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Asphaltene Deposition in Porous Media Micromodels: Experimental Studies and Comprehensive Permeability-reducing Mechanisms

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Highlights

- Mechanism of asphaltene deposition and fouling in porous media have been studied
- Asphaltene deposits and permeability loss in porous media have been investigated
- Impact of the different parameters on asphaltene accumulation have been discussed

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Abstract

Asphaltene-induced formation damage is one of the complicated processes of permeability damage in porous media, particularly in the near-wellbore area. Asphaltene particles precipitate out of the bulk fluid phase during production as a consequence of pressure drop, which may reduce permeability owing to both deposition of asphaltene nanoparticles on porous media surfaces and plugging of pore throats by larger asphaltene agglomerates. Asphaltene precipitation and deposition in production tubes and surface facilities are well-documented concerns, and many solutions for managing them are available. However, the effects of asphaltene in the reservoir, particularly in the near-wellbore zone, are little known. In this study, using an artificial porous medium, experimental data on pressure drop due to changes in parameters such as flow rate, type of precipitant n-alkane solvent (N-heptane alkane solvent and n-decane are used), and percentage of precipitant were obtained. Next, the amount of permeability reduction due to asphaltene deposition in a porous medium has been calculated. To identify the dominant mechanism in reducing clogging, experimental data was fitted with the proposed quasi-experimental models at different time intervals. One of the study's accomplishments was determining the major mechanism of permeability reduction (in vitro) using a reasonably basic model with the least dependent parameters and a decent approximation. According to the findings, pore throat plugging becomes the dominant mechanism of permeability reduction, although filtration cake formation and surface deposition may exist during the tests.

Keywords: Asphaltene deposition, Glass micromodel, Permeability damage, porous media, Solvent injection.

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1. Introduction

Deposition of asphaltene can cause challenges in both upstream and downstream processes (Hamadou, et al.,2008). Asphaltene precipitation may accumulate in pipelines, manufacturing facilities, and heat exchangers in downstream operations. This is more common when the Reynolds number is high. A great deal of research is now being done to address this issue. Asphaltene precipitates may settle in the porous matrix in upstream operations, leading to decreased porosity and permeability, as well as changes in wettability (Mohammed, et al.,2021). Asphaltene adsorbs on the pore surface, covering it and changing its wettability owing to electrochemical interactions. Polar components of crude oil are thought to be the major cause to adsorption. Furthermore, the rate of adsorption by polar molecules is proportional to the wettability change. These phenomena, which often occur at low Reynolds numbers, are poorly understood. To accurately predict the rate of permeability damage in reservoirs caused by asphaltene deposition and devise an appropriate cleanup treatment, it is necessary to accurately forecast the rate of permeability damage in reservoirs caused by asphaltene deposition and apply the necessary remediation treatment. To estimate permeability damage, two factors must be examined. The first is the amount of asphaltene that deposits in porous media, and the second is the measure of permeability loss that is associated with a particular amount of asphaltene deposition. This article uses laboratory experiments to answer the latter question. The oil industry places a high priority on understanding the asphaltene accumulation problem and the variables that influence it, due to the obvious high cost involved with production loss due to asphaltene deposition and remediation techniques such as solvent wash and removal of deposited asphaltene (Soulgani, et al.,2011). There is well-documented research available in the literature in the latter case. Several experimental approaches and modeling tools have been developed during the last decade to explore and monitor asphaltene deposition in flow lines (Hassanpouryouzband, et al., 2017, Ghahfarokhi, et al., 2017, Naseri, et al., 2020, Guan, et al., 2017). However, the difficulties associated with asphaltene fouling inside reservoirs are even less well known, owing to a lack of experimental capabilities. Moreover, the present modeling techniques for evaluating asphaltene deposition in porous media have limited capabilities, either due to a lack of reliable lab data for validation or to the involvement of too many changeable factors that cannot be confirmed or quantified in the lab. In the literature, numerous modeling methodologies are utilized to model asphaltene deposition in porous media (Gruesbeck, et al., 1982, Kord, et al., 2014, Eskin, et al., 2016). In these techniques, several mechanisms such as adsorption, surface deposition, pore throat plugging, deposit entrainment, and pore throat opening have been examined. However, it is still unclear which mechanisms are more important and which could be ignored in modeling asphaltene deposition inside porous reservoir rocks.

Pore-scale investigations of asphaltene accumulation in porous media is an experimental technique that aids in the comprehension of the mechanics of asphaltene deposition (Blunt, et al.,2002). Researchers can explore the asphaltene accumulation profile in porous media using visual observation and image processing technologies (Fadili, et al.,2009, Lin, et al.,2016). Microfluidic devices can also be utilized to analyze the flow pattern near asphaltene deposits. Several experiments have been performed to examine asphaltene deposition. Among these, the following are notable:

