Effect of Miscibility Condition for CO₂ Flooding on Gravity Drainage in 2D Vertical System

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Abstract

In CO₂ flooding process, gravity drainage and miscibility condition are the main factors on the efficiency of oil recovery. In this study, we observed oil recovery for different miscibility conditions in vertical oil reservoir. This was investigated in two dimensional vertical sandstone slab, where unstable gravity drainage phenomena can be formed. CO₂ is injected at bottom into 100% saturated with oil and production port is open at top of the system. We have performed a series of experiments using continuous CO₂ flooding for immiscible and near-miscible conditions. From the experimental results, oil recovery at near-miscible condition is 3.77 times greater than at immiscible condition, particularly in vertical system. It indicated that applying the immiscible CO₂ flooding is ineffective because of gravity override of CO₂ and generation of CO₂ channel at upper side in vertical reservoir. Meanwhile, the results revealed that oil recovery increases considerably once miscibility is reached at outlet. That is, miscibility condition is found to be a sensitive factor on oil recovery particularly in vertical oil reservoir.

Keywords: Miscibility condition; Oil recovery; CO₂ flooding; Unstable gravity drainage; 2D vertical sandstone

Introduction

In CO₂ injection process, the densities and viscosities of oil and CO₂ are the main variables determining the gravity drainage that can cause early CO₂ breakthrough. Once the injected CO₂ moves toward top of the reservoir, CO₂ front contacting with oil is gravitationally unstable, which leads to the decrease in oil recovery. Several researchers showed the importance of miscibility condition and gravity drainage effect on the oil recovery during CO₂ injection. Asghari et al. [1] and Torabi et al. [2] conducted experiments and simulation study considered miscibility condition in fractured system. They showed the oil recovery may decrease far above the miscibility. Trivedi et al. [3,4] also conducted experimental work about effect of CO₂ injection rate at various miscibility conditions in fractured reservoir. Kulkarni et al. [5] reported gravity drainage effect for Gas Assisted Gravity Drainage (GAGD) process under immiscible and miscible conditions. Nasrabadî et al. [6] conducted the simulation study to investigate the effect of density in the 2D vertical reservoir and shown significant effect of gravity and heterogeneity. Although a number of researchers [1-10] have investigated about CO₂ flooding under the various miscibility conditions and the gravity drainage mechanism, none of researchers have been done in vertical oil reservoir.

In this work, we discussed an experimental study to examine the influence of gravity drainage on the oil recovery for the vertical oil reservoir. A series of CO₂ injection experiments have been conducted at immiscible and near-miscible conditions in two dimensional vertical sandstone plates.

Laboratory Study

2D CO₂ flooding apparatus

A special high-pressure aluminum sandstone plate holder with internal diameter of 26 cm and length of 47 cm was manufactured for 2D CO₂ flooding experiments (Figure 1). The sandstone sample is placed between two half-cylindrical acryl within the holder. The confining pressure was always kept 400 psi greater than internal pressure to avoid effect of non-flowing direction [11]. Moreover, the sample plate holder is covered by thermal jacket which is connected at bath circulator to keep the reservoir temperature during experiments. A backpressure regulator was installed at the outlet to maintain the pressure at 600 to 1,000 psi. The syringe pump was used to inject fluids of oil and CO₂ at constant flow rate. The produced fluids are separated at separator, then oil and CO₂ are measured by electronic balance and mass flow meter, respectively, automatically in real time. The CIMON-SCADA data acquisition system was connected to acquire the data automatically per second in real time for pump, pressure transmitters, electronic balance, gas mass flow meter, and temperature sensor [12,13].

Sandstone sample and fluid

The sister brea sandstone plate (dimension: 20×20×2 cm) was used, and its average permeability and porosity were measured as 31 md and 20.04%, respectively. Normal decane was a saturated fluid as oil phase throughout these experiments. The density and viscosity of normal decane at 35°C is 0.72 g/cc and 0.74 cp. The miscibility pressure of CO₂ and normal decane is about 1062.5 psia at 35°C which were determined using commercial PVT software, i.e. CMG-WINPTOPTM [1,2]. The CO₂ (purity 99.999%) was injected constantly at 20 ml/hr as a solvent at immiscible and near-miscible reservoir conditions of 600 psig and 1,000 psig at 35°C.

