EVALUATION OF SURFACTANT PERFORMANCE FOR ENHANCED OIL RECOVERY

POSOUZENÍ VHODNOSTI APLIKACE POVRCHOVĚ AKTIVNÍCH LÁTEK (PAL) PRO POTŘEBY ZVÝŠENÍ VYTĚŽITELNOSTI LOŽISEK UHLOVODÍKŮ

Michal PORZER [1], Petr BUJOK [2], Martin KLEMPA [3], Petr PÁNEK [4]

[1] *Ing, Institute of Geological Engineering, Faculty of Mining and Geology, VŠB – Technical University of Ostrava*
17. listopadu 15, Ostrava-Poruba, tel. (+420) 59 732 5487
e-mail michal.porzer@vsb.cz

[2] *prof. Ing. CSc. Institute of Geological Engineering, Faculty of Mining and Geology, VŠB – Technical University of Ostrava*
17. listopadu 15, Ostrava-Poruba, tel. (+420) 59 732 3529
e-mail petr.bujok@vsb.cz

[3] *Ing, Institute of Geological Engineering, Faculty of Mining and Geology, VŠB – Technical University of Ostrava*
17. listopadu 15, Ostrava-Poruba, tel. (+420) 59 732 5496
e-mail martin.klempa@vsb.cz

[4] *doc. Ing. CSc. Department of Chemistry, Faculty of Metallurgy and Materials Engineering, VŠB – Technical University of Ostrava*
17. listopadu 15, Ostrava-Poruba, tel. (+420) 59 732 4301
e-mail petr.panek@vsb.cz

Abstract

This paper focuses on the field of enhanced oil recovery by means of a chemical flooding of oil deposit especially a surfactant flooding method. The main objective is the application of the aforementioned method at the Czech oil deposit Ždánice – Miocene which bears the crude oil of significant viscosity and gravity that does not allow conventional production methods to be used. We evaluated the performance of various surfactants in the laboratory environment by simulating oil recovery processes.

Abstrakt

Tento výzkum se zabývá problematikou zvyšování výtěžnosti ropy pomocí rozšířeného zavodňování chemikáliemi, z nichž je věnována největší pozornost povrchově aktivním látkám. Dlouhodobým hlavním cílem tohoto výzkumu je aplikace těchto metod v podmínkách české republiky, konkrétně na ložisku Ždánice – miocén, kde vlastnosti obsažené ropy, jako je viskozita a objemová hmotnost, neumožňují použití klasických těžebních metod. Pro vhodnost použití jsme v laboratorních podmínkách simulovali procesy probíhající při těžbě ropy za ložiskových podmínek a hodnotili vliv jednotlivých povrchově aktivních látek na výtěžnost těžké ropy.

Key words: enhanced oil recovery, surfactant flooding, heavy crude oil, Ždánice – Miocene

1 INTRODUCTION

The industry of oil and gas production experiences a significant evolution due to the last decade's improvements in the exploration for new resources, the characterisation of hydrocarbons reservoirs, the completion of production wells, and the production engineering itself. Mathematical modelling and laboratory testing methods are more frequently utilized for success assurance and risk reduction during the production projects. [1]

Significant advances were achieved also in the production of previously hard-to-get oil, i.e. very viscous oil and unrecoverable remaining oil in place. Currently, the oil recovery varies from 30 to 40 % in case of a convenient reservoir and geological conditions. With more challenging geological features in the reservoir or unfavourable formation fluid properties, the oil recovery decreases dramatically to the 10 – 5 % or even less. The improved and enhanced oil recovery methods (IOR and EOR) are in the main focus of production engineers. [2]

Vast majority of conventional and convenient oils, in terms of production difficulty, is already explored, produced, or also depleted, thus the main focus of production companies inclines towards offshore projects, unconventional resources and previously unrecovered oils, the resources of which are considered to be of great importance. Current economical market conditions with the last 3-year growth of price per barrel enables to increase investments in production projects, and therefore the previously expensive technologies like the chemical flooding become to be implemented on a regular basis.

At our facilities of the Department of Geological Engineering, the heavy oil production and enhancement of oil recovery research is based on a long-term cooperation agreement with the Czech oil company Moravské Naftové Doly, a.s. (MND). The hydrocarbons located at the deposit Ždánice – Miocene which is operated by MND are considered to be very promising, especially the 1st lower miocene horizon where the greatest volume of oil and gas in place (ca 60 % of Ždánice – Miocene deposit) is contained. The production attempts at this particular horizon, however, showed significant difficulties caused by the formation crude oil properties. This fact brought the issue of the proper production method possibilities under the discussion. [3, 4]