Bagheri et al. investigated the influence of various production schemes, such as natural depletion and CO2 injection, on the propensity of asphaltene accumulation in porous media (Pak, et al.,2011). Jafari Behbahani used a bottom-hole live oil sample to examine the permeability decline of a tight-sandstone core sample under miscible CO2 flooding procedures induced by asphaltene accumulation. (Jafari Behbahani, et al., 2012). Leontaritis constructed an asphaltene near-wellbore formation damage method to evaluate the severity of formation damage caused by asphaltene accumulation while including time and the impact of asphaltene deposition on the hydraulics of the near-wellbore region as well as the

wellbore itself (Leontaritis,1998). Shirdel et al. investigated asphaltene deposition using the spherical particle model and varied deposition methods based on asphaltene size. The results revealed that reducing the deposition rate by increasing flow velocity owing to expansion and decreasing tubing surface temperature due to thermal gradient from bottom-hole to surface (Shirdel, et al.,2012). Mirzabozorg et al. investigated permeability variations caused by asphaltene deposition using a dual-porosity, dual-permeability model, and found that asphaltene deposition had a greater influence on fracture permeability than matrix deposition (Mirzabozorg, et al.,2009). In this study, we expand on the experience of the glass micromodel and extend our research to two precipitants such as n-Heptane and n-decane, as well as flowrate and solvent to oil ratio. Asphaltene deposition was tracked by photographing the glass micromodel and monitoring the pressure decrease across it. In this paper, we propose a novel, simple model for a coupling pressure drop to permeability decrease. According to the model, Conductivity changes are related to the square root of the pressure decrease. Furthermore, to determine the dominating mechanism in reducing permeability, experimental data were adapted to the provided models of mechanisms such as surface deposition, pore throat plugging, filtration cake formation, and the coefficients of the models were calculated. The physics of particle deposition in a porous media will be described in the subsequent sections. Improved models to identify deposition mechanisms and permeability impairment in porous media are still a challenging issue due to the existence of numerous types of crude oil with different forms of asphaltene particles and a diversity of interactions of asphaltene with other particles in crude oil. Furthermore, permeability degradation caused by asphaltene precipitation may be influenced by porous medium properties and flow hydrodynamics.

2 .Physics of permeability reduction

Roque et al. conducted extensive tests on quartzite porous stone and accurately described the sample before measurements. The influence of several factors on the permeability of the porous medium was explored, including operational parameters, flow rate, concentration, and particle size. The obtained result shows the importance of such factors, particularly in light of the underlying condition that precipitation must be considered (Roque, et al.,1995). Figure 1 show the results in brief. Particle location and deposition kinetics are the most essential characteristics for considering permeability decline and deposition mechanisms. Further research has revealed that permeability decrease is largely reliant on the mechanism of particular particle deposition.

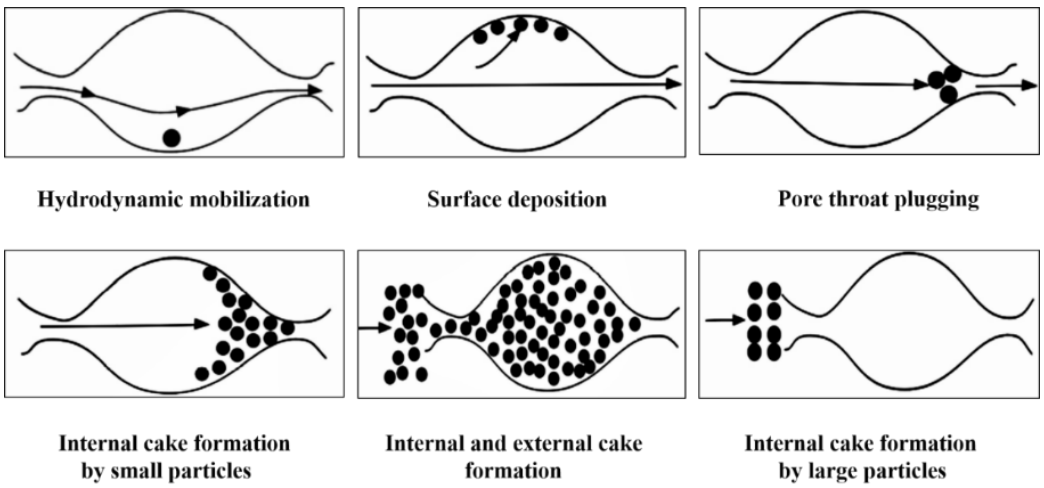

Figure 1

Various particulate processes (Roque, et al, 1995).

2.1. Particle surface deposition

The deposition location in surface deposition is the pore surface. The electrostatic charge differential between the surface of the pore and the particle, as well as the structure of the pore surface, chemical characteristics, and pore density, all have an impact on the kinetics of the deposition process on the pore surface. However, if the deposition on the pore's surface began near the pore's throat, there would be a considerable reduction in permeability. As a result, the impact of throat sediment fractions on permeability decrease is more important than the amount of sediment present. If the suspension flow velocity remains constant, the surface deposition will become strictly monolayer due to tremendous repulsion between almost static particles. For this phase, the monolayer deposition would occur if the opposing energy of aggregation were significant. Due to the results of experiments as well as theoretical sources, it can be concluded that the deposition on the surface has a minor effect on permeability reduction. Small-sized particles (e.g., clay-size and colloidal) are the favorite species to follow the surface deposition mechanism as the large particles are not available (Blauch, et al.,1999).

