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Modification of heavy-oil rheology via alkaline solutions

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ABSTRACT

Hamaca (Orinoco Belt, Venezuela) is considered here as a typical viscous and heavy oil whose rheology and recovery behavior is potentially modified by diluents and aqueous solutions of alkali. Viscosity of dry Hamaca crude oil, mixtures of Hamaca and n-decane, as well as emulsified crude oil was measured ex-situ and in-situ (sand pack) as a function of temperature and shear rate. Hamaca crude oil exhibits temperature-dependent rheological behavior. Between 30 and 50° C, it is slightly shear thinning, whereas from 55 to 80° C, properties are slightly shear-thickening. Shear stress sensitivity becomes greater as shear rate decreases. Crude oil rheological behavior in a sand pack (single-phase flow) has similar trends as bulk crude-oil viscometer measurements. The viscosity of the crude oil decreases most significantly as the concentration of diluent (decane) increases from 0 to 6 wt% but the magnitude of viscosity reduction is less as diluent concentration increases from 10% to 33%. After mixing crude oil with aqueous alkaline silicate and carbonate solutions, viscosity decreases markedly due to formation of oil in water (o/w) emulsions. For sodium hydroxide, however, oil viscosity increases because of formation of water in oil (w/o) emulsions. Given the encouraging changes in bulk oil properties, core flood recovery tests at different temperatures and flow rates were conducted. Alkaline flooding showed recovery of about 43% after 0.5 PV of injection and more than 60% with 5.6 PV of 1 wt% Na_2CO_3 solution. A significant fraction of the oil recovery occurred as o/w emulsion. The apparent relative permeability of the oil phase deviates markedly from the measurements for unemulsified oil.

1. Introduction

In some heavy-oil reservoirs, crude-oil viscosity is commonly ten to hundreds of thousand cP at reservoir temperature. Oil-phase viscosity can increase to millions of cP at low temperature surface conditions. Such viscous, heavy oils generally cannot be produced by waterflood. Injected water is very mobile relative to oil and breaks through to the producer rapidly. Heavy oil while being highly viscous does have some mobility at reservoir conditions. Given high viscosity at reservoir temperature, primary production is commonly limited although so-called "foamy oil" has shown reasonable recovery (Akin and Kovscek, 2002; Arora and Kovscek, 2003; George et al, 2005). Recent estimates put the primary recovery of heavy oil around 5% OOIP according to Alberta Energy and Utilities (2007). Hence, significant oil resources remain for secondary and tertiary recovery operations. The most effective methods, as gauged by oil production, are thermally enhanced oil recovery (EOR) processes. During steam injection or in-situ combustion, oil viscosity is reduced dramatically.

Large crude-oil viscosity negatively impacts heavy-oil productivity through flow resistance in the reservoir and flow resistance within production well tubing. Diluents, such as light hydrocarbons, mix well with heavy crude and are used to reduce viscosity (Allen et al., 1976) because higher molecular weight components such as resins and asphaltenes are easily diluted and dispersed by small hydrocarbon molecules. Aggregation states change in solvents Argillier et al. (2001). The distance between large hydrocarbon molecules are commonly increased in solution and, hence, the friction between them decreases. This is one of the potential viscosity reduction mechanisms.

Chemical flooding is a useful method for enhancing the recovery of light to medium gravity crude oils. Extensive laboratory study and many pilot tests have been conducted in such reservoirs in China, for instance, during the past 20 years (Delshad et al., 1998; Zhao et al., 2006a, 2006b; Gong et al., 2008). Additionally, Türksoy and Suat (2000) studied the effect of sodium hydroxide and sodium silicate solutions for the improved oil recovery of Garzan (26°API) and Raman (17.2°API) crude oils with variable salinity alkaline solutions. Bryan et al. (2008) studied heavy oil core flooding using low field NMR. Both studies

Abbreviations: IFT, interfacial tension; PV, pore volume

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showed positive response to alkali. Heavy oils commonly contain large quantities of asphaltenes that act as emulsifiers McLean and Kilpatrick (1997) and other surface active components such as resins, fatty acids, porphyrins, wax crystals, and so on. Hence, Bryan et al. (2008) observed that both oil-in-water (o/w) and water-in-oil (w/o) emulsions may form during alkali–surfactant floods. The redistribution of water from the flooded channels into emulsified droplets in the oil is at least partially responsible for improved displacement. Chemical and physical combination methods also show excellent oil recovery potential for heavy oil (Guo et al., 2004; Tao and Xu, 2006).

Even though the concept of chemical flooding is not new, the simple empirical trends developed to estimate fluid properties of light oil may be inappropriate for heavy oils. Heavy oils contain complex heavy compounds and their chemistry and colloidal properties generally differ from light oils. Chemical flooding of heavy oil, and especially alkaline flooding, is a relatively new topic. Accordingly, the purpose of this study is threefold: (1) clarify the rheological characteristics of an important heavy crude oil with respect to temperature, (2) examine our ability to modify heavy-oil viscosity and interfacial tension using alkali instead of heat, and (3) demonstrate that alkaline flooding of heavy oil is effective at laboratory scale.

The remainder of this paper presents the various apparatus and materials used. Then, results for viscosity, interfacial tension (IFT), relative permeability of oil and water phases within sandpacks are presented and discussed. Microscopic images of fluid phases are used to document emulsion formation and type. Conclusions complete the paper.

