STUDY ON ENHANCED OIL RECOVERY BY CO2 MICROBUBBLES INJECTION

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論 文 名　: STUDY ON ENHANCED OIL RECOVERY BY CO_2 MICROBUBBLES INJECTION（CO_2 マイクロバブル圧入による石油増進回収法に関する研究）

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論 文 内 容 の 要 旨

Enhanced oil recovery (EOR) by injecting carbon dioxide (CO_2) into oil reservoirs is expected to be a reasonable and sustainable way to reduce greenhouse gas emissions. However, the performance of CO_2-EOR is not always achievable due to several disadvantages, such as density effect, gas channeling, and poor sweep efficiency in heterogeneous porous media. All those challenges reduce effectiveness of CO_2-EOR and increase the operation cost. Therefore, it is supposed that the utilization of CO_2 microbubbles would potentially overcome those challenges in the heterogeneous oil reservoirs and promote a practical approach to achieving both EOR and CO_2 storage. Microbubbles–Colloidal Gas Aphrons (CGAs) have been reported as unique bubbles with micro-size (10-100 μm) consisting of a multilayer shell of surfactant molecules and a spherical gaseous core. The previous studies reported the significant stability of microbubbles in comparison with conventional foam and their high flow restriction ability. However, there have been few sufficient studies on the characteristics of CO_2 microbubble and their selective plugging performance to enhance oil recovery in the heterogeneous oil reservoirs.

This thesis proposes EOR technique with the injection of CO_2 microbubbles and examined the effectiveness of the EOR with laboratory experiments. This study investigated the conditions for CO_2 microbubble generation, the characteristics of CO_2 microbubbles, and the flow behavior of CO_2 microbubbles in porous media using sandpacks through various experiments. The thesis consists of five chapters laid out as follows:

Chapter 1 reviews literatures of CO_2-EOR and discusses the overview and challenges of CO_2-EOR. Therein also highlighted the importance of microbubbles used in petroleum engineering field. The research problem statement and objectives were presented in that regard.

Chapter 2 introduces the experimental process with an overview of measurement methods and analysis. It evaluated the effects of varying the concentrations of Xanthan Gum (XG) polymer, surfactant (sodium dodecyl sulfate, SDS), and sodium chloride (NaCl) on both the stability and bubble size distribution (BSD) of CO_2 microbubbles. CO_2 microbubble dispersions were prepared using a high-speed homogenizer in conjunction with the diffusion of gaseous CO_2 through aqueous solutions. The stability of each dispersion was ascertained using a drainage tests, while the BSD was determined by optical microscopy and fitted to either normal distribution, log-normal distribution or Weibull distribution. The results showed that a Weibull distribution gave the most accurate fit for all experimental data. It was shown that the size of microbubble was able to be controlled by changing the concentration of either SDS or XG polymer. Those changes increased the microbubble stability as a consequence of structural enhancement of the microbubble. On the other hand, the stability was reduced as the NaCl concentration was increased because of the gravitational

effect and coalescence of the microbubble.

Chapter 3 investigates the plugging performance of CO_2 microbubbles in both homogeneous and heterogeneous porous media through a series of sandpack experiments. CO_2 microbubble fluid were prepared by stirring CO_2 gas diffused into XG polymer and SDS solution with different gas:liquid ratios. Then, CO_2 microbubbles fluids were injected into single-core and dual-core sandpack systems. The results show that the rheological behaviors of CO_2 microbubble fluid in this study followed the Power-law model at room temperature. The apparent viscosity of CO_2 microbubble fluid increased as the gas: liquid ratio increased. CO_2 microbubbles could block pore throat due to the "Jamin effect" and increase the flow resistance in porous media. The blocking ability of CO_2 microbubbles reached an optimal value at the gas:liquid ratio of 20 % in the homogeneous porous media. Moreover, the selective plugging ability of CO_2 microbubbles in dual-core sandpack tests was significant. CO_2 microbubbles exhibited a good flow control performance in the high permeability region and flexibility to flow over the pore constrictions in the low permeability region, leading to an ultimate fractional flow proportion (50 %:50 %) in the dual-core sandpack model with a permeability differential of 1.0:2.0 darcy. The fractional flow ratio was considerable compared with a polymer injection. At the higher heterogeneity of porous media (0.5:2.0 darcy), CO_2 microbubble fluid could still establish a good swept performance. This makes CO_2 microbubble fluid injection a promising candidate for heterogeneous reservoirs where conventional CO_2 flooding processes have limited ability.

Chapter 4 evaluates the plugging performance of CO_2 microbubbles on oil recovery from the single sandpack and parallel sandpack flooding tests. All flooding tests were conducted at 45 ^oC. The flooding scheme consisted of the injection of brine water (20000 mg/L NaCl concentration) followed by the CO_2 microbubble injection and chase water flooding. In the single sandpack flooding test, about 61.4 % of the original oil in place (OOIP) was recovered after 3 pore volumes of water flooding. Then 0.5 pore volumes of CO_2 microbubble fluid was injected into the sandpack, which caused a blockage in pore spaces. The oil recovery was improved by 23.6 % by the chase water flooding at the following stage. In the heterogeneous model constructed with parallel sandpack model, CO_2 microbubbles flooding could significantly improve the displacement efficiency in a low permeability sandpack compared to the base solution flooding with the heterogeneous model which had the same permeability ratio. The CO_2 microbubble could adjust to fractional flows in the heterogeneous reservoir and recover the remaining oil. As a result, the injection of CO_2 microbubbles improved the total oil recovery up to 86.9 % compared to the injection of base solution with 75.3 % in total. When the low/high permeability ratio of the parallel sandpack is reduced to 1.0:2.0, injecting CO_2 microbubbles enhanced the oil recovery to 93.3 % in total. The displacement efficiency increases with the decrease of sandpack heterogeneity. The results suggest that CO_2 microbubble is favorable to enhanced oil recovery in heterogeneous reservoirs.

Chapter 5 concludes the present research by highlighting the major findings and further research suggestions.