2.2. Pore-throat plugging by bridging

Pore-throat bridging occurs when a particle goes through a pore throat and forms a bridge. The particle can link to two previously deposited particles on a pore-throat surface (three particles bridging) or to a previously deposited particle and the pore-throat area (two particles bridging). When particles are larger than the pore-throat size, pore-throat bridging can happen (single-particle bridging). The pore bridge gives a means for upstream particle collection, significantly decreasing the fluid flow velocity via these pores. During this phase, the most rapid decrease in permeability is observed (Civan,2016, 2011).

2.3. Internal Cake Formation

When the proportion of bridged pore throats approaches a critical level, the pores are no longer connected across some critical damage layer. When the proportion of bridged pore throats hits a certain level, the pores are no longer connected across some critical damage depth. A fast decline in downstream particle concentration signifies the beginning of internal cake formation. The distribution and abundance of smaller particles (including colloidal and clay-sized) in the flow stream measure the extent of permeability damage (Manshad, et al.,2018).

2.4. External Cake Formation

Particles accumulate upstream as internal cake formation is completed, and may form filter cakes at the interface. This process is not important in a fracture/gravel-pack system because internal filter-cake formation would dominate and continue over the length of the held fracture (Blauch, et al.,1999).

3. Model for permeability reduction

A simple model was created to describe the impact of different variables on asphaltene deposition and to determine a relationship between capillary tube deposition and formation damage (Bemani, et al.,2017). The friction pressure drop P is determined as follows using the well-known Poiseuille's equation for laminar flow (Bemani, et al.,2017).

$$V = \frac{\Delta P D^2}{32 \mu L} \tag{1}$$

Where L is the length of the tube over which pressure loss is recorded in cm, D is the diameter of the capillary in cm, V is the fluid velocity in centimeters per second, μ is fluid viscosity in centipoises, and P is pressure loss over length L in dyne/cm.

The flow velocity was sub-stationed in the previous equation as equation 2 (Bemani, et al.,2017), where q is the volume rate of flow in cubic centimeters per second, and giving Poiseuille's equation for laminar flow equation 3 (Bemani, et al.,2017):

$$V = \frac{4q}{\pi D^2} \tag{2}$$

$$\Delta P = \frac{128 L \mu q}{\pi D^4} \tag{3}$$

The following equation was used to compute the initial pressure drop (Bemani, et al.,2017).

$$\Delta P_0 = \frac{128 L \mu q}{\pi D_0^4} \tag{4}$$

Where ΔP_0 and D_0 are the initial pressure loss and capillary diameter, respectively. As a result, the equation is used to compute the ratio of pressure decrease at a certain period to the beginning pressure drop (Bemani, et al.,2017) :

$$\frac{\Delta P}{\Delta P_0} = \left(\frac{D_0}{D}\right)^4 = \left(\frac{r_0}{r}\right)^4 \tag{5}$$

Making a connection with Darcy's formula for linear flow in a porous medium (equation 6), permeability can be equated to (Bemani et al.,2013) :

$$q = \frac{kA\Delta P}{\mu L} \tag{6}$$

$$k = \frac{r^2}{8} \tag{7}$$

The permeability ratio derived from equations 6 and 7 is as follows (Bemani, Ashoori and Bahrami,2017):

$$\frac{K}{K_i} = \sqrt{\frac{\Delta P_i}{\Delta P_t}} \tag{8}$$

ΔP_t depicts the current pressure drop. The expression K/K_i represents the permeability ratio for a moment and indicates permeability reduction. Wojtanowicz et al. proposed a theory of solid particle filtration that provides a tool for identifying permeability impairment processes such as surface

deposition, pore throat blockage, and filter cake development. They suggested that equations 9 to 11 describe permeability decrease via the aforementioned method (Wojtanowicz, et al.,1987).

$$\sqrt{\frac{K}{K_0}} = 1 - A \times t \tag{9}$$

$$\frac{K}{K_0} = 1 - B \tag{10}$$

$$\frac{K}{K_0} = \frac{1}{1 + C \times t} \tag{11}$$

K indicates permeability at time t, K_0 represents reference permeability, and t denotes time, and A, B, and C refer to constants in the dimension of the inverse of time. It should be mentioned that these mechanisms are investigated under conditions in which only one permeability damage mechanism is prominent; nevertheless, in most situations, more than one mechanism may coexist. Bagherzadeh et al. introduced a model by combining surface deposition and throat blocking models to evaluate the coexistence of two processes at the same time (Qian, et al.,2019). This research group conducted an experiment on formation damage due to asphaltene precipitation under CO_2 injection conditions in one of the Iranian carbonate oil reservoirs and develop an experimental model. They demonstrated that when surface deposition and pore plugging processes coexist, equation 12 could accurately represent permeability behavior:

$$\frac{K}{K_0} = a \times t^2 + b \times t + c \tag{12}$$

Furthermore, excessive solid concentrations at the pore surface might form a cake layer, which limits the flow channel and reduces permeability. As a result, equation 11 was changed to alter the moment at which the filter cake production process begins. This time was denoted as t_0, and the solution to equation 13 was as follows:

$$\frac{K}{K_0} = \frac{1}{1 + C \times (t - t_0)} \tag{13}$$

4. Experimental procedure

Experiments on asphaltene accumulation in porous media might be divided depending on how the oil and solvent are blended: outside (external mixing) or in the porous medium (internal mixing). Another method is to dissolve asphaltene particles in a solvent (such as hexane) and then inject the mixture into porous media. Assuming that we eventually choose the internal mixing strategy, the three methods are discussed below.

