Enhanced Oil Recovery from Heterogeneous Reservoir by Blocking Performance with In/situ Formed Sodium Carbonate Gel

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論　文　名　：　Enhanced Oil Recovery from Heterogeneous Reservoir by Blocking Performance with In-situ Formed Sodium Carbonate Gel
(炭酸ナトリウムゲルの原位置生成による不均一性貯留層からの採油増進)

区　　分　：甲

論　文　内　容　の　要　旨

In an enhanced oil recovery (EOR) using water flooding or chemical flooding, residual oil in higher permeability regions or layers is primarily recovered due to the macroscopic flow mechanism. On the other hand, it is known that oil recovery from lower permeability regions including larger residual oil saturation becomes more difficult, because fluids flow rate through the oil recovered regions is further increased with increasing relative permeability due to low oil saturation. Therefore, it is a challenge to deliver injected fluids into the lower permeability regions to get higher oil recovery factor. In particular, in the case of heterogeneous reservoirs including large variation of fracture or layer permeabilities, it is necessary to decrease or stop channeling flows through those high permeability regions by a blocking agent to operate effective EOR.

The scope of this research considered characterizing and evaluating the potential of sodium carbonate gel (SC-gel), which is formed from the aqueous solution of sodium metasilicate ($Na_2SiO_3 \cdot 9H_2O$; S-MS) reacted with dissolved CO_2 gas, as blocking performance in the heterogeneous reservoirs. In order to apply the SC-gel as the blocking agent for EOR after water flooding, the permeability and flooding tests were also carried out using sandstone cores.

This dissertation consists of five chapters.

Chapter 1 is the introductory chapter, which addresses the importance of the oil recovery process from heterogeneous reservoirs by blocking high permeable pathways, and its challenges. The overviews of oil recovery mechanism starting from primary to tertiary oil recovery and previous researches on water-shut off treatment methods. The EOR approaches were highlighted comprehensively in this chapter for both megascopic and microscopic oil displacement efficiency.

Chapter 2 describes the experimental research process with an overview of qualitative and quantitative methods, data collection, recording and analysis. It also presents the materials, such as crude oil (Japanese light crude, JLO) and chemicals, used in gel formation coreflooding experiments and interfacial tension measurement (IFT) between oil and the S-MS water solutions including the experimental setups measurement instrument. Furthermore, Raman spectroscopy and scanning electron microscopy/energy dispersive X-ray (SEM-EDS) spectroscopy that were used to analyze molecular compounds and chemical characterization of the gel formed in the experiments is explained. The sandstone core was used to measure the threshold pressure gradient (TPG) after in-situ forming SC-gel in it. The cylindrical heterogeneous core (43 mm in diameter and 72 mm in length) was constructed by combining two semi-cylindrical Berea sandstone cores with different permeability (50 and 300 mD). It was used for coreflooding test after injecting saline water and JLO into the core to evaluate the blocking effect in the heterogeneous reservoir.

Chapter 3 explains the physical and chemical gel properties of the SC-gel formed by giving various conditions. As the physical properties, the gelation time, gel strength, and gel stability were measured for sodium metasilicate concentrations (1-10 wt%), CO_2 Gas pressure (2-7.5 MPa), temperature (25-80 ºC), salinity (NaCl; 0.1-10 wt%), divalent ion (Ca^{2+}; 10-10000 ppm), and light crude oil interaction (JLO-I). Both Raman and SEM-EDS spectroscopies revealed that the gel was a sodium carbonate type (SC gel). In the measurements on sensitivity study of the effects of CO_2 gas pressure, salinity (NaCl), divalent ion (Ca^{2+}) as well as the gel forming behavior in a porous media, 5 wt% was used as the baseline concentration of S-MS solution. Gelation time after CO_2 gas injection was around 1 to 24 h depending on temperature and pressure. Gel strength increased with higher S-MS concentration and CO_2 gas pressure. Furthermore, measurements of gas permeability and threshold pressure gradient (TPG) were carried out to evaluate the blocking effect by forming SC-gel in the sandstone core. It was found that TPG and gas permeability of the sandstone core increased by 2.6 times and decreased about 1/10 to that of water saturation by filling in-situ SC-gel.

Chapter 4 evaluates the alkaline flooding and blocking performance of in-situ formed SC-gel on oil recovery from the heterogeneous reservoirs.

Firstly, IFT between S-MS solution and crude oil was measured, because it is expected that the alkaline flooding using S-MS solution is applied to recover oil after water flooding and before blocking operation. The IFT was reduced to around 0.1 mN/m from 27 mN/m of the case of water. Furthermore, it was observed that by stirring and mixing 0.5-2 wt% of S-MS solution including 0.1-10 wt% of NaCl and the oil, micro-emulsion consisting water droplets (0.5-50 μm) in oil were was generated and stable up to three weeks. Based on these results, it is concluded that S-MS solution also can be used as an alkaline chemical for EOR.

Secondly, the coreflooding test was carried out using the heterogeneous core combining two Berea sandstone cores with different permeability. In the test, the water flooding by injecting saline water (2 wt% NaCl) at 0.1mL/min into the core saturated with oil (JLO) was pre-conducted until no oil recovery when oil recover factor (RF) became a constant value (57% in this test). Next, 0.5 pore-volume(PV) of 1 wt% S-MS solution was injected at 0.1 mL/min as the alkaline flooding that recovered with increasing 3.3% in RF. Then 0.3 PV of 5wt% of S-MS solution was injected at the same flow rate with increasing 2.4% in RF, then CO_2 gas was injected at 2.0 MPa by closing the down-stream valve. After the injections, the core was shut-in to form in-situ gel for 2 days. During the shut-in, the core pressure decreased to 1.6 MPa from 2.0 MPa due to CO_2 gas dissolution and forming the gel. Meanwhile the pH, pressure drop in the core, volumes of micro-emulsion and water-solution in the produced fluids were monitored during the core flooding test to investigate fluids flow-properties in the core. When 2 PV water was injected at 0.1mL/min after forming SC-gel, RF increased 9 % with increasing the pressure drop 1.5 times (apparent permeability decreased to 67%) by forming the in-situ SC-gel in the core. It was concluded that the blocking operation by forming in-situ SC-gel by injecting S-MS solution and CO_2 gas was effective for the heterogeneous oil reservoir after water and alkaline floodings.

Chapter 5 is a summary and conclusion of major findings of present research including the research interest for the future study.