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Full Length Article

A new approach to study deposition of heavy organic compounds in porous media

Sasan Dabir [a], Bahram Dabir [b], Rouzbeh Ghanbarnezhad Moghanloo [c,*]

[a] The University of Southern California, United States
[b] Amirkabir University of Technology, Iran
[c] The University of Oklahoma, United States

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ABSTRACT

A two-dimensional pore network model is presented to validate the deposition of heavy organic compounds (HOC) formed out of an oleic phase in a porous medium. The thickness of the deposition covering the pore surface and the associated pressure drop across each channel of the pore network as well as the overall pressure drop across the entire network model were simulated using the Wang-Civan deposition model. The results were then compared to the measured total pressure drop for each experimental run. Heptane and decane were the two types of precipitator (solvent) used in the experiments with carbon numbers of 7 and 10, respectively. Additionally, three crude oil/solvent volumetric ratios of 10:5, 10:6, and 10:7, as well as three different total flow rates of 4, 8, and 12 ml/h were examined to investigate their impacts on the deposition of HOC. The deposition was evaluated through release and deposition coefficients for each experiment. Results indicated that as the solvent carbon number, crude oil/solvent ratio, and total flow rate of crude oil and solvent increases, the deposited layer and the corresponding total pressure drop decreases, the deposition continues until the complete blockage of the entire network because of deposition.

1. Introduction

The importance of asphaltene and heavy organic compounds (HOC) in the petroleum industry stems from its negative effects on exploration, recovery, transportation, and treatment [19,25]. For instance, asphaltene deposition can reduce porosity and permeability, which can lead to plugging of well-bores, transportation pipes, processing equipment [13,7,19]. Asphaltene also increases the catalyst fouling and coke formation during treatment processes [21,16]. There are some factors with serious effects on HOC precipitation; these effects can be categorized as the nature, saturation, and distribution of reservoir fluid. Other factors are mineralogy of the rock, pressure, temperature, and the nature of the injection fluid and total amount of asphaltene and resins that exist in the reservoir oil. The intensity of permeability degradation due to the deposition of asphaltenes depends on the medium in which the deposition occurs. The model validation for dynamic CO_2 miscible injection tests by Bolouri and Ghoodjani [18] shows that the main mechanisms of asphaltene deposition in sandstone cores are cake forming and adsorption; while in the case of carbonate cores is the gradual pore blocking and pore sweeping. Civan [5] investigated the significance of the dispersion mechanism and temperature variation on fines migration and deposition, and consequent permeability impairment in porous media by a practical phenomenological models considering temperature variation and particle transport by advection and dispersion in porous media. The electro-kinetics effect known as potential generation is another influencing parameter which occurs due to the flow of the reservoir fluid.

Investigation and study of the fluid flow in a porous media has a broad application in different realms of science and engineering including the oil and water industries. Sophistications regarding the fluid flow in porous media and the inability to predict hydraulic parameters of the fluid in a porous media efficiently have caused limitations; as in most cases, the porous media has been considered a unit control system to simplify the case. Moreover, the acquired linear (Darcy's law) and nonlinear (Forscheimer's equation) equations for the pressure gradient and fluid velocity have been derived based on observations and experimental work.

Minssieux [13] investigated the deposition of asphaltene experimentally in porous media for the first time. Minssieux conducted the experiments on dead oils with different asphaltene contents

* Corresponding author.
E-mail addresses: sdabir@usc.edu (S. Dabir), drbdabir@aut.ac.ir (B. Dabir), Rouzbeh.gm@ou.edu (R. Ghanbarnezhad Moghanloo).