4.1. Asphaltene Particle Suspension Injection in Porous Media

Asphaltene particles are suspended in a solvent such as hexane, decane, or heptane and injected at a constant flow rate into a fresh porous media, which is a common methodology used in studies of formation damage caused by asphaltene deposition. Using this approach, it is also straightforward to keep track of the amount of asphaltene that has entered the porous medium**.**

4.2. Oil/Solvent Mixture Injection in Porous Media

In this procedure, one syringe pump injects oil while another injects solvent. The laboratory setup may inject oil and solvent into a mixer at widely varying but consistent flow rates, which is linked to a glass micromodel. The solvent quantity in the injected mixture varies as the solvent-to-oil flow rate ratio changes. The pressure difference along the porous medium is measured, and while the flow rate and viscosity of the injected fluids remain constant, any variation in the pressure difference reveals changes in the permeability of the porous media. Figure 2 depicts a schematic of the micromodel setup used in this study. Two constant-rate programmable syringe pumps (BS-8000/9000 from Braintree Scientific, U.S.A.), glass micromodel, camera, a well calibrated (1.5e+5 Pa range) pressure transducer, data logger, and accumulator are all components of this setup.

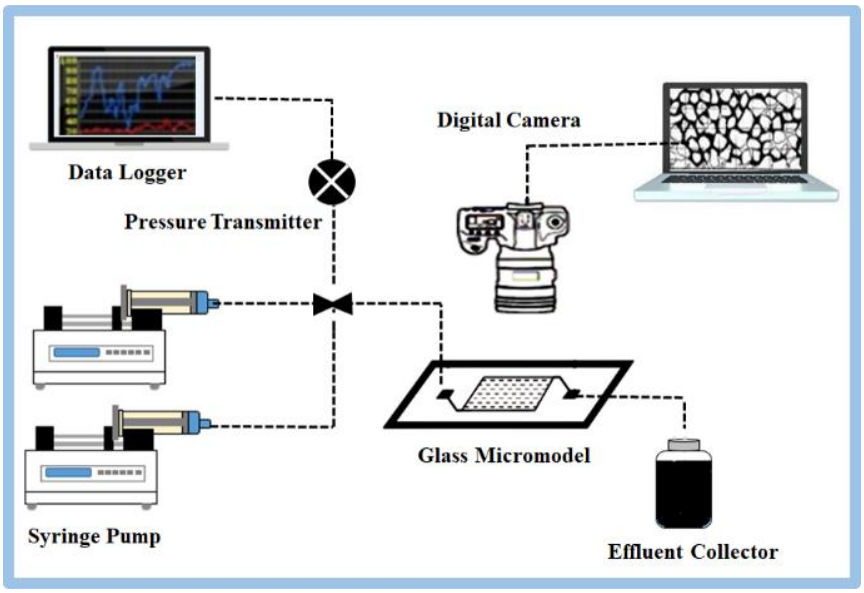

Figure 1

Setup of micromodel experiment and visualization system.

In this study, a sample of crude oil from one of the fields in southern Iran has been used. N-decane and n-heptane are used as precipitants. The inlet fluid of crude oil and precipitant enter the micro-glass model after combination. At this time, the inlet and outlet pressure difference of the glass micromodel is recorded. Over time, the pressure difference increases due to the deposition of asphaltene. The experiment continues until the micromodel is completely clogged. Tables 1 and 2 detail the physical properties of the micromodels as well as the compositions of the crude oil samples. It should be emphasized that each experiment in this study was conducted twice, and the average results were reported. Figure 3 shows the error bar diagram (inlet fluid containing 62.5% by volume of normal heptane and a flow rate of 8 ml/h). The experimental data has also been smoothed for easier comparison. It should be noted that this set of tests is performed at laboratory temperature and pressure.

On the other hand, a precipitate is used to destabilize the asphalt. However, the temperature and pressure of oil tanks are higher than the temperature and laboratory pressure and are formed in oil fields due to changes in temperature and pressure of asphaltene deposition, and this difference in conditions can have a significant impact on the results. The closer test conditions to the oil reservoir conditions, the more reliable results obtained. However, performing such tests in the laboratory can be less cost-effective in understanding the mechanisms of sediment formation and creating a scenario to prevent it.

