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The investigation of crude oil derivatives elution from porous structure

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ABSTRACT

Crude oil and its derivatives migration in porous structure are important aspects of chemical engineering**,** since they are vital for processes such as oil extraction and soil remediation. Understanding the multiphase flow in porous rocks is necessary for Enhanced Oil Recovery (EOR) and can lead to this process intensification. In methods of oil extraction such as water flooding or polymer flooding liquids are pumped with high pressure to increase the sweeping efficiency of medium. Thus, the knowledge in this field is important for all people engaged in this process. Oil and its derivatives transport in porous structure occurs also during ground leaching techniques used in soil remediation after emergency release of these liquids. Therefore the research in field of transport in porous media are necessary to conduct this process efficiently. The aim of the experiment was to check the sweeping ratio of paraffin from porous structure for different volumetric flow of leaching liquid. We also measured pressure at the inlet to bed, which allowed us to follow the stages during elution process. To analyze concentration in obtained samples we used TurbiscanLab® device.

Keywords**:** emulsion elution, oil-in-water transport, porous media

1. INTRODUCTION

The issues connected with the flow of liquids through porous media are in interest of a research of chemical and process engineering. The results of investigations into phenomena of elution of high viscosity fluid from porous structure by low viscosity medium can be applied in oil extraction or soil remediation [3,13,14]. Also, knowledge in flow of different fluids through porous structure have application in areas such as geomechanics, hydrogeology, and reservoir engineering [10,17].

Forced oil flow in porous media has practical application to Secondary and Enhanced Oil Recovery (EOR) techniques. They posses a great potential, and are believed to satisfy global demand-supply balance for oil recovery [4,15,16]. In technique called 'water flooding' the water under high pressure is injected to the reservoir containing oil in order to improve sweeping efficiency. Fig. 1 presents the scheme of 'water flood' used in crude oil recovery. The understanding of complex multi-phase flow in porous structure such as sandstone, dolomite or limestone may be helpful in optimizing oil extraction processes, especially the ones that use water as a eluting medium. The recovery factor is increased when water is injected to reservoir containing oil and it is explained by improved sweep and better displacement properties of such medium [1]. Sometimes during this techniques highly viscous emulsions are created [2,9,12].

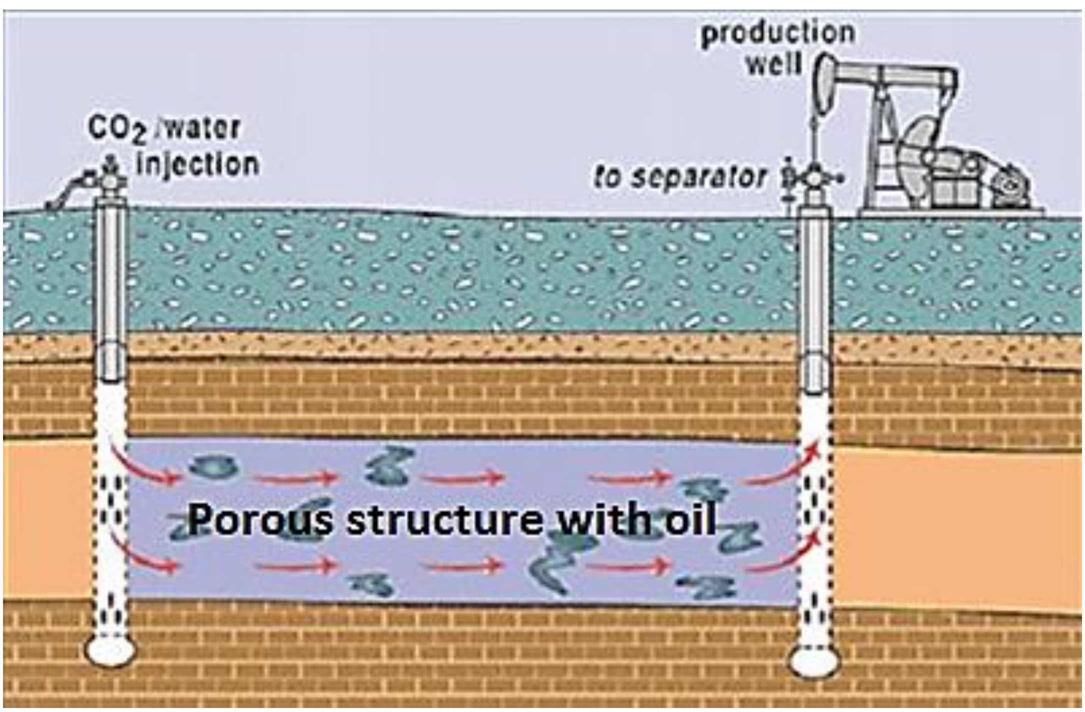

Figure. 1 Scheme of 'water flood' technique used in crude oil recovery
[source: www.rigzone.com]