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Nomenclature

r	the width of micro-channel [m]
r_m	the minimum value of the widths of the channels [m]
r_a	the average value of the widths of the channels [m]
L	the length of each micro-channel [m]
d_h	the equivalent hydraulic diameter of each micro-channel [m]
A	the cross-sectional area of the channel [m^2]
p	the "wetted" perimeter of the channel [m]
Q	flow rate in the channel [m^3/s]
μ	viscosity of the fluid [kg/m s]
$P_{i,j}$	pressure at each node [Pa]
δ	the thickness of the deposited layer in each segment of the channel [m]
δ_{ave}	the average thickness of the deposited layer along the channel [m]
$C_{i,j}$	the mass concentration of the particles at each node [kg/m^3]
M_A	the mass of suspended particles per unit volume in each segment of the channel [kg/m^3]
ϕ	fraction of cross-sectional area in the channel free of deposited HOC particles [–]
ϕ_0	the initial value for ϕ [–]
A_v	the open cross-sectional area of the channel [m^2]
A_0	the initial value for the cross-sectional area of the channel [m^2]
v	the flux of the liquid phase [m^3/m^2 s]
ρ_A	density of the suspended HOC particles [kg/m^3]
C_{SA}	the mass concentration of suspended particle in each segment of the channel [kg/m^3]
α	the release coefficient [1/m]
β	the deposition coefficient [1/s]
σ	the snow ball effect factor [–]
γ_i	the instantaneous plugging deposition rate coefficient [1/m]
u_l	the superficial velocity of the fluid [m/s]
v_l	the interstitial velocity of liquid phase (u_l/ϕ) [m/s]
$v_{cr,l}$	the critical interstitial velocity of the fluid [m/s]
d_{pt}	the average pore throat diameter [m]
$d_{pt,cr}$	the critical pore throat diameter [m]
V_A	volume fraction of each segment which is occupied by the deposited HOCs [–]
V_{dep}	the deposited volume of HOC particles in each segment [m^3]
V_{depov}	the overall amount of deposited volume along the channel [m^3]
ΔP	the pressure difference along the micro-channel [Pa]
ΔP_0	the initial value for ΔP [Pa]

using natural core samples with varying permeability. The effect of the asphaltene deposition on permeability of the carbonate rock was investigated by Ali and Islam [1]. Civan [6], for the first time, represented a model for the simultaneous deposition of paraffin and asphaltene in a porous media using different formulation of parallel-pathways model represented by Gruesbeck and Collins [9]. An improved model of Civan [6] was then reported by Wang et al. [24], which later improved further to model the deposition of asphaltene in a reservoir [23].

Leontaritis [12] presented the first model for the deposition of asphaltene in an oil reservoir near the wellbore. Almehaideb [2] also investigated the deposition of asphaltene near the wellbore. Deposition of asphaltene during primary oil recovery and CO_2 flooding was simulated using a compositional simulator [15]. Wang and Civan [23] used a black-oil simulator to simulate the deposition of asphaltene in a reservoir. Considering the asphaltene aggregation effect, Kohse and Nghiem [11] improved the compositional simulator with the use of the Wang and Civan model. Dahaghi et al. [3] proposed a simple model in which variations in a number of parameters can be taken into account. The model can be used as a practical tool to describe permeability reduction for the flow of suspended particles in porous media. Network models were used to acquire more detailed information regarding properties such as permeability of the system with the use of two-dimensional or three-dimensional flow models [14].

In this study, a two-dimensional network model consisting of a set of micro channels, in which three or more channels have been connected to each other at each node, was used to investigate the deposition of heavy organic compounds including asphaltenes in each channel of the network. The size distribution of the channel network affects the discharging volume. The physical properties of the network model, such as the size of the network model and diameter and length of each channel, are usually estimated based on the structure of the porous media itself. Different statistical distribution functions have been presented for all radii of network channels by researches to develop the proposed network models. Using the following probability distribution function for a two-dimensional network, the width and corresponding hydraulic diameter of each micro channel were calculated for the network model in this study:

$$f(r) = \frac{(r - r_m)}{(r_a - r_m)^2} \exp\left[-\frac{1}{2}\left(\frac{r - r_m}{r_a - r_m}\right)^2\right] \tag{1}$$

where r_m, r_a are the minimum and the average widths of the micro channels respectively.

Assuming that

$$\frac{L_i}{r_i} = 10 \tag{2}$$

Corresponding length of each micro channel was obtained.

In this study, a 11 × 11 of nodes network model (121 nodes in the middle plus the injection and discharge nodes) was fabricated and used to conduct a set of experiments to investigate the effect of solvent carbon number, crude oil/solvent ratio, and total flow rate of crude oil and solvent on the deposition of HOC. A mathematical model was also proposed to predict the deposition of heavy organic compounds and to calculate the thickness of the deposited layer and the corresponding pressure drop due to deposition of HOC in each channel of the network, as well as the overall pressure drop across the entire network model.

This paper is structured as follows: fluid characterization; experimental set up; description of the experimental work; numerical modeling; calculation of deposition thickness as a function of time and associated pressure drop both locally and across the whole system.

2. Materials and method of experiment

2.1. Materials

Heptane and decane with the purity (GC) of >99% from Merck Chemical Co. were the alkanic precipitants used for the