Table 1

Physical properties of the micromodel

Size of micromodel	Throat length	Throat diameter	Number of pores in the width	Number of pores in the length	Coordination number
10×5 cm2	0.5 mm	1.6 mm	32	108	6

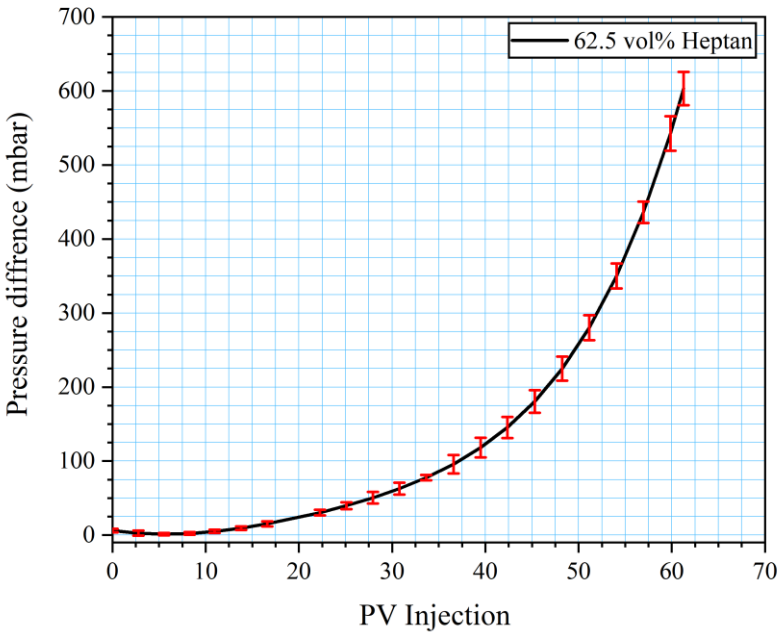

Figure 3

Error bar diagram of pressure drop versus time, precipitant to oil ratio (62.5% v/v) and constant total flow rate (Q_t=8 ml/h).

Table 1

Composition and characteristics of the crude oil

Specification	Unit	Value
Density of dead Oil	°API	24.9
Viscosity at ambient temp	cp	2.21
Asphaltenes	Mass fraction	0.041
N_2	Mole fraction	0.000
CO_2	Mole fraction	0.000

H_2S	Mole fraction	0.000
C_1	Mole fraction	0.000
C_2	Mole fraction	0.319
C_3	Mole fraction	0.938
i-C_4	Mole fraction	0.431
n-C_4	Mole fraction	1.896
i-C_5	Mole fraction	1.630
n-C_5	Mole fraction	2.775
C_6	Mole fraction	6.363
C_7	Mole fraction	8.300
C_8	Mole fraction	9.541
C_9	Mole fraction	8.282
C_{10}	Mole fraction	7.422
C_{11}	Mole fraction	5.961
C_{12}	Mole fraction	4.828
C_{13}	Mole fraction	4.473
C_{14+}	Mole fraction	37.734

5. Experimental results

5.1. Effect of precipitant type on asphaltene deposition

Asphaltene is a polydisperse combination of the most polarizable and heaviest components of the oil. The application of various n-alkane precipitants leads to precipitates with considerable changes in chemical and physical characteristics. Tavakkoli et al. used the indirect technique to demonstrate that lighter hydrocarbons are stronger asphaltene precipitants (Tavakkoli, et al.,2014). According to research, the number of asphaltene-precipitated increments as the carbon number of the precipitant reduces, implying that lighter hydrocarbons are stronger precipitants, and thus the volume fraction of precipitant required to cause asphaltene precipitation increases as the carbon number of the precipitant rises. As lighter hydrocarbon is used, the lighter composition in crude oil is increased, and the polarity of crude oil decreases. Asphaltene, which are the heaviest fraction of the oil, are insoluble in the light hydrocarbons, and therefore, the oil becomes a poor solvent for the asphaltene. Therefore, when lighter hydrocarbons are used as precipitants, more asphaltene is expected to precipitate. The onset of asphaltene precipitation increases as the carbon number of the precipitant increases. This change in onset volume fraction is related to the Gibbs free energy of mixing, which is determined by the difference in solubility parameters between n-paraffin and asphaltene, as well as the ratio of asphaltene molar volume to n-paraffin molar volume. As the carbon number of n-paraffin increases, the solubility parameter difference decreases, and the molar volume ratio decreases in the entropy of mixing. Both changes reduce the Gibbs free energy of mixing and improve the compatibility of asphaltene and precipitant. It is also reported that asphaltene precipitated by stronger precipitants is heavier and more aromatic than asphaltene precipitated by lighter hydrocarbons (Tavakkoli, et al.,2014). Figure 4 shows the micro-model pressure drop in the experiment with n-heptane and n-decane. According to the results of n-heptane injection, it has caused more asphaltene deposition and more pressure drop.

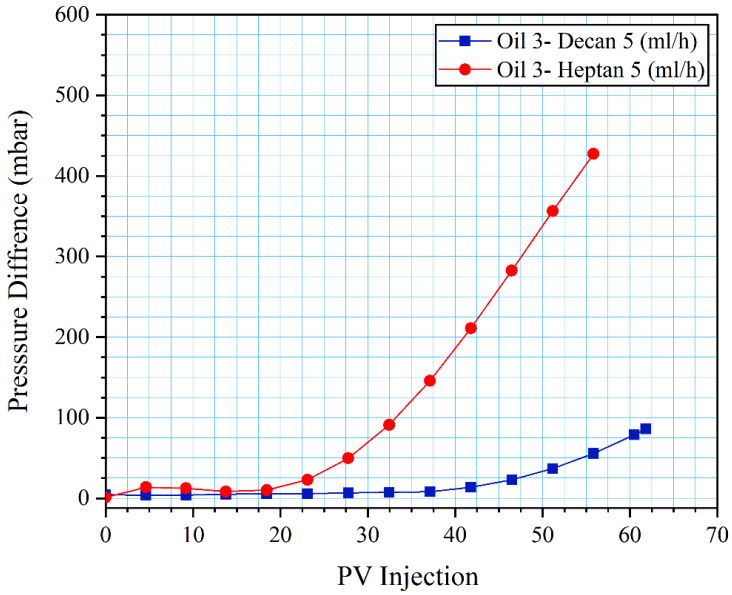

Figure 4

Pressure drops versus time for constant precipitant to oil ratio (62.5% v/v) and constant total flow rate (Q_t=8 ml/h) for n-heptane and n-decane.

