ISSN 2229-5518

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

Piotr Pacholski, Jerzy Sęk

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 Δp 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: vo – 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 Δp 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)

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

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

---

- *Piotr Pacholski is currently pursuing doctoral degree program in chemical engineering in Lodz University of Technology, Lodz, Poland, E-mail: piotr.pacholski@edu.p.lodz.pl*
- *Jerzy Sęk is assistant professor in Lodz University of Technology, Department of Chemical and Process Engineering, Lodz, Poland, E-mail: jerzy.sek@p.lodz.pl*

ISSN 2229-5518

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.

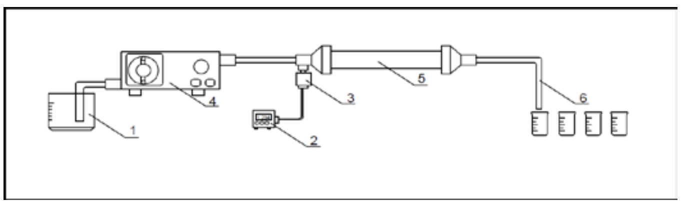

Fig 1. Equipment used in experiments 1-container with liquid, 2-pressure indicator 3-signal converter, 4-peristaltic pump, 5- pipe with microspheres, 6- outflow section where samples were collected

The peristaltic pump type 372C used in experiment 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.The emulsion was prepared as following: oil, water and emulsifier were mixed together to obtain emulsion with different concentration. Mixing process were conducted with usage of high speed hand automatic mixer. Mixing time was three minutes. It is known that viscosity of fluid influence on its flow, it is reason why this parameter was checked. Three oil in water emulsions with different concentration were prepared- 50% O/W, 60% O/W and 70% O/W. All emulsions had addition of 2% of Rokacet emulsifier. It was also tested that they are stable emulsion with stability time of more than 24 hours.

2.1 Emulsion elution process

During the tests the equipment presented in the Fig. 1 one was used. The certain amount of porous bed-1,089 kg with strictly determined parameters was mixed with previously prepared emulsion and placed into the pipe. After this, the pump was started and the elution process began. In every 30 seconds period the pressure showed by the pressure indicator was noted. The eluted liquid containing emulsion was collected in bakers with the 100ml capacity in order to conduct more analysis The elution process was stopped when the steady state began. The water was pumped with the same flow rate during the entire process.

During test influence of emulsion concentration on elution process was tested. The 50%, 60% and 70% O/W emulsion was prepared in order to test its behaviour during flow. The analysis was conducted with the water flow rate set to be constant at 5,5·10-6 [m3/s]. Microspheres used in the test had diameter 200-300μm and porosity φ=0.32. The pipe that was mounted had 0.3[m] length. The emulsion composition is presented in table nr 1.

Tab. 1- Emulsion composition

Emulsion concentration [%]	Oil volume [dm^3]	Water volume[dm^3]
50%	0,10	0,10
60%	0,12	0,08
70%	0,14	0,06

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 shows 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.

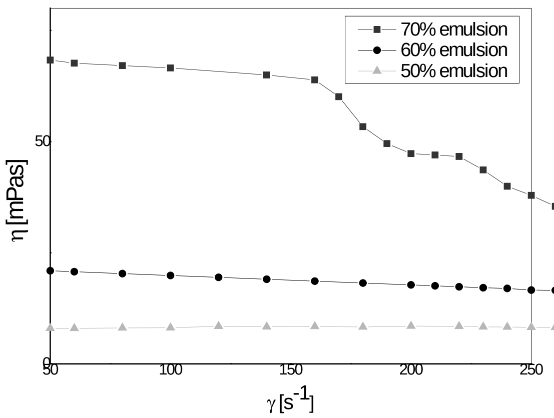

Fig 2. Emulsion rheological properties

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 1,2·105 [Pa]. The pressure observed for steady state was higher and its value was 0,5·105 [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.

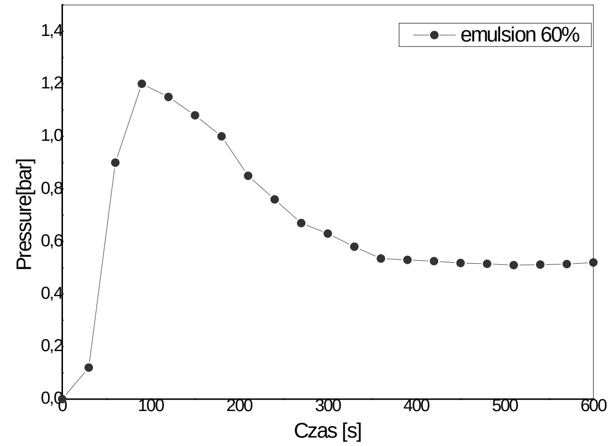

Fig. 4- Pressure versus time in case of elution of 60% emulsion from porous bed

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 1,35·105 [Pa]. Moreover, it was higher than in situation where 50% or 60% emulsion was eluted. Steady state pressure was also bigger and equalled to 0,8·105 [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.

