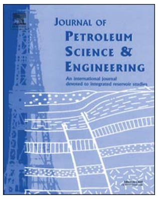
Journal of Petroleum Science and Engineering 151 (2017) 330–340

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol



Characterization of asphaltene deposition process in flow loop apparatus; An experimental investigation and modeling approach

Ali Khorram Ghahfarokhi, Peyman Kor, Riyaz Kharrat*, Bahram Soltani Soulgani

Petroleum Engineering Department, Petroleum University of Technology, Ahwaz, Iran

ARTICLE INFO

Keywords:
Asphaltene
Deposition
Precipitation
Flow assurance

ABSTRACT

This paper describes the results of experimental tests in co-injection of precipitant agent/oil through a flow-loop setup to measure and characterize the deposition of precipitated asphaltenes along in-line test section. To do this, a novel experimental flow loop setup was designed and constructed to carry out the turbulent flow of oil (Re up to ≈7500) at desired oil-precipitant volumetric dilution ratio (DR), volumetric rate of flow and radial temperature gradient of the test section. Since the formation of deposit layer makes it difficult for the oil flow along the tube, change in pressure difference across the test section of setup was recorded along the time to measure the amount and extent of deposition process at desired condition. The experimental results revealed that, while radial temperature gradient of tube does not affect deposition process much, increasing the velocity of fluid across the tube further sweeps the precipitated particles from vicinity of wall before they have enough time to stick in contrary to oil-precipitant ratio; where the deposition rate is enhanced with increasing DR. Furthermore, these observations were thoroughly analyzed and with utilizing the concept of deposition efficiency, a new mathematical model proposed and verified for prediction of asphaltene deposition rate. The results of this work provide better insight into dynamics of asphaltene deposition and could create a better framework for conducting forthcoming experiments and developing new models of asphaltene deposition in pipelines.

1. Introduction

Asphaltene deposition in producing wells, pipes, and surface facilities have been a serious problem with a wide economic import to the oil industry. Deposition of asphaltene on the wall of production tubing (Abouie et al., 2015; Eskin et al., 2011; Kor and Kharrat, 2016) or in pores of reservoir (Civan, 2001; Darabi et al., 2014; Fallahnejad and Kharrat, 2015; Saraji et al., 2010) reduces available space to oil flow and subsequently, oil production rate decreases.

Asphaltene is the heaviest component of petroleum liquid and known as insoluble in alkanes such as n-pentane (C5) or n-heptane (C7), but soluble in aromatic solvents such as toluene, benzene or pyridine (Mullins et al., 2007). Generally, asphaltenes are stable in oil phase at reservoir condition. Variation in temperature, pressure and composition of oil can induce asphaltene instability. Asphaltene stability in crude oil has been subject of investigations over many years (Hirschberg et al., 1984; Nghiem and Coombe, 1997; Tavakkoli et al., 2013; Victorov and Firoozabadi, 1996). Asphaltene stability models can be classified as either thermodynamic or scaling models (Jafari et al., 2013). The cubic equation of states (Kohse et al., 2000; Nghiem et al., 1993; Tavakkoli et al., 2009), Micellization theory (Victorov and Firoozabadi, 1995) , PC- SAFT equation of state (Abouie et al., 2016; Assareh et al., 2016; Gross and Sadowski, 2001; Panuganti et al., 2012) and CPA equation of state (Li and Firoozabadi, 2010; Nasrabadi et al., 2013) are the example of the models have been used to study asphaltene precipitation thermodynamically. On the other hand, scaling models are based on aggregation and gelation phenomena (Ghahfarokhi, 2016; Sahimi et al., 1997). Asphaltene precipitation or deposition is often reported interchangeably; however, the difference is well defined. Precipitation is defined as solid phase formation from the bulk liquid phase, primarily as a function of thermodynamic variables (i.e., temperature, pressure, and composition). Deposition, however, is known as the creation and growth of a deposited layer on a surface. Therefore, precipitation is a prerequisite to asphaltene deposition, but it is not a sufficient condition for deposition (Kor et al., 2016). Much research work has been conducted in the area of asphaltene precipitation in the past several decades, although the mechanism of asphaltene deposition is still not well-understood (Juyal et al., 2005). According to Buckley. (2012), an experimental investigation on asphaltene deposition can be classified

---

* Corresponding author.
E-mail addresses: Kor.peyman@gmail.com (P. Kor), kharrat@put.ac.ir (R. Kharrat).

http://dx.doi.org/10.1016/j.petrol.2017.01.009
Received 24 July 2016; Received in revised form 13 November 2016; Accepted 4 January 2017

Table 1
Summary of advantages and disadvantages of conducting deposition experiments at different geometries.

