The analysis of elution process of high concentrated emulsions from porous media

Piotr Pacholski, Jerzy Sek

Abstract: Emulsion flow through porous media is phenomena that is crucial for many processes that occur in chemical technology business. Example can be Enhanced Oil Recovery techniques, soil remediation and treatment of oily wastewater. The flow through porous media is not easy to describe, because of rheological properties of oil-in-water emulsions and because of phenomenon's that can occur. As an example during two phase flow: oil and water through porous media it is possible to observe the interception of oil to porous structure as well as filtration of oil in pores. In this study, we tried to examine the influence of oil-in-water emulsion concentration on process of its elution from porous media.

Keywords: porous media, emulsions, oil-in-water, flow through porous media, enhanced oil recovery, elution process, multiphase flow

1. INTRODUCTION

Multiphase flow in porous media is commonly discussed topic in chemical industry. Formation of emulsion is especially important during oil extraction, soil remediation with usage of surfactants and wastewater treatment on coalescent filters. As an example during crude oil extraction, emulsions can form during oil elution from soil [1]. During this technique inside rocks the oil-in-water emulsion or water-in-oil emulsion can be formed. The obtained system is later separated into oil and water phase [2].

Another example of emulsion flow through porous media is remediation process. Contaminated soil can be remediated with usage of high pressure elution with water. Therefore the understanding of migration of emulsion inside soil can allow companies to reduce cost connected with remediation, and also better prediction of contaminated zone [3].

Another interesting example of flow emulsion through porous media is usage of coalescent filters to treat wastewater. Oily wastewater are very often in form of emulsion, usually oil-in-water and can be purified by filters that are build like porous media [4].

The fundamental theory that describe flow through porous media is law created by Darcy [5]. It is one of elementary equation that describe flow of fluid through porous media. This law can also be applied to explain flow indicated by pressure. In this case, the driving force will be the pressure difference $\Delta p$ between the pressure produced by pump and the atmospheric pressure. The Darcy law in presented situation can be described as (1):

$$v_o = k \frac{\Delta p}{l} \tag{1}$$

Where: $v_o$ - volumetric flow rate,
$k$ - the proportionality coefficient for certain porous media,
$l$ -the distance of flow

Emulsion flow through porous structure is more complicated than either oil or water flow. Until now many mathematical models to describe this phenomena were created. The models concern the relation of fluid between porous structure and between each phase [6]. Therefore in case of multiphase flow, the driving force is created not only due to pressure difference $\Delta p$ but also due to capillary pressure $p_c$. The existence of capillary forces can have significant effect on fluid flow in porous structure [7]. In the equation (1) it is possible to introduce mentioned coefficient $p_c$ in order to receive the equation (2)

$$v_o = k \frac{\Delta p + p_c}{l} \tag{2}$$

Where: $p_c$-capillary pressure between phases in system

During emulsion flow through porous media very often the emulsion droplets have size that are similar to pores. When it happens it can be observed that some of the oil droplets are filtered in the area between pores- it is explained by straining mechanism. It happens when capillary force is smaller than viscous force. It is also recognized as the main reason for permeability reduction when oily water is injected into porous media [8]. Van der Waals forces can also lead to capture the oil droplets and effect in reduction of water permeability[9]. Interception of oil to porous structure is another mechanism that occurs during this process, and leads to reduce of space between pores in structure. Since pores are either blocked or significantly reduced by retained drops, emulsion flow takes place along the adjacent space that left [10].

The analysis of literature shows that emulsion flow through porous structure is complex issue which is important...
to investigate because of the use of this process in many industrial fields. There is a real need to fill in the gaps that exist in described subject.

The aim of experiments presented in this paper was to investigate the viscosity of the oil-in-water, emulsion and to determine the effect of their concentrations on the elution process of this type of two phase system from the porous bed. Experiments were conducted for the emulsion O/W with concentration of internal phase of 50%, 60% and 70%.

2. METHODOLOGY OF EXPERIMENTS

The measurement equipment that were used in experiments is shown in Fig. 1. It consisted of five elements: container with liquid, pressure indicator, signal converter, peristaltic pump and pipe with microspheres.

![Fig 1. Equipment used in experiments 1-container with liquid, 2-pressure indicator 3-signal converter, 4-peristaltic pump, 5-pipe with microspheres, 6-outflow section where samples were collected](image)

The peristaltic pump type 372C used in experiments was produced by ELPIN-PLUS manufacture. It was calibrated before measurements to obtain its characteristics. The signal converter PT-5261M was connected with pressure indicator MD-5270, which scale is in bar. The pipes were made from stainless steel. They had length of 0.2[m], 0.3[m] and 0.5[m]. The diameter of pipe was 0.05[m]. The following materials were used: microspheres with diameter 200-300[µm] and porosity φ=0.32, edible oil with viscosity of 60 [mPa·s] in ambient temperature and density of 865kg/m³, tap water and emulsifier Rokacet obtained from PCC Rokita S.A. Microspheres were used instead of sand, since this material have strictly determined porosity and spheres diameter. Edible sunflower oil was used because of its non-toxicity. The experiments were carried in ambient temperature of 250C.

