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Novel Application of Deep Eutectic Solvents for Enhanced Heavy Oil Recovery

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Abstract

In this study, for the first time to our knowledge, the effectiveness of two different types of Deep Eutectic Solvents (DESs) namely DES1: Choline Chloride:Glycerol (1:2) and DES2: Choline Chloride:Urea (1:2), in enhancing heavy oil recovery was thoroughly investigated.
In the first part, the effects of DES type, DES concentration, operating temperature, secondary and tertiary injections and brine salinity on emulsification, wettability alteration, IFT reduction and oil recovery by core flooding experiments were examined. Heavy oil with 16 ºAPI and formation brine from one of the Omani heavy oil fields was utilized. The core flood experiments were conducted at reservoir condition and using Berea sandstone core plugs. The results showed that the two DESs have not significantly produced stable emulsions with the heavy oil. They increased the IFT of oil-brine system. The two DESs altered the wettability of the sandstone rock surfaces from liquid-wetting towards intermediately air-wetting conditions at oil-air-rock system. Based on the core flooding results for both DES solutions at 50 vol.% concentration, it was revealed that the heavy oil recovery can be further improved by 14.0% and 23.2% for DES1 and DES2, respectively. Dilution of the DES solution by reducing concentration from 50 to 25 vol.%, did not significantly affect the heavy oil recovery enhancement. Further dilution of the DES solutions, however, resulted in reduction in heavy oil recovery factor. The recovery factor of diluted DES injection from 50 to 5 vol.% was in the range of 6.3 to 8.7 % for DES1 and DES2, respectively. The DES flooding in tertiary stage led to higher total recovery factor as compared to the secondary mode. In addition, results confirmed that the selected DESs of this study can tolerate a wide range of salinities and negligible changes were observed in oil recovery at different brine salinity during tertiary DES injection. Results of capillary number calculations indicated that although DES solutions increased the IFT value, the capillary numbers in DES flooding due to higher viscosity ratio and wettability alteration were higher than brine flooding case. Therefore, wettability alteration and improvement of viscosity ratio were considered as the main mechanisms of enhancing the heavy oil recovery by DES injection.
In the second part of the study, we investigated possible formation damage induced by DES injection as new enhanced heavy oil recovery method in sandstone reservoirs. Core flooding tests were performed at reservoir conditions to measure permeability changes by DES injection. In order to quantify the formation damage, static adsorption of DESs on Berea sandstone crushed core samples were determined. Furthermore, to understand the main mechanisms leading to the formation damage, fresh and treated core samples were analyzed by scanning electron microscopy (SEM), X-ray diffraction (XRD), and computed tomography (CT) scanning. Observations showed that despite the DES's beneficial roles in preventing severe

water shock damages and clay stabilization, there was still formation damage caused by re-crystallization, precipitation and adsorption processes which ultimately led to reducing the permeability of the core samples.

The third part of the study focused on the effect of rock type on the performance of DES injection for heavy oil recovery. Carbonate core plugs from an Omani oil field were used and the obtained results were compared with the results for the sandstone formation. The comparison results revealed that generally the DESs were more effective for heavy oil recovery from sandstone formation. Also, in case of carbonate rock unlike sandstone rock, DES1 outperformed DES2 in terms of wettability alteration as well as oil recovery enhancement. Furthermore, injection of DES solutions did not cause any significant changes in permeability of carbonates.

In the last part of this study, primary and secondary DES flooding at different concentrations followed by steam flooding experiments at reservoir conditions were conducted. Results of thermogravimetric analysis (TGA) verified the relatively high thermal stability of both DESs as chemical agents to be used in thermal EOR methods. Core flooding results of sequential steam flooding and pure or 50 vol.% diluted DES injection showed higher total recovery factors, up to 12 % IOIP extra recovery, compared to steam flooding alone. However, using further diluted DES solution, i.e., 5 vol.%, caused the same or even less total recovery factors compared to secondary steam flooding. At the same DES concentrations and injection scenarios, DES2 exhibited superior heavy oil recovery enhancement of 12.1 % IOIP extra recovery compared to steam alone, while DES1 showed a 5.8% IOIP extra recovery compared to steam alone. In terms of heavy oil in-situ upgrading by steam flooding and steam/DES flooding, the results were also promising. Analysis of physicochemical properties of produced oil by steam flooding showed that presence of DES in the steam flooding process led to an improved in-situ upgrading of heavy oil compared to steam injection alone. In this study heavy oil upgrading was represented in terms of increase in API gravity (up to 3.5 API), reduction in sulfur content (16.6 % desulfurization) and increase in the yields of saturate hydrocarbons. It was found that DES1 exhibited better overall performance than DES2 in terms of in-situ heavy oil upgrading.