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Visualization of asphaltene precipitation and deposition in a uniformly patterned glass micromodel

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ABSTRACT

Precipitation and deposition of asphaltene are among chronic operational problems for recovering oil from reservoirs of high asphaltene content. The present experimental study aimed at investigating the process of precipitation and deposition of asphaltene in a uniformly patterned glass micromodel. This was carried out by the injection of n-heptane while setting the other operating conditions, such as temperature, pressure and flow rate unchanged. Synthetic oil solutions containing toluene and n-heptane with asphaltene content of 5 wt% were prepared and injected to the micromodel under different wettability conditions. Precipitation of asphaltene gradually started once n-heptane was introduced to the micromodel. It was found that asphaltene precipitation occurred as injected n-heptane diffused into the oil phase and destabilized the dissolved asphaltene. The destabilization of dissolved asphaltene occurred along with the formation of a cloud-like, semi-solid phase which evolved from the oil phase due to the diffusion of n-heptane molecules indicating the onset of asphaltene precipitation. As soon as precipitation took place, the color of oil phase changed from black to grey due to loss of dissolved dark asphaltenes. Asphaltene precipitation in the oil-flooded micromodel was more likely to occur due to the deposition of asphaltene onto the micromodel surface and passages. Finally, it was found that not all precipitated asphaltene particles would deposit, instead it was more likely occurrence (i) for the oil-flooded micromodel; (ii) micromodels passages with tortuosity and complicated flow paths which have been generated by the deposition of precipitated asphaltenes and (iii) the interface of n-heptane and the oil phase.

1. Introduction

Crude oil contains many components but can generally be divided into four major groups of saturates, aromatics, resins and asphaltenes [1]. Among these constituents, asphaltene is considered to be the most polarizable component with the highest molecular weight and most complex structure. Several investigations have shown that asphaltenes are dispersed in crude oil by resin molecules as peptizing agents [2–5]. Asphaltene is a complex mixture of mainly aromatic rings attached to hydrocarbon chains and heteroatoms such as nitrogen, oxygen and sulfur as well as metals. This makes the characterization of asphaltenes extremely difficult from one crude to another [6]. Accordingly, asphaltenes are commonly defined as solubility class of crude oil components. Asphaltenes are soluble in aromatics such as toluene and xylene, while insoluble in normal alkanes such as n-pentane and n-heptane [5,7,8]. The stability of asphaltene in crude oil may be disrupted due to changes in temperature, pressure, composition and surface characteristics of rock/fluid interface [9–11].

In recent years, EOR processes have gained attention for enhanced recovery of oil reservoirs which are rapidly getting depleted. Many of such EOR processes include the injection of fluids of various types to oil reservoirs, which may lead to precipitation and deposition of asphaltene. The precipitation of asphaltene, in turn, is known as one of the most challenging and costliest problems which may occur during the recovery of oil reservoirs. The detrimental impacts of asphaltene precipitation and deposition can be summarized as: permeability reduction, changes in crude physico-chemical properties, wettability alteration, pore clogging, and changes in stability of oil/water emulsions.

In the literature, sometimes the terms asphaltene “precipitation” and “deposition” have been used interchangeably. This has been despite the fact that precipitation is a phenomenon in which

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asphaltene evolves from oil phase and becomes a separated solid phase as particles which their sizes are bigger than 500 nm [12]. On the contrary, deposition is the process in which adhesion or cohesion of asphaltene particles onto solid surfaces or formerly deposited asphaltene would occur respectively [13]. Therefore, not inevitably all precipitated asphaltene particles would deposit onto surfaces. In other words, precipitation is a necessary but not sufficient perquisite condition for deposition.

Micromodels of various types have extensively been used to investigate the precipitation and deposition of asphaltene as they mimic structurally the porous structure of oil reservoirs. Mattax and Kyte [14] pioneered the development of glass micromodels. They used micromodels with the network of channels to observe fluids interfaces in porous media and investigated the effect of wettability on oil production during water-flooding. Bonnet and Lenormand [15] made larger and more complex micromodels by the use of photo-etching procedure. They constructed micromodels with pore sizes similar to those in oil reservoirs. Davis and Jones [16] used photo-sensitive resists which could become very persistent to different solvents when subjected to ultraviolet (UV) rays to coat the surface of the glasses. The procedure followed by acid etching process and final refinement. Several other researchers used different methods and technologies to construct and make proper micromodels with different characteristics [17–19]. Recently, Mohammadi et al. [20] have reported a procedure for constructing glass micromodels by laser technology.

