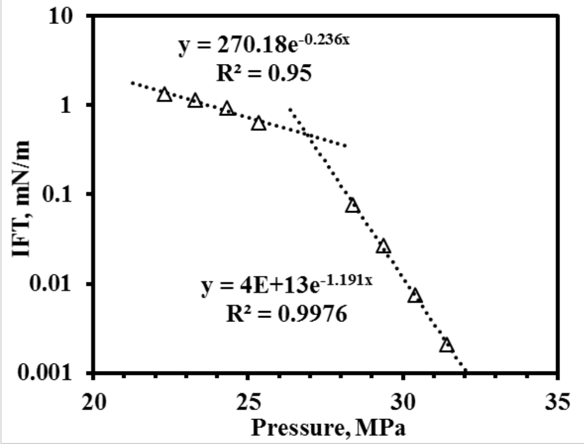

Fig. 2 IFT VS Pressure

2.6 Empirical formulas

Empirical correlation can also be used to determine MMP. Reservoir temperature, molecular weight of a plus fraction, and the mole fraction of a light component in the reservoir oil, are considered to be the main factors that greatly affect MMP. Generally, empirical formulas overestimate the MMP for light oils and underestimate the MMP for heavy oils. Correlations derived by Alston (1985), Sebastian (1985) and Yuan (2004) can be used for the prediction of impure CO_2 flooding. It should be noted that the first two formulas has limited pseudo-critical temperature of the injection gas [5, 6, 7]. The contaminant content cannot be over 10%. Comparatively, the application range of Yuan (2004) correlation is much wider [7]. However, relative errors of these three correlations are all higher than 10%. Two reasons are regarded for this big deviation. Firstly, the built of the correlations are mostly based on specific reservoirs with very limited data. In addition, the thermodynamic properties near the critical region is not easy to be forecasted. Generally a slight deviation of either reservoir conditions, or fluid compositions, may cause much bigger deviation of MMP.

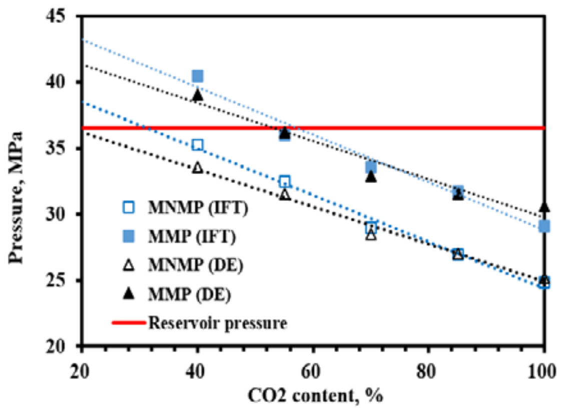

Fig. 3 MNMP & MMP VS CO_2 content

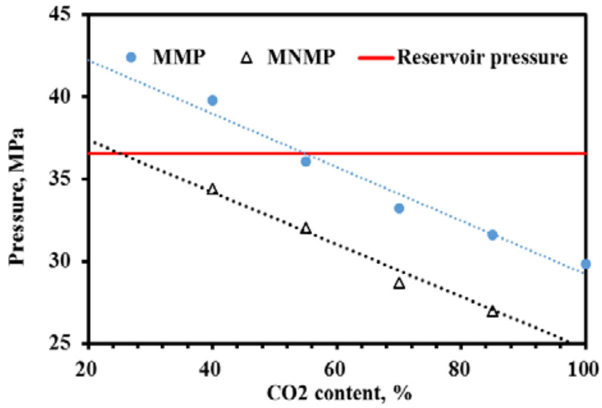

Fig. 4 Lower limit of CO_2 content

2.7 Lower limit of CO_2 content

Fig.3 and Fig.4 are the predicted MNMP and MMP under different CO_2 content. Obviously, with the reduction of CO_2 content, both of the lower and upper boundaries of near-miscible flooding increase linearly. Comparatively, MNMP decreased much faster. For each 10% CO_2 content reduction in the injection gas, MMP and MNMP increase 1.62 MPa and 1.59 MPa, respectively. In other words, the near-miscible flooding scope gets wider but the difficulty to achieve near-miscible flooding increases. It is concluded that methane, which is the main components of the contaminants, enhanced the difficulty of achieving miscibility. Compared with the reservoir pressure of MPa, the corresponding CO_2 content interval for near-miscible flooding of the targeted well QHD29-2E-4 can be determined to be 25-55%. Thus, for the production gas with the CO_2 content higher than 25% can be injected to develop the reservoir by near-miscible flooding.

3. Summary

According to the slim tube simulation results with denser test points, pressure interval of near-miscible flooding with varying CO_2 content was determined by the plot of displacement efficiency, IFT and injection pressure. Under reservoir conditions (122.5^{o}C, 36.53 MPa), the interval of CO_2 content for near-miscible injection is 25-55%. Consequently, the lower limit of CO_2 content for achieving near-miscible flooding in the well QHD 29-2E-4 is 25%. In addition, the contaminants (mainly CH_4) can greatly increase the pressure interval of near-miscible flooding. For the targeted oil and gas system, as each 10% decrease of CO_2 content, MNMP increase 1.59 MPa, MMP increase 1.62 MPa.

4. Acknowledgement

This research was financially supported by Open Foundation of State Key Laboratory of Offshore Oil Exploitation (2015-YXKJ-001).

References

[1] Shyeh-Yung, J.J. Mechanisms of miscible oil recovery: effects of pressure on miscible and near-miscible displacements of oil by carbon dioxide. In Proceedings of SPE Annual Technical Conference and Exhibition. Dallas, Texas. 1991. October 6-9.

[2] Sohrabi, M., Danesh, A., Tehrani, D. H., Jamiolahmady, M. Microscopic mechanisms of oil recovery by near-miscible gas injection. Transport in Porous Media. 72 (2007)351-367.

[3] Chen H., Yang, S., Ren, S., Yu, D. H., Lu, H., Li, F., & Zhang, X. Crude oil displacement efficiency of produced gas re-injection. International Journal of Green Energy. 10 (2013) 566-573.

[4] Chen H., Yang, S., Zhang, X., Ren, S., Dong, K., Li, Y., Meng, Z., Wang, L., Lei, H., Ma, Q. Study of phase behaviour and physical properties of a natural gas reservoir with high carbon dioxide content. Greenhouse Gases Science and Technology. 6(2016)428–442.

[5] Alston, R.B., Koklis, G.P., and James, C.F. CO_2 minimum miscibility pressures: A correlation for impure CO_2 streams and live oil systems, J. Spe. 25(1985)268-274.

[6] Sebastian H M, Renner T A, Wenger R S. Correlation of minimum miscibility pressure for impure CO_2 streams, J. Journal of Petroleum Technology. 37(1985)2076-2082.

[7] Yuan H, Johns R T, Egwuenu A M, et al. Improved MMP Correlations for CO2 Floods Using Analytical Gas Flooding Theory, J. Spe Reservoir Evaluation & Engineering. 8(2004)6-18.