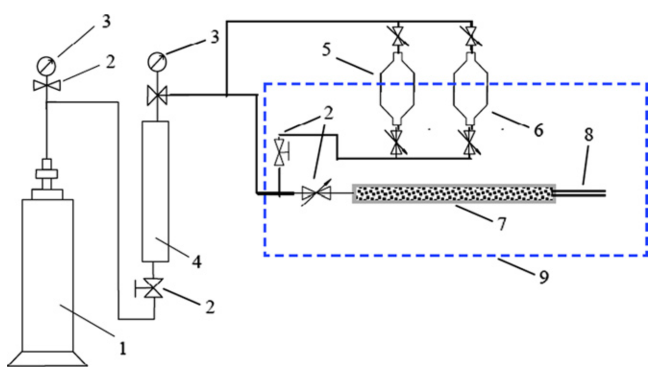

Fig. 1. Schematic of flow experiment 1. gas tank, 2. valve, 3. pressure gauge, 4. gas cylinder (constant pressure provision), 5. oil cylinder, 6. alkali solution cylinder, 7. sand pack, 8. measurement tube and 9. water bath.

2. Apparatus and materials

A variety of apparatus and materials are used. A Brookfield DV-ii viscometer is used for all ex-situ viscosity measurements as a function of shear rate and temperature. A VWR water bath is used to maintain constant system temperature (± 0.5 °C). A University of Texas Model 300 spinning drop tensiometer is used for oil/water IFT measurements. The sandpacks are made of stainless steel tube with inner diameter (ID) of 0.65 cm and two different lengths. Both are packed with a clean 120 mesh sand. In order to investigate the flow behavior of the crude oil and oil recovery that displaced with different alkli, a sand pack with a length of 15 cm is used and placed into the constant-temperature water bath, Fig. 1. For relative permeability measurement, a sand pack with a length of 50 cm is used and placed into the oven with a fixed temperature, Fig. 2.

The crude oil is a 9°API sample of Hamaca from the Orinico Belt of Venezuela (Peng et al., 2009) that was filtered and dewatered. The other liquids are reagent grade toluene, reagent grade decane, and house-distilled water. The alkali materials are reagent grade NaOH, $NaHCO_3$, Na_2CO_3, and analytical grade pure sodium silicate, 40 wt% (balance is water).

3. Procedures

Different aqueous concentrations of NaOH (0.055 wt%, 0.0625 wt%, 0.125 wt%, 0.25 wt%, 0.5 wt%, 1 wt%), Na_2CO_3 (0.0625 wt%, 0.125 wt%, 0.25 wt%, 0.5 wt%, 1 wt%), and Na_2SiO_3 (0.125 wt%, 0.25 wt%, 0.5 wt%, 1 wt%, 2 wt%) as well as oil solutions with different volumes of decane were prepared. Fluid phases are pre-equilibrated before any measurements are conducted. The viscometer was used to measure pure crude-oil viscosity, crude oil mixed with decane, and the oil in water emulsion. Temperature was varied from 29–85° C and the shear rate was in the range of 0.5–200 rpm. For interfacial tension (IFT) measurements, the temperature was set at 48° C.

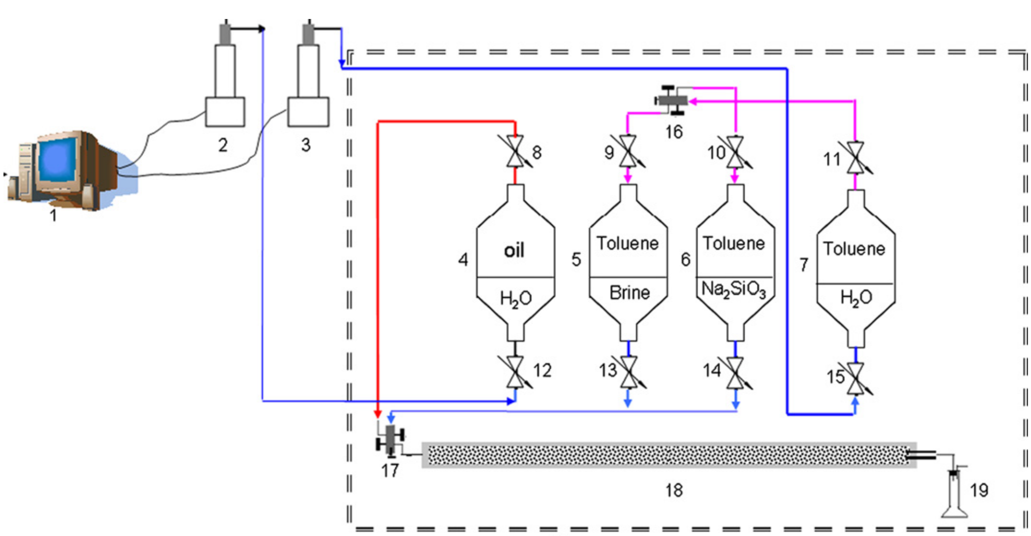

Fig. 2. Experiment apparatus for relative permeability measurement 1. Data Collector (PC), 2, 3. Isco pump, 4, 5, 6, 7. Cylinder, 8, 9, 10, 11, 12, 13, 14, 15. Two way valve, 16, 17. Three way valve, 18. Sand Pack, 19. Collector, 20. Oven.