The onset of asphaltene precipitation has been the subject of many studies. Several experimental procedures have been proposed in the literature to detect the onset of precipitation. Interfacial tension (IFT) measurements [6], gravimetric technique, acoustic resonance technique, light scattering technique using near infrared (NIR) and filtration experiments are among several methods that have been employed to detect the onset of asphaltene precipitation [21–25]. Other methods including high pressure microscopy and particle size analysis have also been used intensively to determine the pressure of asphaltene precipitation onset [25,26]. There are also some other techniques which are based on visual observations and analyses. Nonetheless, only few studies have been carried out to visualize asphaltene precipitation and deposition in porous media. By the utilization of high pressure glass micromodels, Danesh et al. [27] investigated the precipitation of asphaltene during miscible gas injection. With the help of experimental visualization in low pressurized heterogeneous glass micromodels, Dehghan et al. [28] investigated the performance of water alternating solvent (WAS) process for heavy oil recovery. Nonetheless, no fundamental study has been conducted to visualize the onset of asphaltene precipitation as well as the rate of asphaltene precipitation and deposition using synthetic oils.

The purpose of the present study was the visualization of asphaltene precipitation which would lead to pore deposition and clogging. In this study, this was primarily addressed only through the injection of precipitant, here n-heptane while setting the other parameters such as temperature, pressure and flow rate unchanged. Accordingly, n-heptane, which is widely known as asphaltene precipitator, was used to change the composition of fluids in the micromodel and subsequently to get the dissolved asphaltene precipitated. This has been discerned in this study with a help of a uniformly patterned glass micromodel where synthetic solutions with a certain content of asphaltene were used as surrogate oil. This arrangement helped to investigate how asphaltene precipitation occurred during composition changes as well as respective mechanisms and the rate of precipitation and deposition of asphaltene for water- and oil-flooded micromodels.

2. Materials and methods

2.1. Geometrical characteristics and assembly of glass micromodel

Glass micromodels can be used for visualization and simulation of two-dimensional flow processes in oil reservoirs. The utilization of glass micromodels would also help to get better insight into processes such as precipitation, deposition as well as changes in flow regime which may occur in oil reservoirs. Accordingly, in the present study, a glass micromodel with uniformly patterned structure was designed, constructed and used to study the precipitation and deposition of asphaltene. The simple and uniform structure of the micromodel ensured that parameters such as pore roughness, different aspect ratios, and different pore geometry would not affect the afore-mentioned processes. Moreover, the simple pattern was chosen to avoid the impact of chaotic tortuosity and complicated flow paths on the process of precipitation and deposition. In the course of experiments though, the structure of flow paths may change as a result of precipitation and deposition of asphaltene. Fig. 1 represents a schematic diagram of the constructed glass micromodel.

To construct the micromodel, simple window glass known as float glass was used. The first step was the attachment of paper stickers which was non-acidic to one side of the glass with a desired size. By the use of laser technology, the desired flow patterns which had been designed using Corel Draw X7 software were cut on the stickers. The next step was to rinse the glass and the stickers in HF acid before washing the glass with water. The optimized concentration of HF acid for this process was 39 vol% and the acidic rinsing was repeated several times. While doing this and after washing the glass with water, flow paths were carefully cleaned and polished to achieve a perfect etching process. After removing the sticker, another glass with the same size was placed on the prepared etched glass and then both glasses were put in the furnace. The temperature of the furnace was gradually increased up to 750 °C at which the two glasses were firmly adhered together. More details about the furnace timing for the construction of the micromodel are provided in Table 1. Soon after finishing the heating process, the glasses were cooled down gradually to avoid thermal stresses. Geo-physical characteristics of the constructed glass micromodel are provided in Table 2.

2.2. Experimental set-up

A sketch of experimental set-up is presented in Fig. 2. The working fluids such as synthetic solutions, oil, water or n-heptane were

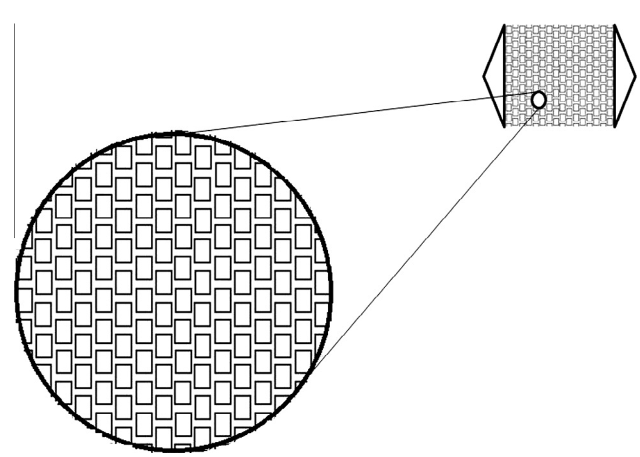

Fig. 1. Geometrical structure of the investigated glass micromodel.