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Determination of minimum miscibility pressure for CO_2 and oil system using acoustically monitored separator

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ABSTRACT

All methods which allow to increase recovery from oil field after primary and secondary recovery are called enhanced oil recovery (EOR). Minimum miscibility pressure (MMP) of gas and oil system plays a crucial role during planning and developing of EOR CO_2 miscible flooding. The slim tube test (STT), the pressure rising bubble apparatus, the pressure-density diagram (PDD), the vanishing interfacial tension (VIT), etc. have been used as the petroleum industry approaches for evaluation of the MMP for hydrocarbons and CO_2. Experiential and theoretical calculations are also applied for the assessment of MMP. This paper presents a new technique to measure MMP and investigate the phase behavior of the analyzed fluids using acoustically monitored separator. The images of oil and CO_2 are taken at different pressures during the measurement. Intensity of separation line between CO_2/oil has a relationship with the densities of investigated fluids. Evaluation of MMP can be registered for decayed line, when pressure increases. This experimental method of MMP is time-saving and more easily to perform than other experimental methods of evaluation MMP.

1. Introduction

Enhanced oil recovery (EOR) can be considered as subgroup of improved oil recovery (IOR) methods and refers to all techniques that allow to increase oil recovery after primary and secondary recovery processes. A typical EOR solution involves injection of a fluid other than water into reservoir. Injectants have economic value, consequently, EOR methods are sensitive to oil prices. Due to constant increasing demand for oil in the world, these processes are important. EOR processes can be classified under three main groups. These are: thermal techniques (steam injection, in-situ combustion), chemical flooding (polymer, surfactant, alkali) and miscible gas injection (nitrogen, hydrocarbon gas, CO_2, sour gas etc.) [12]. Gas injection methods are the most applicable for worldwide oil fields, but owing to geological, technical and economic conditions the foreign experiences cannot be directly applied to specific region, implementation must be preceded by a number of studies and pilot tests [27]. These studies may include: developing a generic integrated framework for optimizing CO_2 sequestration and EOR based on known parameters distribution [9], risk analysis [8], evaluation of CO_2 storage mechanisms [3,4] and employ optimization to determine the optimum developmental strategy to maximize both oil recovery and CO2 storage [3,4] before implementing CO_2-EOR technique on the industrial scale. Technological and technical aspects like well spacing, pressure maintenance, injection pattern, injection rate and injection volume affect efficiency of CO_2 flooding [19]. CO_2 improves oil recovery by swelling the oil and reducing its viscosity. For EOR projects carbon dioxide can be obtained from flue gas (captured) or naturally occurring CO_2 reservoirs. Extensive corrosion preventive techniques should be taken into account, due to potential destruction of materials in presence of CO_2.

MMP represents the minimum pressure at the operating temperature, at which displacement process is miscible, below that pressure, immiscible drive mechanism takes place. The hydrocarbons solubility has a direct relation with pressure and CO_2 density, while it has inverse relation with chain length and temperature [26] .The two main techniques are used for the determination of MMP and can be classified as analytical techniques, which are based on numerical computations and experimental methods. [28], Ahmadi and Ebadi [2] and Ahmadi et al. [1] used artificial intelligence (AI) solutions including fuzzy modeling, evolutionary algorithms to predict MMP. Essentially, rising bubble apparatus (RBA), pressure-density diagram (PDD), the slim tube test (STT), the vanishing interfacial tension technique (VIT), X-ray computerized tomography (CT) scanner

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and magnetic resonance imaging technique (MRI) are recognized as approaches of MMP measurements. A detailed description and operational procedure for the RBA are provided by Christiansen and Haines [7], Elsharkawy et al. [11], Novosad et al. [20], Thomas et al. [25]. The disadvantage of the RBA method, which was proposed at 1980s is lack of quantitative information and MMP is obtained from visual observations Christiansen and Heines, 1987. Evaluation of MMP with RBA is dependent on monitoring and interpretation of the bubble shapes traveling through the oil column in the glass tube. STT has been widely used but limited by long-lasting measurements and the lack of uniform criteria. The MMP measured with the STT is very dependent on the criteria used to interpret slim-tube performance [11]. STT method was compared with RBA by Bon et al. [6], Elsharkawy et al. [11], Novosad et al. [20], Thomas et al. [25], Zhou and Orr [29], Dong M. et al. [10] Data reported in the literature show that MMPs values measured with RBA are comparable in magnitude with those determined with STT. The gathered results revealed that the key advantage of the RBA method is its reliability and speed. The VIT technique defines MMP as the lowest pressure at which the interfacial tension between miscible fluids turns to zero – disappears [23]. This method demands: capturing the image of an oil drop, digitalizing the interface to identify coordinate points and solving the Laplace capillary equation iteratively [24]. MMP determination with X-ray CT technique in porous media for CO_2/n-decane system was investigated by Liu et al. [17,18] at 20, 30 and 37.8 °C, and can be associated with health risk due to radiation. Estimation of MMP for CO_2 and liquid *n*-alkane system using improved MRI was performed at the same temperatures as in previous work Liu et al. [17,18] MRI techniques of measurement can be considered as costly, due to equipment facility value and demand for energy – involve a really high amount of electric current supply [21].