5.2. Effect of the flow velocity on asphaltene deposition

Figure 5 shows the effect of the flow velocity on the deposition behavior. The flow rate varied from 4 ml/h to 12 ml/h at constant n-heptane to oil ratio. According to Figure 5, the deposition rate rises as the flow rate increases and shows a higher final pressure. This indicates that at greater flow rates, more asphaltenes deposit with significantly faster deposition kinetics. According to Nabzar and Aguiléra (Nabzar, et al.,2008), the deposition kinetics reduces as the flow rate is increased due to entrainment or detachment. This is directly opposed to the findings of this study. This contrast can be explained by the difference in speeds used. The observed contrast can be attributable to a balance between deposition kinetics and shear removal. Shear removal plays a vital role in deposition over a specific shear rate, potentially resulting in a reduced deposition rate with a rising flow rate. The result of the increasing mass of deposited asphaltenes with increasing flow rates suggests that the velocities utilized are in the domain where deposition kinetics overcomes shear removal. More experiments with different velocities are needed to confirm this idea. It should be noted that increased flow leads to a higher concentration of precipitated asphaltenes. In addition, in this case, at a higher flow rate, the number of particles that pass through the pore at the same time increases and the clogging intensifies. This is especially important during flow in a porous medium and the passage of particles through pores and cavities. Figure 6 shows the photos taken after the experiment at various flow rates. These images show that with a higher total flow rate, there will be more asphaltene deposits. They also reveal that there are more asphaltene deposits at the entrance, but fewer asphaltene deposits are observed further down the micromodel.

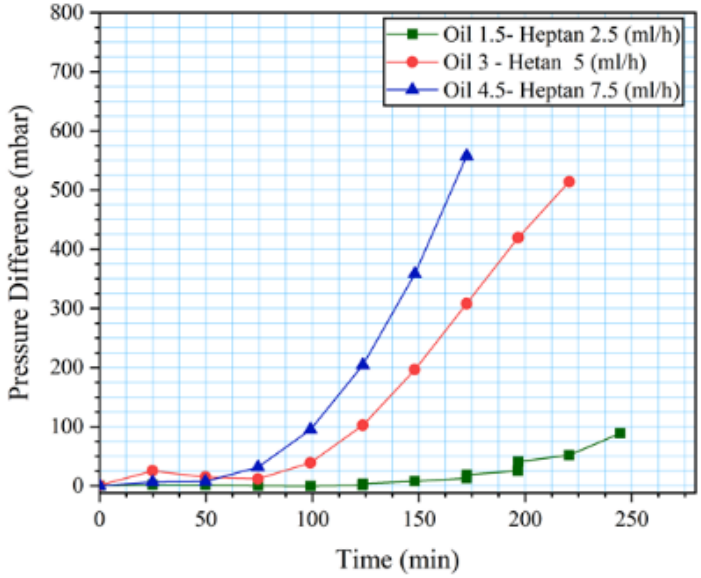

Figure 5

Pressure drops versus time for a constant n-Heptane to oil ratio (62.5% v/v) at different volumetric flow rates (Q_t = 4,8,12 ml/h).

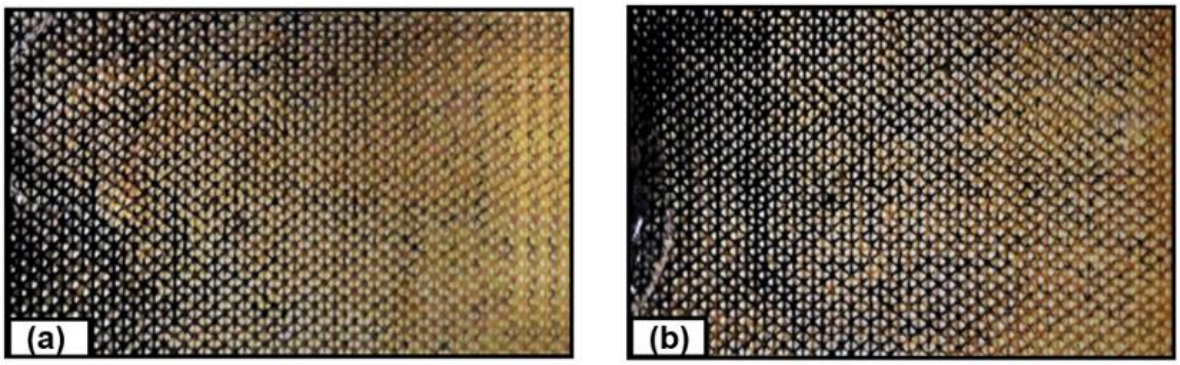

Figure 6

Imaging of glass micromodels (a) flow rate 12 ml / h (b) flow rate 8 ml / h. Two hours after the test, which shows the progress of asphaltene deposits in the porous medium.