Another example of multiphase flow in porous media can be soil remediation [12]. The porous structure of ground can be easily exposed to oil derivatives for example during accidental release of transported liquid hydrocarbons. Presence of petroleum or its derivatives in soil affects its physical and mechanical properties [6,18]. It also leads to reduce of water capacity of the soil and prevents exchange of air in soil pores. It results in disorders in relationships of organic carbon to nitrogen and phosphorus and may lead to death of organic live present there [5,20]. For hydrocarbons pollutants removal, the surfactant aquafier remediation (SAER) can be used. It involves the injection of pure water or water with active agents to porous structure and elution of petroleum derivatives [8,19].This technique is very similar to the experiment that we conducted.

The paper deals with the aspect of forced elution of an paraffin oil from the porous bed. We checked the influence of volumetric flow rate of eluting fluid on the sweeping efficiency. In research we used TurbiscanLab® apparatus, that allowed us to determine the concentration of oil in eluted samples.

2. MATERIALS AND METHODS

The measurement equipment that was used in experiments is shown in Fig. 2.

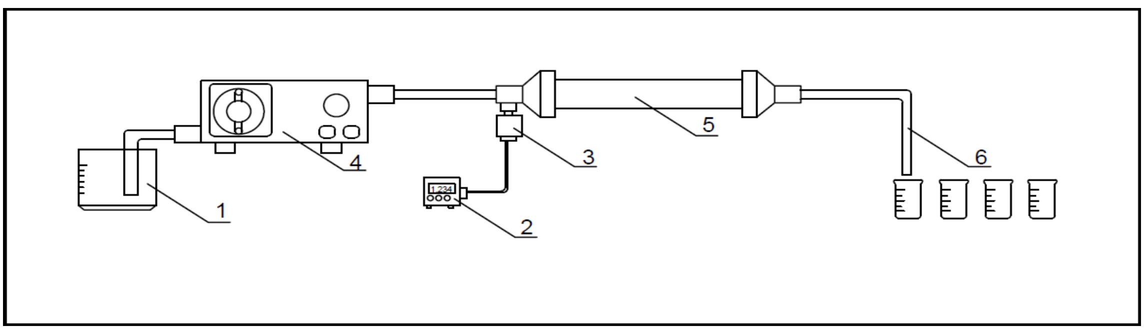

Figure 2. Equipment used in experiments: 1-container with liquid, 2-pressure indicator, 3-signal converter, 4-peristaltic pump, 5-pipe with microspheres, 6-outflow section with flow indicator

In the experiments we used the peristaltic pump produced by ELPIN-PLUS manufacturer. It was calibrated before measurements to obtain its characteristics. The signal converter PT-5261M was connected with pressure indicator MD-5270, which scale was in [bar]. The pipe was made from stainless steel and it had length of 0.3 m. The diameter of this pipe was 0.05 m. Microspheres for porous bad had mean diameter of 100÷200 μm. Porosity of used bed was equal $\varphi = 0.34$. We used the following liquids: paraffin oil with viscosity of 110 mPa·s in ambient temperature and density of 865 kg/m^3, tap water and emulsifier Rokacet obtained from PCC Rokita S.A. Glass microspheres were used instead of sand or soil, since this material have strictly determined porosity and grain diameter. Paraffin oil was used instead of crude oil because of its safety. The experiments were carried in ambient temperature of 25 °C. To obtain standard curve of concentration of paraffin in water we prepared emulsion as following: oil, water and emulsifier were mixed together to obtain dispersed system with certain concentration. Emulsification process was conducted with usage of high speed hand automatic mixer. Mixing time was three minutes. The system had addition 2% of Rokacet emulsifier. Emulsions had stability time of more than 24 hours. During experiment the certain amount of porous bed with previously mentioned parameters was placed into the pipe and mixed with paraffin oil. Tab. 1 presents the properties of porous structure and the amount of paraffin oil mixed with bed.

Table 1. Porous structure properties used in experiments

Bed length [m]	Mass of porous bed [kg]	The amount of paraffin oil mixed with bed [ml]	Saturation of porous bed [-]
0,3	0,724	150	0,99

During the experiment we leached the bed with plain tap water, with different volumetric flow rates. The eluted liquid containing emulsion was collected in bakers. We took 100ml samples, in order to perform further analysis. The leaching process was stopped when the steady state was obtained, in other words when obtained pressure was not changing for more than $0{,}1 \cdot 10^5$ [Pa].

