



Prediction of asphaltene precipitation risk in oil wells using coupled thermohydraulics model

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ARTICLE INFO

Keywords:

Asphaltene precipitation
Two-phase flow
Asphaltene instability
Parametric study

ABSTRACT

Asphaltene precipitation and deposition is a major flow assurance challenge, which manifests itself in reservoir, production tubing, and flowline and process facility. Asphaltene may precipitate due to two main factors, namely high asphaltene content, and high difference between reservoir pressure and oil bubble-point pressure, i.e. precipitation driving force, even if asphaltene content is low. The objective of this study is to develop a predictive simulation tool to assess the risk of asphaltene precipitation in oil wells and to estimate the asphaltene risk window. Further objective is to use the developed simulation tool to generate well design and production scenarios to efficiently prevent, mitigate and manage asphaltene precipitation. A comprehensive asphaltene deposition workflow is developed to identify the major steps to enable a solution strategy. To implement the workflow, Ansari et al. (1994) mechanistic two-phase flow hydrodynamic model in vertical wells is coupled with two Asphaltene precipitation thermodynamic models, namely de Boer et al. (1995), and Wang et al. (2006). In this study, de-Boer et al. model is extended from a single point reservoir model to a multi-point wellbore model; while Wang et al. is used to predict and compare the asphaltene instability with live-oil instability along wellbore. The developed simulator was validated to predict the risk and depth window of asphaltene precipitation in Middle East oil wells, resulting in a reasonable agreement with the field data. In addition, the simulation tool is used to carry out a parametric study to investigate the impact of oil gravity, and reservoir pressure on asphaltene precipitation risk.

1. Introduction and literature review

Asphaltene deposition is a serious problem in the oil industry, which manifests itself over the entire production system including reservoir, production, transportation and processing system components. With petroleum industry trend toward exploration and production of deep reservoirs, and heavy asphaltic resources, the challenge of asphaltene deposition increases, which may threatens projects economics and safety. In wellbores, asphaltene deposition may result in production loss by partial or complete plugging of production tubing. To avoid complete production tubing plugging, a continuous monitoring and cleaning is required. Furthermore, plugging of sub-service safety valve (SSSV) and their actuation mechanism, x-tree valves, and other downhole equipment, such as electrical submersible pump may result in serious safety concerns. Asphaltene deposition in surface facilities is also serious flow assurance issue, which might be catastrophic. Asphaltene may deposit not only inside separators and treaters, but also on safety, process, and monitoring systems including indication equipment, high-pressure safety devices, and relief valves. Therefore, an early prediction of asphaltene deposition at surface facilities will save human and financial project assets.

Three major hydrocarbon fractions exists in crude oil systems, namely asphaltene, resins, and wax. While the physical and chemical properties of wax are somewhat understood, the properties of resins and asphaltene are still ambiguous (Firoozabadi, 1999). The amount of asphaltene in crude oil depends on several factors such as the source of the crude, burial depth, API gravity of the crude, and the sulfur content (Speight, 1991). An asphaltic system is considered colloidal system with no volatile fractions. Such asphaltic system consists of three components, namely, asphaltene (dispersed phase), resins (peptizing agent), and oil (the dispersion medium) (Yen, 1995). Although there is no universally agreed upon definition of asphaltene, the classic definition of asphaltene is based on its solubility in a specific solvent. Therefore, asphaltene is defined as insoluble in normal alkanes such as *n*-pentane, and soluble in excess benzene and toluene (Firoozabadi, 1999), and is a dark brown to black friable solid that has no definite melting point and decomposes leaving a carbonaceous residue under heating (Mansoori, 1997). Although not much is known about the chemistry of asphaltene, the knowledge of asphaltene chemistry is essential in providing accurate chemical properties and thereby accurate characterization and modeling. Asphaltene consists of hydrocarbon molecules such as

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<https://doi.org/10.1016/j.petrol.2018.04.024>

Received 1 January 2018; Received in revised form 8 April 2018; Accepted 12 April 2018

Available online 14 April 2018

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hydrogen and carbon, and hetero elements, i.e. oxygen, nitrogen and sulfur. Differences in the asphaltene composition from one region to another are anticipated due to the different maturation processes and the nature of the source. A comparison of elemental composition of asphaltene from worldwide sources indicates that the hydrogen to carbon ratio (H/C) varies over 0.05–1.15 %wt. On the other hand, data shows a notable variation in the content of hetero-elements, namely oxygen content which ranges from 0.3 to 4.9 %wt., and sulfur content which ranges from 0.3 to 10.3 % wt. Nitrogen content is relatively less, and varies from 0.6 to 3.3 % wt. The elemental composition data clearly shows that the change in composition of asphaltene is due to variation of hetero-elements content and not hydrocarbons molecules (Speight, 1991). Determination of actual molecular structure of asphaltene was found difficult due to the complexity of its molecules. Nevertheless, asphaltene consists of aromatic nuclei that contains alkyl and alicyclic (naphthenic) systems, and hetero elements (nitrogen, oxygen, and sulfur) are scattered in different locations. Determination of accurate molecular weight of asphaltene is also a challenge. The low solubility of asphaltene in solvents used in molecular weight measurement, and the presence of adsorbed resin in asphaltene are the two main challenges to determine asphaltene molecular weight. The reported molecular weight of asphaltene varies within 1000–2,000,000, which depends on the method of determination as well as measurement conditions. Therefore, a careful precipitation of the asphaltene to extract all resin and the right choice of the measurement method are key factors for reliable molecular weight determination (Speight, 1991).

