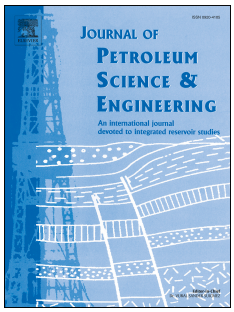
Accepted Manuscript



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PII: S0920-4105(17)30713-1

DOI: 10.1016/j.petrol.2017.09.008

Reference: PETROL 4251

To appear in: *Journal of Petroleum Science and Engineering*

Received Date: 13 June 2016

Revised Date: 6 August 2017

Accepted Date: 8 September 2017

Please cite this article as: Mohebbinia, S., Sepehrnoori, K., Johns, R.T., Kazemi Nia Korrani, A., Simulation of asphaltene precipitation during gas injection using PC-SAFT EOS, *Journal of Petroleum Science and Engineering* (2017), doi: 10.1016/j.petrol.2017.09.008.

Simulation of Asphaltene Precipitation during Gas Injection Using PC-SAFT EOS

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Abstract

Oilfield problems owing to asphaltene precipitation are well known. Asphaltenes can block pore throats or change the formation wettability and thereby reduce the hydrocarbon mobility. Simulation of asphaltene precipitation during gas injection requires a comprehensive thermodynamic model, which accounts for the complex phase behavior of asphaltenes. In this paper, PC-SAFT EOS is implemented for the first time in a compositional reservoir simulator to model asphaltene precipitation. The additional computational time of PC-SAFT compared to the cubic equations-of-state such as Pen-Robinson (PR EOS) is decreased by improving its root finding algorithm. A deposition and wettability alteration model is then integrated with the thermodynamic model to simulate the dynamics of precipitated asphaltenes. Different gas injection scenarios are modeled to show the effect of gas injection on apshaltene precipitation and deposition.

Simulation results show that the profile of the damaged area by asphaltene deposition is governed by the shape of the asphaltene precipitation envelope for the reservoir fluid. The damage caused by asphaltene deposition, through plugging and wettability alteration, was revealed as a decline in productivity index curves. Results indicate that a reservoir fluid can have precipitation risk during gas injection even if it does not exhibit precipitation in the primary recovery life of a field. The computational time of the simulations using PC-SAFT EOS were compared to those using PR EOS for different number of components. Results of these comparisons show the feasibility of using PC-SAFT in compositional simulations.

Introduction

Mixing oils with a solvent incompatible with asphaltenes may lead to asphaltene destabilization and result in a sticky solid phase (Gonzalez *et al*. 2008). Asphaltenes can block pore throats or change the formation wettability by adsorbing onto the reservoir rock and thereby reduce the hydrocarbon mobility (Leontaritis *et al.* 1994). Deposition may cause serious formation damage anywhere in the reservoir domain, especially around the production well where the maximum pressure decline happens.

Asphaltene deposition problem during oil production has motivated several research studies on phase behavior modeling of asphaltenes as a function of temperature, pressure, and composition. In spite of extensive research on asphaltene phase behavior, few studies have been reported on the simulation of asphaltene precipitation during gas injection. The potential of asphaltene precipitation in gas flooding is not usually predicted because reservoirs often contain light oils, which have low asphaltene contents. However, light oils have lower asphaltene solubility and therefore a greater likelihood of asphaltene destabilization under physical or chemical disturbances (Sarma 2003). In some cases, the reservoir has no previous asphaltene precipitation during primary production and therefore the potential of precipitation is overlooked for gas injection (Sarma 2003). Examples are the hydrocarbon gas injection project in Rainbow Keg River "B" pool (Nagel *et al.* 1990) and CO_2 flood pilot project in Midale field in Canada (Beliveau and Payne 1991). These gas floods experienced asphaltene precipitation after gas injection into the reservoir, even though there was no prior asphaltene precipitation problem in preceding primary production or water flood phases.

Existing thermodynamic models for asphaltene precipitation are categorized into two main fundamental approaches: colloidal and solubility. Models based on the colloidal approach assume asphaltenes as suspended solid particles, which are peptized by resins in a colloidal system (Leontaritis and Mansoori 1987, Leontaritis 1988). The theory of the colloidal behavior of asphaltenes is attributed to Nellensteyn (1924). He expressed the asphaltic compounds as a hydrocarbon medium containing dispersed aggregates or flocs of asphaltenes which are stabilized by resins and other hydrocarbons absorbed on their surface. In 1987, Leontaritis and Mansoori proposed a colloidal model to predict asphaltene precipitation onset. Based on the colloidal approach, Victorov and Firoozabadi (1996) proposed a thermodynamic micellization model in which asphaltenes are considered to exist in the crude oil within micelles. Micelles consist of an asphaltene core stabilized by protective layers of resins and components other than asphaltenes (Victorov and Firoozabadi 1996, Pan and Firoozabadi 1998). Asphaltenes and resins in micelles are in thermodynamic equilibrium with their monomers in oil under stable conditions (Pan and Firoozabadi 1998). As long as the micellar cores are thermodynamically stable, asphaltene particles are not problematic in crude oil. However, the thermodynamic equilibrium can be disturbed by physical or chemical interactions. These interactions can dissociate the protective shell and cause asphaltene flocculation (Allenson and Walsh 1997).

According to the solubility approach, asphaltenes are dissolved in the crude oil and form a real solution (Hirschberg *et al.* 1984, James and Mehrotra 1988, Burke *et al*. 1990). In solubility models, precipitation is considered to occur in a solid-liquid equilibrium (SLE) or a liquid-liquid equilibrium (LLE) state. One of the SLE solubility models is the solid model proposed by Nghiem and Coombe (1997). Nghiem and Coombe (1997) assumed that the heaviest component in the oil can be split into a non-precipitating component and a precipitating component (i.e., asphaltenes).

Flory-Huggins regular solution based models (Hirschberg *et al.* 1984, Rassamdana *et al.* 1996) and EOS models are other examples of the solubility approach. SAFT (Chapman *et al.* 1990) is an EOS model used by Ting *et al.* (2003) to model asphaltene phase behavior. This EOS, which is based on statistical mechanics, can efficiently account for molecular polydispersity. Ting *et al*. (2003) assumed that polar-polar interactions are insignificant in asphaltic crudes and van der Waals forces can sufficiently explain the interactions between the molecules. That is, they neglected the association term in SAFT.