Results and Discussion

In order to investigate the oil recovery performance by the continuous CO₂ flooding process, we conducted the experiments for Immiscible (IMS) and Near-Miscible (NMS) conditions in vertical
oil reservoir. The experimental conditions are listed in Table 1. The experimental results were illustrated in Figures 2-4.

Figure 2 represents the behavior of the average pressure between inlet and outlet of the reservoir system and Figure 3 presents oil recovery during 25 hours. As shown in Figure 2, in the case of immiscible condition, the average pressure was almost maintained at 640 psig, that is, pressure difference between inlet and outlet is close to zero. However, unlikely the immiscible condition, the average pressure in near-miscible condition is increased and it became above the Minimum Miscible Pressure (MMP). At the early stage of CO2 injection before 7 hours (0.88 PV injections) in the case of near-miscible condition, even though the oil is immiscibly displaced by the injected CO2, oil is more produced than the case of immiscible condition because of higher density of CO2 in near-miscible condition than in immiscible condition. After the MMP reached (7 hours), the CO2 of gas phase is changing to
The pressure is slightly decreased due to the decrease in CO\textsubscript{2} volume and oil is more produced due to miscibility. After that time, miscible front is reached at outlet, oil is more rapidly produced together with CO\textsubscript{2} from 22 hours (Figures 3 and 4).

As shown Figure 3, the oil recovery of immiscible condition is 20.09% at 25 hours of CO\textsubscript{2} injection (3 PV). Generally, miscibility may not occur, but there will be significant benefits for oil recovery due to a reduction in interfacial tension and viscosity, and swelling and solution gas effects [14,15]. However, according to these results, oil recovery is very low for the vertical oil reservoir at immiscible condition. These reason is, although some of injected CO\textsubscript{2} dissolved into oil, due to the movement of CO\textsubscript{2} of low density into upper side of vertical reservoir, the supercritical state because of increasing in pressure. Therefore, the pressure is slightly decreased due to the decrease in CO\textsubscript{2} volume and oil is more produced due to miscibility. After that time, miscible front is reached at outlet, oil is more rapidly produced together with CO\textsubscript{2} from 22 hours (Figures 3 and 4).

In this study, we discussed an experimental study of CO\textsubscript{2} injection process to examine the influence of gravity drainage on the oil recovery for the vertical oil reservoir. From the experimental results at different miscibility conditions, we have drawn the followings: In the case of immiscible condition, CO\textsubscript{2} starts producing much earlier than the one in near-miscible case. This is a reason that as CO\textsubscript{2} immiscibly displaces the oil, CO\textsubscript{2} channel can be generated at upper side because of gravity override of CO\textsubscript{2}. Therefore, applying the immiscible CO\textsubscript{2} flooding is ineffective at vertical reservoir. However, in near-miscible case, once practical CO\textsubscript{2} production is appeared, that is, miscibility front is arrived at outlet, CO\textsubscript{2} starts producing much more great than the case of immiscible. Eventually, as results aforementioned, oil is recovered in near-miscible condition is significantly larger than the amount of oil in immiscible condition. As a result, we found out that oil recovery at immiscible condition (600 psig) is 20.09% which is significantly less than the one at near-miscible condition (1,000 psig) of 75.71%, in vertical oil system.

**Conclusion**

In this study, we discussed an experimental study of CO\textsubscript{2} injection process to examine the influence of gravity drainage on the oil recovery for the vertical oil reservoir. From the experimental results at different miscibility conditions, we have drawn the followings: In the case of immiscible condition, CO\textsubscript{2} starts producing much earlier than the one in near-miscible case. This is a reason that as CO\textsubscript{2} immiscibly displaces the oil, CO\textsubscript{2} channel can be generated at upper side because of gravity override of CO\textsubscript{2}. Therefore, applying the immiscible CO\textsubscript{2} flooding is ineffective at vertical reservoir. However, in near-miscible case, once practical CO\textsubscript{2} production is appeared, that is, miscibility front is arrived at outlet, CO\textsubscript{2} starts producing much more great than the case of immiscible. Eventually, as results aforementioned, oil is recovered in near-miscible condition is significantly larger than the amount of oil in immiscible condition. As a result, we found out that oil recovery at immiscible condition (600 psig) is 20.09% which is significantly less than the one at near-miscible condition (1,000 psig) of 75.71%, in vertical oil system.

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**References**


