Non-equilibrium Phase Behaviour and Mass Transfer of Alkane Solvent(s)–CO_2–Heavy Oil Systems under Reservoir Conditions

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Abstract

In-situ formation of foamy oil, i.e., a mixture of oleic phase and entrained gas bubbles, has been accepted as a main mechanism resulting in a better-than-expected production performance in a heavy oil reservoir. A robust and pragmatic technique was developed to quantify non-equilibrium phase behaviour of alkane solvent(s)–CO_2–heavy oil systems under reservoir conditions. Experimentally, constant-composition expansion (CCE) tests have been conducted for alkane solvent(s)–CO_2–heavy oil systems with a PVT setup under various non-equilibrium conditions. Theoretically, mathematical formulations were developed to quantify the amount of the evolved gas as a function of time, while mathematical models for compressibility and density of foamy oil are respectively formulated. In addition to determining individual diffusion coefficient with consideration of natural convection induced by swelling effect, a novel and pragmatic technique was proposed to quantify dynamic volume of foamy oil for the aforementioned systems under non-equilibrium conditions by taking into account preferential mass transfer of each component in a gas mixture. It is found that an increase in either volume expansion rate or pressure decline rate results in an increase in the critical supersaturation pressure, whereas a high temperature leads to a low critical supersaturation pressure. When pressure is below the pseudo-bubblepoint pressure, density and compressibility of foamy oil are found to sharply decrease and increase at the pseudo-bubblepoint pressure, respectively. Compared with the individual diffusion coefficient for each component in a gas mixture determined with the traditional methods, a relatively large value has been found during mass transfer processes in a supersaturated oleic phase. Also, pseudo-bubblepoint pressure and rate of gas exsolution is found to dominate the volume-growth rate of the evolved gas, which is directly proportional to supersaturation pressure, pressure decline rate, and concentration of each gas component under non-equilibrium conditions.

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