In this work, a new method is presented for evaluation of the MMP of CO_2 and oil system by using acoustically monitored separator. The main advantage of sonic response method (SRM) comparing to previous methods is its ability to provide real volume distribution of the two fluids and their interface during the experiment without encroachment into system. This method also combines relatively low capital and operating expenditures with health safety.

2. Experiment

2.1. Apparatus and materials

The experimental facility is shown in Fig. 1 and constitutes two Teledyne Isco syringe pumps for controlling injection pressure during evaluation of minimum miscibility pressure, acoustically monitored separator (AMS), two accumulators, vacuum pump and storage for effluents. Two transfer cylinders (moveable piston type) made of highly corrosion resistant metal alloy (Hastelloy C-276) were connected to the pumps for storing and flowing the test fluids (oil and CO_2). AMS and accumulators were placed in the industrial oven.

AMS system is the two phase separator, which consists of two bore tubes mounted vertically in a stable base. The dual bore cylinder is a 20 in. section of Hastelloy C-276 with a 0.5 in. diameter of separation and measurement bores. The accuracy of the measurement can be adversely affected by the phenomena of emulsion during mixing two fluids. The dual bore design eliminates this error by allowing the two immiscible fluids of different densities separate due to gravitational forces in the first column while measuring the interface height in the second column. The higher density fluid communicates between the two bores in the base block while the lower density fluid flows through

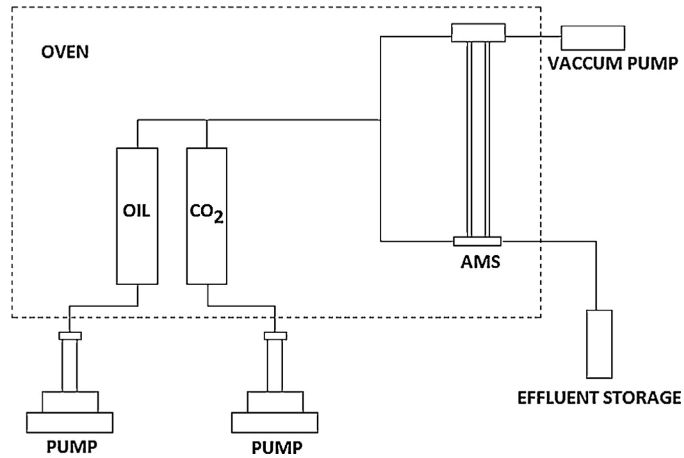

Fig. 1. Diagram of the apparatus for determination of MMP.

a similar connection block mounted to the top of the two tubes. This solution provides a stable meniscus for measurement.

The boundary between fluids is determined by the comparison of the travel time of the reflected pulse from the fluid interface and from a known point located in the higher density fluid and above transducer, which generates acoustic wave. The transducer consists of piezoelectric crystal attached to a titanium diaphragm. The interface is distinct for two immiscible liquids, despite changing level as function of time, pressure and temperature but it comes through fuzzy to completely disappearing for miscible fluids. That phenomena is considered as point when total miscibility takes place. Fluid of uniform density makes impossible for registration and detection of sound wave reflection. The AMS unit can be operated at temperatures up to 150 °C and pressures up to 10 000 psi.

2.2. PTV characteristics of liquids

For the experiment oil from one of polish oil fields was selected. Density of oil was determined in accordance with ASTM D1480-15. Viscosity of crude oil was determined by using a falling ball viscometer in accordance with ISO 12058-1. In Fig. 2 oil viscosity as a function of temperature is presented. Water content in oil was measured in accordance with ISO 9029. PVT properties of analyzed oil are shown in Table 1. Industrially produced CO_2 with 99.99% purity was used (Air Liquide).

The structural group composition analysis was performed on the basis of the PN-72/C-04025 method A. The asphaltene content was determined in accordance with the method described by Kim et al. [16]. In Table 2 content of individual hydrocarbon groups are given.

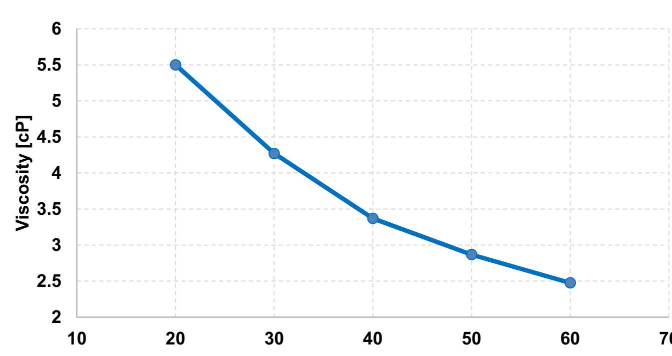

Fig. 2. Viscosity of selected oil for the MMP experiment as function of temperature.