5.3. Effect of precipitant fraction on asphaltene deposition

Figure 7 illustrates the pressure drop trend for three distinct experiments performed at a fixed volumetric flow rate of Q_t = 8 ml/h with different n-heptane to crude oil ratios of 58.7, 62.5, and 67.5 percent**.** According to Figure 7 as the precipitant fraction increases, the pressure drop increases, proving a faster deposition rate. Increasing the content of n-heptane in the combination enhances both the initial precipitation kinetics and the concentration of asphaltenes in the fluid mixture. The following graphic is generated by equation 8 using pressure drop data**.** Figure 8 describes the effect of the precipitant to oil volume ratio on permeability reduction. As seen in Figure 8, the precipitant to oil ratio increases the rate of permeability reduction because of the increasing instability of asphaltene.

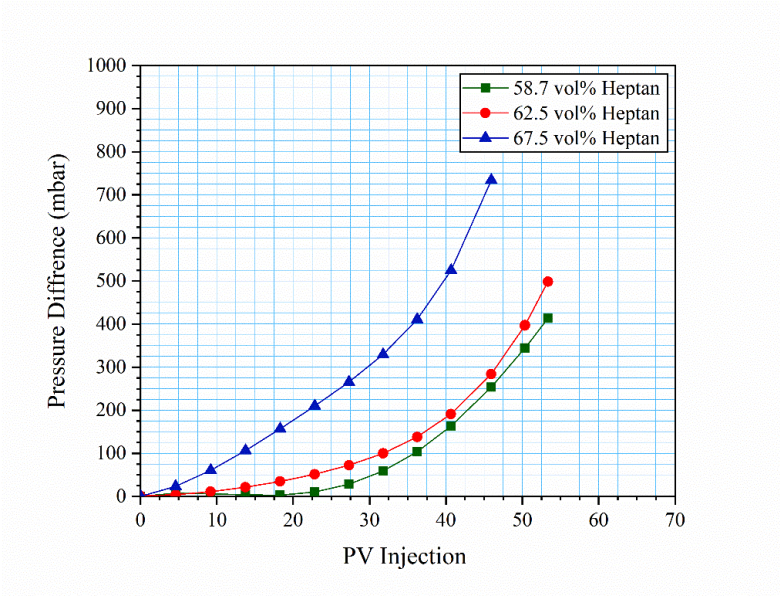

Figure 7

Pressure drops versus PV (pore volume) injection for a constant flow rate Qt=8 ml/h at different n-Heptane fraction (58.7, 62.5, 67.5 % v/v).

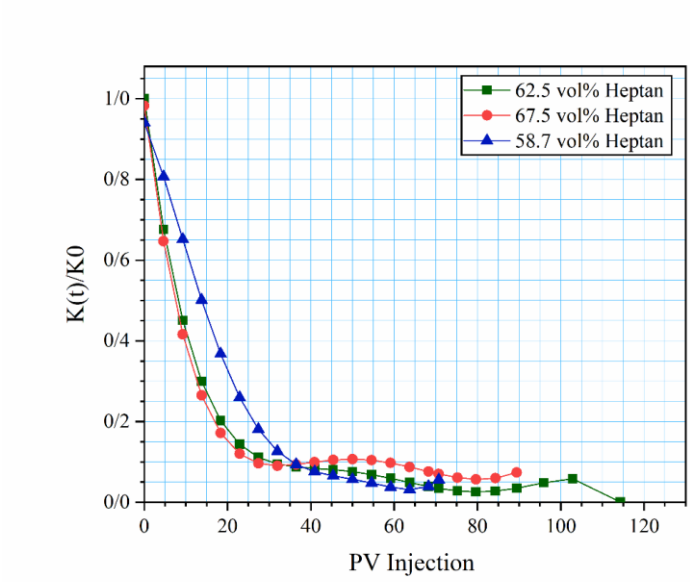

Figure 8

Permeability reduction versus PV (pore volume) injection for a constant flow rate Qt=8 ml/h at different n-heptane fraction (58.7, 62.5, 67.5 % v/v).

6. Comparison of experimental results with developed models

As the mechanisms of permeability impairment alter during the tests, it is essential to divide each test into discrete-time domains to determine dominant mechanisms. Consequently, the first test was divided into several domains based on the verification of experimental data with the proposed model, such that an exact match was seen for each period. Permeability data at 1–13.6 pore volumes domain were fitted using a quadratic polynomial function that accounts for the simultaneous coexistence of surface deposition and pore throat plugging mechanisms, as seen in Figure 9**.**

Figure 10 depicts the results of fitting equation 13 on permeability data through 13.6-35.1 injected pore volume, which confirms that the filtration cake formation is the predominant mechanism in this domain. Figure 11, which is allocated to the 35.1-57.2 pore volumes domain shows that equation 10 is in accordance with experimental data. Consequently, the pore throat blocking mechanism is prominent.