3. RESULTS

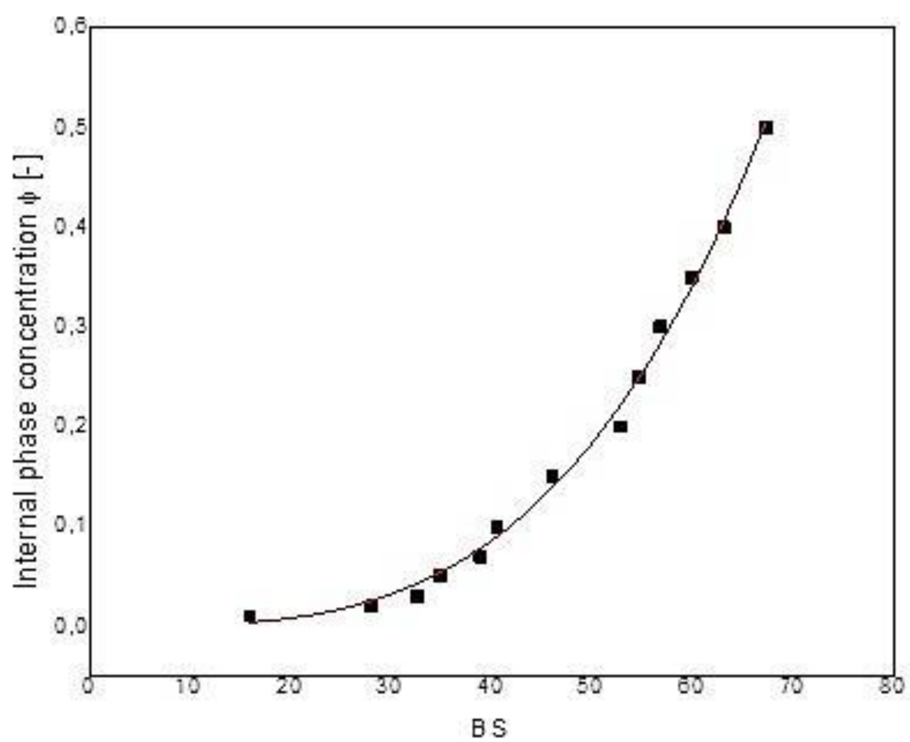

Figure 3. Standard curve of internal phase concentration for paraffin oil in water emulsion. The axis X represents the amount of reflected light (BS), while the Y presents the internal phase concentration

In order to read concentration with TurbiscanLab® of eluted samples we prepared standard curve. Therefore we firstly made five emulsions with known concentration. We prepared this emulsions with the technique presented before. For all samples we checked the light backscattering with TurbiscanLab® apparatus, and calculation was made for certain concentrations as described in literature [7]. We therefore created the dependency BS = f(φ) presented in the Figure 3. This standard curve can be described with the following equation (1), where concentration of oil φ depends on backscattering light (BS).

$$\varphi = BS^{3,02} * 10^{-6} \quad (1)$$

The total volume of eluted paraffin is presented in second column of the Tab. 2. It can be seen that from 150ml of paraffin that was in porous bed the highest amount equal to 51,55ml was leached during the volumetric flow rate equal to $Q_v = 7{,}5 \cdot 10^{-6}$ m^3/s. It can be also observed that efficiency of sweeping of porous bed with the volumetric flow rate of $Q_v = 7{,}5 \cdot 10^{-6}$ m^3/s was more than two times higher than in case of flow rate $Q_v = 5{,}5 \cdot 10^{-6}$ m^3/s. Therefore it can be concluded that it will not be efficient to use low volumetric flow rate of eluting liquid in techniques related to oil extraction or remediation of porous structure.

In order to better understand the efficiency of process we transformed the obtained data. The sweeping efficiency E_f was calculated from the equation (2). In the third column of Tab. 2 we present the data from second column calculated with the equation (2).

$$E_f = (V_{or}/V_c) \cdot 100\% \quad (2)$$

V_{or} – Total amount of eluted oil
V_c – The amount of oil used to saturate porous bed

From the last column in Tab.2 it can be seen that the sweeping efficiency varied from 14,61% to 34,36%. The highest efficiency was observed for flow rate of $Q_v=7{,}5 \cdot 10^{-6}$ m^3/s. It can be noticed that efficiency in this case was 2,35 times higher than for $Q_v=5{,}5 \cdot 10^{-6}$ m^3/s. Therefore it is possible to state that volumetric flow rate of eluting liquid influence the sweeping efficiency in a great degree.