In asphaltene deposition, the asphaltic system thermodynamic state is crucial to study the behavior of asphaltene precipitation under any given temperature, pressure and compositional conditions. Asphaltene phase behavior envelope is a p-T plot that shows the thermodynamics conditions under which asphaltene solid particles precipitate. On the other hand, the locus of points at which the asphaltene flocculate (aggregate) is called Asphaltene Deposition Envelop (ADE). The determination of the boundaries of ADE is a challenging task. For example, ADE does not have a critical point because a critical point requires a bubble point and a dew point lines; however, ADE does not have dew point line because asphaltene does not vaporize at high temperature, yet it disintegrates. Therefore, ADE consists of bubble point line only, and upper and lower ADE boundaries (Leontaritis, 1989). Asphaltene flocculation process is known to be irreversible, which means that once the upper ADE boundary is crossed and asphaltene flocculates, reversing the thermodynamic path will not de-flocculate the asphaltene (Leontaritis, 1989). On the other hand, Hirschberg et al. (1984) questioned the fact that asphaltene irreversibility depends on how titration experiments is conducted. For example, when additional precipitant is added after asphaltene precipitate, asphaltene precipitation process will not be reversed because the re-dissolution requires more equilibration time. In addition, in a previous experimental work, Hirschberg et al. (1984) observed that after asphaltene precipitate, it starts dissolving as the pressure increases from 280 to 1000 bar. An explanation for this contradictory behavior is that asphaltene perception is thermodynamically reversible, while flocculation could be either reversible or irreversible, depending on the nature of the crude. In oil field operations, asphaltene flocculation process is seen irreversible due to the large size of asphaltene flocs and their adsorption affinity to solid surfaces, sand, and fine particles, which may not wash away by chemical remediation techniques (Mansoori, 1997).

Four major factors control the onset and amount of asphaltene deposition, namely pressure, temperature, oil composition and flow condition/conduit material, i.e. Electrokinetics effect. The temperature affects the internal energy and the density of the liquid phase, which subsequently affects oil-phase solubility parameter (Burke et al., 1990). Therefore, as the temperature increases, oil phase density decreases, and solubility to resins increases, resulting in resin transfer from micelles (a polar structure of asphaltene particle surrounded by resin particles) to oil phase. Consequently, the attractive force of micelles

increases due to the exposure of polar asphaltene particles, leading to asphaltene flocculation. However, the effect of temperature is found to be insignificant (Takhar et al., 1995). System pressure has a minimal effect on asphaltene precipitation above bubble point pressure where oil composition is constant, while it has significant effect at and below bubble point pressure (MacMillan et al., 1995). Above bubble point, decreasing system pressure has the same effect of increasing temperature described above. On the other hand, below bubble point, pressure decrease increases the oil density, which disturbs resins equilibrium, resulting in resins migrating from micelles to oil phase. This will expose polar asphaltene particles, leading to asphaltene flocculation and deposition (Burke et al., 1990). Asphaltene precipitation also depends on oil composition, i.e. introducing n-alkanes into the system upsets resin concentration equilibrium, transferring the resin from micelles to the oil phase, which promotes asphaltene flocculation and deposition (Takhar et al., 1995). Finally, as asphaltic crude oil flows in metallic conduit, an electrical potential difference may be generated due to charged particles motion and friction. Consequently, generated electrokinetic field increases the colloidal particles polarity, leading to asphaltene particle attraction and flocculation. The generated electrokinetics potential depends the flow regime, i.e. laminar vs. turbulent, asphaltene polarity and structure, and conduit thermal and electrical characteristics (Mansoori, 1997).

Several investigators developed prediction simulation tools by modeling the asphaltene thermodynamics behavior under static lab condition. However, hydrodynamic flow condition has a significant effect on both asphaltene precipitation, and more importantly on asphaltene particles transportation, entrainment, and deposition. Kabir and Jamaluddin (2002) developed a pragmatic, cost-effective, and environmental friendly solution to mitigate tubular asphaltene deposition in south Kuwait wells. A thermodynamic fluid characterization of the crude oil was carried out based on which they proposed a mitigation solution, which consists of a 20% of a de-asphalted oil with 1% dispersant (in volume), which ensured asphaltene solubility along the entire production string according to their field tests. Alkafeef et al. (2005) developed a simple method to predict the asphaltene deposition onset under flow condition, as well as the deposit thickness. A verification study of their method against data acquired in west Kuwait field shows a reasonable agreement. Abdallah et al. (2010) investigated asphaltene deposition in onshore wells located in Abu Dhabi by intensive thermodynamic fluid characterization, which is used to calibrate a thermodynamic based simulator to study the effect of process and production conditions on asphaltene stability. In their study, an EOS is used to model the asphaltene phase behavior, and kinetic and transport models to model the deposition behavior. Kurup et al. (2012) developed a simulation tool to predict the location and amount of asphaltene deposits in wellbores. Alapati and Joshi (2013) developed an efficient field method to test chemical inhibitors and dispersants, which does not require high-pressure reservoir samples, thus it is cost effective, and time efficient. Sulaimon and Govindasamy (2015) developed an empirical correlation to predict asphaltene deposition tendency in Malaysian crude oil. Their correlation is based on the Colloidal Instability Index, Refractive Index and molecular weight of both oil and lumped fraction of crude oil. Abuie et al. (2015) modeled asphaltene deposition in wells operating under gas lift, using a comprehensive thermal compositional wellbore model. The prediction shows that injecting light gas composition promotes asphaltene precipitation in the well. Hashmi and Firoozabadi (2016) conducted a lab-scale capillary experiment to study the removal mechanism of asphaltene deposits. In their study, three chemical inhibitors were used to reverse/remove asphaltene deposits. Among the three, the strong organic surfactant dodecyl-benzene-sulfonic acid is found to be the most effective to remove asphaltene deposits and with concentration of ten times less than that required by toluene.

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