Geometry (Material)	Advantages	Disadvantages	Capability of Each Geometry in Simulating Real Flow of Oil in Well			
			(Black points show that the Geometry is able to simulate the specified feature)			
			Axial Shear Force	Turbulent Oil Flow	Live oil Reservoir Condition	Enough Asphaltene Deposit to affect heat transfer
Capillary Tube	1. Requires Low volume of fluid 2. The pressure difference along a capillary can be measured 3. Accumulation of deposited material can be Visualized.	1. Mostly unable to simulate the intensive turbulent flow2. Cannot model the live-oil reservoir	•			
Capillary Tube (glassy)			•			
Tube (Large Capillary)	1. Turbulent flow with Reynolds number up to 30,000 can be operated 2. Deposited asphaltene is thick enough to affect the heat transfer coefficient	1. Requires large volume of fluid 2. 2. Unable to simulate live oil reservoir fluid	•	•		•
Taylor–Couette (TC) cell	1. Adaptable to operate at high temperature and pressure (Up to 105 MPa and 200 °C) 2. 2. Shear rate can be varied by changing rotational speed.	1. Requires larger amount of sample than capillaries 2. More expensive than capillaries and tubes		•	•	

in two main geometries: tubes of capillary (Boek et al., 2008; Broseta et al., 2000; Nabzar and Aguiléra, 2008a, 2008b; Wang et al., 2004) or larger dimensions (Alboudwarej et al., 2004; Jamialahmadi et al., 2009) and Taylor –Couette (TC) cells (Akbarzadeh et al., 2011b; Zougari et al., 2006). The summary of benefits and limitations of performing experiments at each geometry is explained in Table 1.

1.1. Capillary tests

Broseta et al. (2000) constructed the capillary setup of asphaltene deposition and performed experimental tests by co-injecting the various ratio of heptane and xylene into the 100 ft long stainless steel capillary at low shear rates. The pressure drop measurements were used to detect the asphaltene deposition onset and also asphaltene deposition envelope while the qualitative discussion was made about the rate of asphaltene deposition and removal. Wang et al. (2004) concluded that increasing molecular weight of asphaltene precipitant leads to the higher amount of deposition material in 0.02-in. stainless steel capillary. For example, asphaltenes precipitated by n-C_{15} cause much more deposition than an n-C_7 agent. Nabzar and Aguiléra (2008a, 2008b) studied the effect of a wide range of shear rates on the kinetics of asphaltene deposition in capillary flow. They showed that there are two critical shear rates that affect deposit creation: at low shear rates up to first critical shear rate the deposition is in diffusion-controlled regime, whereas beyond the firsts critical shear rate to the second critical, the deposition of colloidal asphaltene is more sensitive to shear rate than the previous regime while both critical shear rates depend on stability of asphaltene in the mixture. In the most recent work, Hashmi et al. (2015) introduced a new deposition model suggesting that asphaltene deposition on the metal surface is governed by the diffusion-driven mechanism. Asphaltene deposition was assessed by injecting a mixture of asphaltene precipitant agent and oil into a small capillary tube, which led to asphaltene deposition. Measurement of pressure drop across the pipe was used to understand dynamics of asphaltene deposition. The agreement was found between model predictions and experimental data. However, the model was developed for laminar flow, and further investigation is required to apply the model to turbulent flow of oil.

1.2. Taylor - couette cell tests

The cell, which is based on Taylor-Couette (TC) flow principles, was designed to simulate the hydrodynamic (e.g. turbulence, shear) and thermal (temperature and heat transfer) characteristics of oil in production lines (Zougari et al., 2006). Initially, the deposition test in the TC cell was performed in batch mode (closed) where the Cell containing the STO was displaced with live oil and the spindle is turned on and its rotational speed is set to desired shear rate (Akbarzadeh et al., 2011a). However, for oil with low asphaltene content, the amount of obtained asphaltene was a very small thus interpretation of tests was difficult. In order to overcome the limitation, later work was done with supplying fresh sample during the course of a test in flow through mode which produced larger amounts of asphaltene deposit. They found that shear has a significant impact on deposition in TC cell where the rate of asphaltene deposition is smaller at a pressure close to onset point than pressure close to bubble point of reservoir fluid (Akbarzadeh et al., 2011a).

1.3. Pipe-circular

Jamialahmadi et al. (2009) utilized the thermal approach to measure the rate of asphaltene deposition via the measurements of the heat transfer coefficient and the thermal resistance of deposited asphaltene in the pipe-circular flow. They proposed Arrhenius type of equation for adhesion force between flocculated asphaltene and metal surface and the proposed model was verified with results of experi-