Table 2. Total volume of eluted oil from porous bed [source: own work]

Volumetric flow rate [ml/s]	Amount of eluted oil from bed [ml]	Sweeping efficiency [%]
$Q_v = 5{,}5$	21,91	14,61
$Q_v = 6{,}5$	36,31	24,20
$Q_v = 7{,}5$	51,55	34,36

The chart in Fig. 4 presents the dependency of pressure change from time, when the bed was saturated with 150 ml oil. The square points represents the pressure obtained during the flow with $Q_v = 5{,}5 \cdot 10^{-6}$ m^3/s, while the dots presents the values for flow with $Q_v = 6{,}5 \cdot 10^{-6}$

m^3/s and the triangles state for eluting liquid volumetric flow rate equal to $Q_v = 7,5 \cdot 10^{-6} m^3/s$. The highest obtained pressure was achieved during the flow rate of $Q_v = 7,5 \cdot 10^{-6}\ m^3/s$ and equalled to $1,6 \cdot 10^5$ Pa. Meanwhile the lowest pressures are observed for $Q_v = 5,5 \cdot 10^{-6}\ m^3/s$ flow rate. In this case the maximum obtained pressure equalled to $0,9 \cdot 10^5$ Pa.

From the Fig. 4 we can conclude that during high pressure elution three main steps may be observed. In the first stage rapid pressure increase is observed. It occurs because the porous structure is highly saturated with highly viscous oil. It causes the increased flow resistance and therefore sufficiently high pressure that is needed to allow oil migration to take place. During this stage the breakthrough of water and formation of the largest flow channels occurs. The concentration of eluted fluid is the highest, which means that the most of oil is eluted during this phase, and saturation of porous medium with oil drops significantly drops. Stage two begins when maximum pressure is reached in the porous bed inlet and it ends when pressure stabilizes. In this period the pressure goes down since the flow resistance is smaller. It causes the increase permeability of porous medium. Over this phase the amount of oil eluted is the highest. Last, nearly steady stage begins when the pressure is stabilized and there is no change in the flow resistance. In this phase only very little amount of paraffin is eluted. It is related to the fact that water flows then in certain paths in porous medium from which oil was eluted in previous stages.

In the conducted experiment we managed to investigate the elution process of high viscosity oil from porous bed. We checked the influence of volumetric flow rate of eluting liquid on sweeping ratio. We also determined the pressure at the inlet to bed and were able to observe three stages during elution

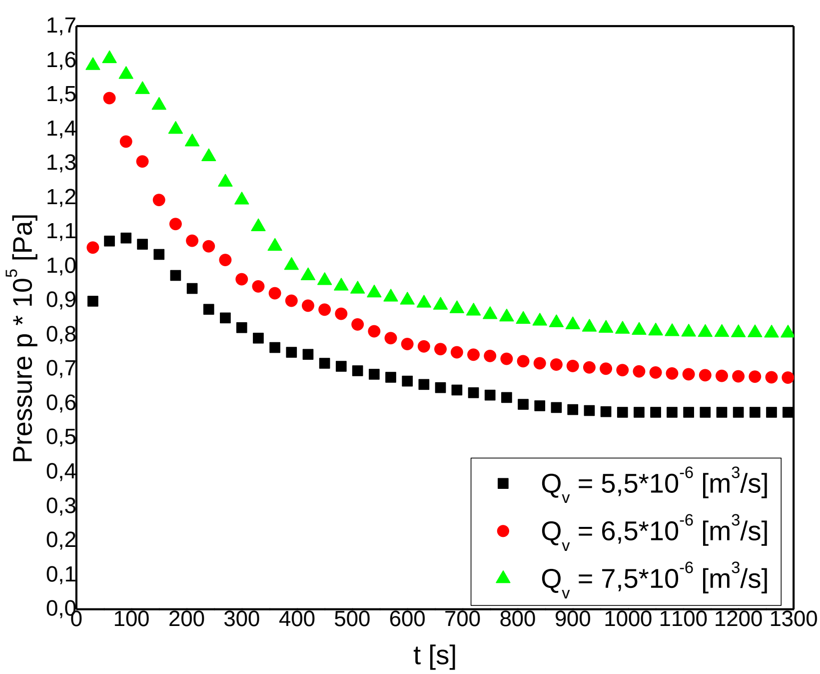

Figure 4. Pressure obtained during emulsion elution process for different flow rates of eluting liquid

4. CONCLUSION

Volumetric flow rate influence on pressure obtained during elution experiments was checked. The sweeping efficiency varied from 14,61% to 34,36%. The highest efficiency was observed for flow rate of $Q_v = 7{,}5 \cdot 10^{-6}$ m^3/s. In this case sweeping efficiency was 2,35 times higher than for $Q_v = 5{,}5 \cdot 10^{-6}$ m^3/s The concentration of oil eluted changes within time of process. The higher the volumetric flow rate was, the bigger maximum pressure showed indicator. During oil derivatives elution from porous media the three main steps were observed: peak pressure related to the beginning of elution process, pressure drop when the most of oil is eluted and steady state. During the last stage there is no significant change in pressure at the inlet to porous structure.

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