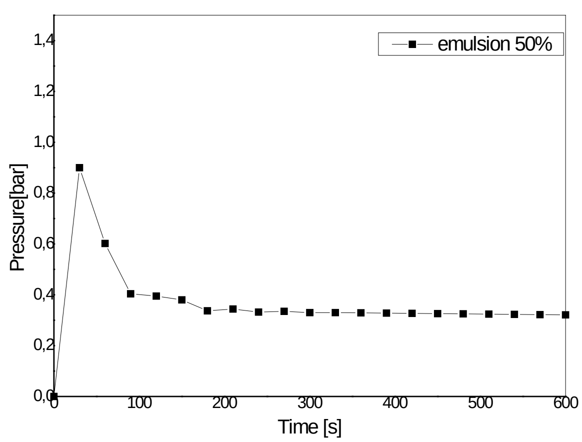

Fig. 3- Pressure versus time in elution of 50% emulsion from porous bed

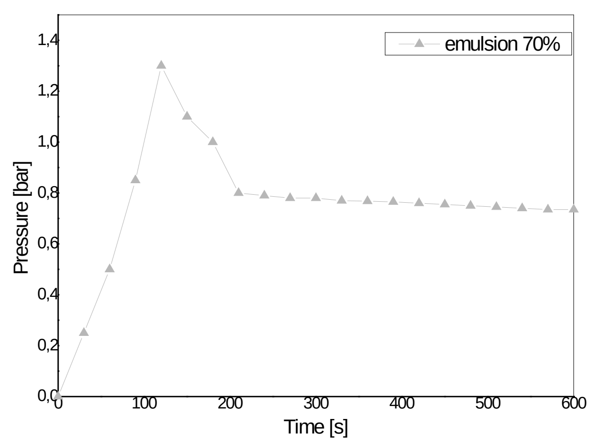

Fig. 5- Pressure versus time in case of elution of 70% emulsion from porous bed

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

ISSN 2229-5518

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 stage 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 ·105 Pa, while for emulsion concentration of 70% was higher by 0,3 ·105 Pa and equalled to 1,2 ·105Pa.

5. REFERENCES

[1] Langevin D., Poteau S. , Hénaut I. , Argillier J. (2004) Crude Oil Emulsion Properties and their Application to Heavy Oil Transportation, Oil & Gas Science and Technology, Vol. 59, No. 5: 511-521

[2] Jewulski J., Wojnarowski P. (2007) Selected aspects of perfecting secondary methods of oil deposits exploitation, AGH Drilling, Oil, Gas : 769-778

[3] Crawford S., Clifford J., David K., John W.(1997) Effects of emulsion viscosity during surfactant enhanced soil flushing in porous media, Journal of Soil Contamination, 6:4, 355-370

[4] Ronald E. Terry (2001) Encyclopedia of Physical Science and Technology 3rd Edition vol. 18, Academic Press : 503-518

[5] Darcy H. (1856), Les Fontaines Publiques de la Ville de Dijon, Dalmont, Paris

[6] Schramm L. L. (1992) Emulsions Fundamentals and Applications in the Petroleum Industry, Advances in Chemistry Series, American Chemical Society 231: 219-232

[7] Marle C. (1981) Multiphase Flow in Porous Media, Institut Francais Du Petrole, Editions Techniship, Paris: 16-22

[8] Mendez Z D C. (1999) Flow of Dilute Oil-in-water Emulsions in Porous Media. Ph.D. Dissertation. Austin, University of Texas at Austin, Texas

[9] Buret S, Nabzar L and Jada A.(2008) Emulsion deposition in porous media: impact on well injectivity. Paper SPE 113821 presented at Europec/EAGE Conference and Exhibition, June 9-12, Rome, Italy

[10] Török J., Tóth J., Gesztesi G. (2006) Polydispersed O/W Emulsions in Porous Media: Segregation at Low-Tension Conditions, Journal of Colloidal and Interface Science 295: 569–577