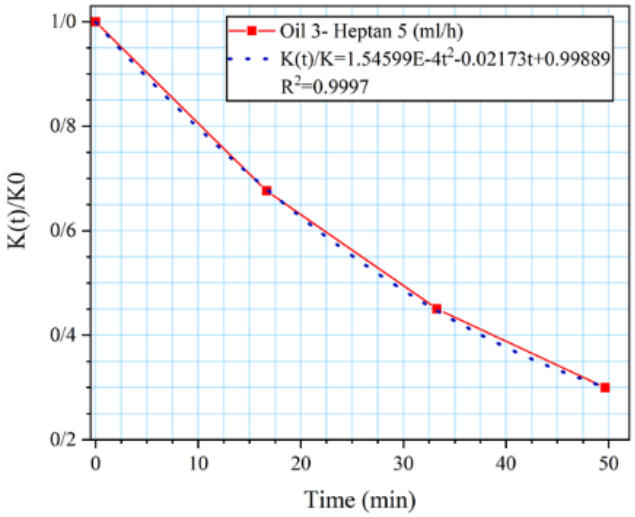

Figure 9

Regression of experimental permeability data by using combination of surface deposition and pore throat plugging mechanisms in 1-13.6 pore volumes domain.

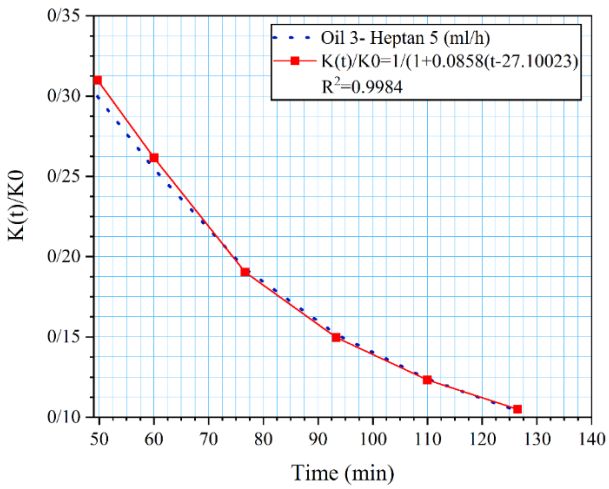

Figure 10

Regression of experimental permeability data by using filtration cake formation mechanism in 13.6-35.1pore volumes domain.

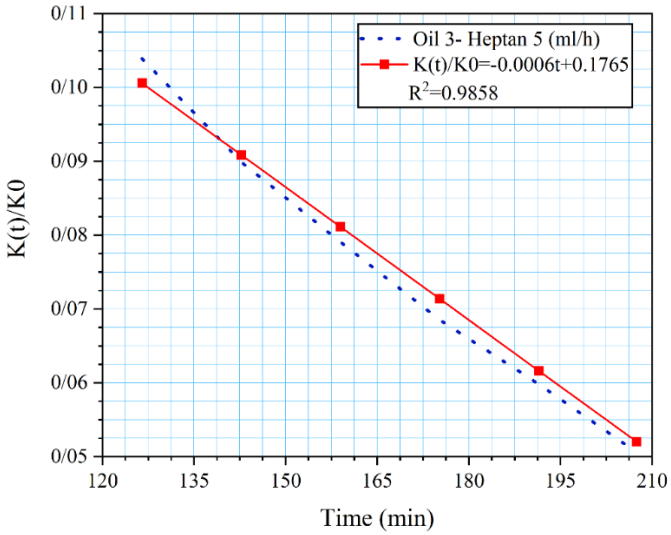

Figure 11

Regression of experimental permeability data obtained by using pore throat plugging mechanism in 35.5-57.2 pore volume domain**.**

7. Conclusion

- The deposition rate increases as the flow velocity. It seems this happened because in the experiments performed and the selected flow velocity, the stress rate was not high enough to overcome the kinetics of asphalt deposition.
- The higher the precipitant to oil ratio, the higher the quantity of asphaltene deposition. Because the size and quantity of unstable asphaltene agglomerates grow with increasing precipitant volume. In other words, asphaltene content has a direct influence on asphaltene deposition.
- As the precipitant carbon number increases, its compatibility with asphaltene also increases, and as a result, the deposition rate and instability of asphaltene decrease.
- Based on the validation of experimental results with the proposed models of permeability reduction, a great correlation was found between the collected data and the related models, indicating that the models may accurately predict permeability behavior.
- According to the examination of permeability impairment data, it can be shown that permeability reduction mechanisms fluctuate with pore volume.
- In the early stages of testing, experimental data on permeability reduction is more in line with the quadratic polynomial function that accounts for the simultaneous coexistence of surface deposition and pore throat plugging mechanisms. In the middle of the experiment, the experimental data is in good agreement with the filtration cake formation model. However, in the end times when this interval covers more time than the experiment, the experimental data are more consistent with the pore throat-plugging model.

Identifying the dominant mechanism in reducing permeability caused by asphaltene deposition could lead to the development of chemical inhibitors or other preventative measures. This research can also be used to optimize asphaltene sedimentation processes.

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