3. RESULTS AND DISCUSSION

High concentrated emulsions based on edible sunflower oil show non-Newtonian behaviour, this is reason why rheological properties of emulsions were checked with rheometer. Fig. 2 shows the viscosity [mPa·s] versus shear rate [1/s] for prepared emulsions. All the tests were carried in ambient temperature of 250C. In presented case only 50% O/W emulsion is Newtonian fluid with viscosity 8.24 [mPa·s] when 60% and 70% O/W emulsions show non-Newtonian behaviour, which means that they are shear thinning fluids.

The diagram in Fig. 3 shows the dependence of overpressure from the time in case of flow of eluting liquid with volume of Qv=6.5·10⁻⁶ m³/s. The emulsion concentration that was mixed with porous media was 50%. The highest observed pressure was 0.9·10⁵ Pa and the pressure during steady state was 0.35·10⁵ Pa. In the beginning it is possible to observe the pressure increase. The pressure growth until the elution stage begin. Then it starts to slowly drop, and it means the beginning of the elution phase.
Fig 2. Emulsion rheological properties

The chart in Fig. 4 shows similar the same dependence as it was in case of Fig. 3, but this time the emulsion concentration that was used was 60%. In this situation the highest observed pressure was equal to 1,2·10^5 [Pa]. The pressure observed for steady state was higher and its value was 0,5·10^5 [Pa]. It is worth to notice that the Fig. 4 shows similar trend to Fig 3. It means that at the beginning it the increase of pressure is observed. In this stage there is no elution, and the water is drilling the channels to flow in. In the next phase the pressure goes down, and it means the actual beginning of elution period. The steady state is observed after about 400 seconds after the experiment began.

Fig 3- Pressure versus time in elution of 50% emulsion from porous bed

Fig 4- Pressure versus time in case of elution of 60% emulsion from porous bed

The figure presented in Fig. 5 shows dependency of pressure and time in case of elution of 70% oil-in-water emulsion from porous media. The volumetric flow of eluting liquid remains the same as in case of Fig.3 and Fig.4 In this figure it is possible to observe that the highest observed pressure came to value of 1,35·10^5 [Pa]. Moreover, it was higher than in situation where 50% or 60% emulsion was eluted. Steady state pressure was also bigger and equalled to 0,8·10^5 [Pa]. During this situation, the second stage of elution, meaning the one between the peak and the steady state was the shortest and came after period of 100 seconds.

Fig. 5- Pressure versus time in case of elution of 70% emulsion from porous bed

As it was mentioned the main aim of experiments was to investigate the influence of emulsion concentration on process of its elution from porous media. In Fig. 1-5 it is observed that the pressure increase was higher, when
emulsion concentration to be eluted was also higher. Also at
the first stage of experiment the pressure grows until certain
level. The first increase is due to a fact that porous structure is
saturated with emulsion in high degree, which causes high
flow resistance. Therefore the pressure that is need to elute it
from media needs to adequately high. Also pressure observed
during steady state is higher when the more concentrated
emulsion is used. It suggest that permeability of porous bed
depends from emulsion concentration that is mixed with it.

4. CONCLUSION

From experimental results obtained in this research, it
can conclude that elution of emulsion highly depend on their
initial concentration in porous bed. In all experiments it was
possible to observe stages during its elution. Firstly the
pressure is growing until the time that elution process begins.
This rapid pressure rise is linked to high flow resistance that is
due to highly saturated porous bed. After this phase the
pressure starts to decrease, which means the beginning of
emulsion elution from

porous media. It was observed that the pressure increase was
higher, when emulsion concentration to be eluted was also
higher. It means that resistance flow for porous media that is
saturated with emulsion with higher concentration will be
bigger than in situation of lower concentrated emulsion. As an
example, for emulsion concentration of 50% the maximum
obtained pressure equalled to 0.9·10^5 Pa, while for emulsion
concentration of 70% was higher by 0.3·10^5 Pa and equalled
to 1.2·10^5Pa.

5. REFERENCES

Crude Oil Emulsion Properties and their Application
to Heavy Oil Transportation, Oil & Gas Science and
Technology, Vol. 59, No. 5: 511-521
perfecting secondary methods of oil deposits
exploitation, AGH Drilling, Oil, Gas : 769-778
Effects of emulsion viscosity during surfactant
enhanced soil flushing in porous media, Journal of
Soil Contamination, 6-4, 355-370
Science and Technology 3rd Edition vol. 18,
Academic Press : 503-518
de Dijon, Dalmont, Paris
Applications in the Petroleum Industry, Advances in
Chemistry Series, American Chemical Society 231:
219-232
Institut Francais Du Petrole, Editions Techniship,
Paris: 16-22
Austin, University of Texas at Austin, Texas
deposition in porous media: impact on well
injectivity. Paper SPE 113821 presented at
Europec/EAGE Conference and Exhibition, June 9-12,
Rome, Italy
O/W Emulsions in Porous Media: Segregation at
Low-Tension Conditions, Journal of Colloidal and
Interface Science 295: 569–577