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Non-Iterative Phase Behavior Model with Application to Surfactant Flooding and Limited Compositional Simulation

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Abstract

Hand’s method is typically used to empirically calculate the equilibrium compositions for ternary systems between two liquid phases. Oil field application of Hand’s method is generally limited to surfactant phase behavior with oil and brine, primarily because the excess oil and brine phases are nearly immiscible. Hand’s method is not accurate to represent liquid-vapor equilibrium, especially as oil and gas become miscible. It also requires iterations, which means that convergence can be slow depending on the initial guess.

In this paper, we present a new empirical phase behavior model to replace Hand’s method. The new method is faster and more accurate, and applicable for both surfactant phase behavior and liquid-vapor equilibrium. The new approach is non-iterative and always finds a tie line or its extension even for the limiting tie line at the critical point. Our approach transforms tie lines to a new compositional space, where all tie lines become parallel. Equilibrium compositions are then easily determined in the transformed space. Besides improved accuracy and robustness, the flash calculations for ternary systems show that the new method is up to 100 times faster than conventional calculations using a cubic equations-of-state (EOS), and seven times faster than Hand’s method. When incorporated in a compositional simulator, the new method reduces flash calculation time to nearly zero compared to the solution of the pressure/compositional equations. Thus, speedup is proportional to the fraction of time occupied by flash calculations within the simulator. For example, if flash calculations are 50% of total simulation time, speedup is nearly a factor of two using the new approach. This approach is ideally suited for fast recovery estimations for miscible gas floods, and fills the gap between standard or modified black-oil models and fully compositional simulations.

Introduction

Phase split calculations are essential to model compositional effects in compositional reservoir simulations, and solubility ratios in surfactant flooding. Compositional modeling with a cubic EOS, however, is computationally intensive and generally requires the use of large grid-block sizes. Because of this limitation, black-oil models are often preferred because of their speed and simplicity. Black-oil models, however, are inaccurate to model displacements where compositional effects are dominant, such as those that occur during gas flooding. A variety of limited compositional models have been developed over the years to fill the gap between black-oil models and fully compositional models, but these often make phase behavior approximations and assumptions that are inaccurate.

The most widely used limited compositional models fall into three main categories: constant *K*-value models, four-component simulators, and pseudo-ternary compositional models. Constant K-value models, such as those of Bolling (1987) and Whitson (1988), make K-values a function of temperature and pressure. These models are limited in accuracy to immiscible floods where K-values are relatively independent of composition. The second type, four-component simulators, generally adds a solvent component to the standard black-oil models. Many of these also use Todd-Longstaff (1972) mixing rules, and/or parameters, such as relative permeability, that change based on whether the pressure is above or below the MMP. These models, however, suffer from the same deficiency of compositional dependence as in black-oil models. More recently, pseudo-ternary compositional models, such as that by Tang and Zick (1993), attempt to model both compositional and pressure dependence using only three components: dead oil, dry gas, and solvent. Their model assumes that all tie lines go though the apex of a ternary diagram corresponding to dead oil. They further simplify phase behavior by approximating the pressure-dependent dew-point and bubble-point curves by two linear segments that extend to a critical point. These simplifications, although better than previous limited compositional models, are not physical and can lead to inaccuracies in modeling the compositional changes that occur during a displacement of oil by gas.