The three hydrocarbon deposit horizons were located in the lower Miocene sediments and were named the 1st, the 2nd and the 3rd horizon. The fundament of the Neogene formations belongs to the Brunovistulian terrane and is formed by fractured granitoids which are locally mylonitized. The deposits of the 1st and the 2nd horizons are isometric with a maximum length of ca 2 km and 1.2 km in width. The depth of these horizons varies from 700 to 1000 m under the ground surface (Fig.1). [5]

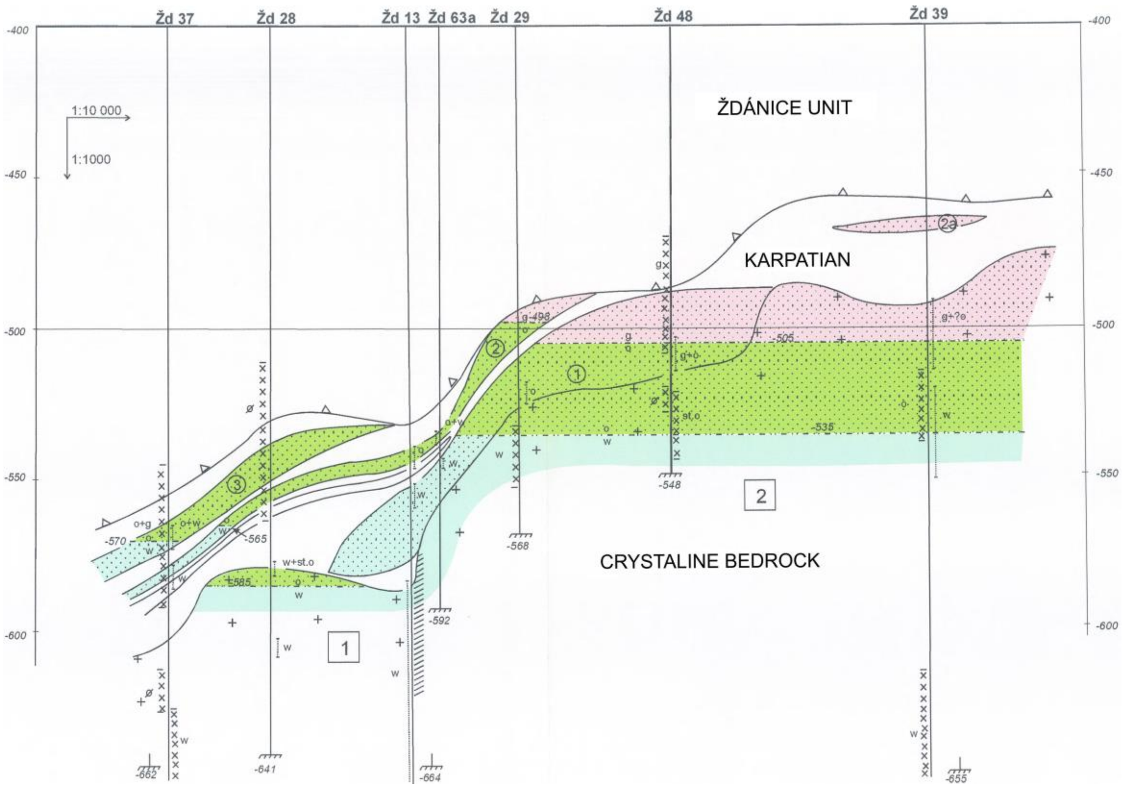

Fig. 1 The Ždánice Miocene deposit (circled numbers 1-3 mark the 1st to the 3rd lower Miocene horizons) [3]

The oil, which the 1st lower Miocene horizon bears, is classified as paraffinic-napthetic, very viscous (ca 250 mPa·s at 20 °C) with a heavy fraction content and with the gravity of about 21° API. The oil bearing zone in the fractured crystalline fundament is about 30 m thick. The reservoir formations of basal Miocene clastic sediments which are of sandstone to conglomerate character have the porosity of 10 – 20 % and the permeability ranging from 81.06 to 202.65 mD. The formation brine is classified as strongly mineralized with an average mineralization of 11996.87 mg/l. [3, 6]

The original formation pressure on the gas – oil contact (-505 m) was 7,088 MPa and the formation temperature was 29.2 °C. The original oil in place was assessed to be 8.944 million bbl; associated gas: 30.29 million m^3; natural gas in the gas cap: 63.604 million m^3. [3, 6]

Conventional methods for producing the crude oil (i.e. downhole pumps, etc.) are considered ineffective for the cases of very viscous oil recovery. Therefore, the utilization of EOR methods seems appropriate. Extensive mathematical modelling was applied to the evaluation of various EOR methods effectiveness at the 1^{st} lower Miocene horizon. Predictive modelling was conducted for following production scenarios: water flooding, application of polymers, application of chemicals (i.e. surfactants, alkali, acids, and solvents), steam injection, *in situ* combustion, and carbon dioxide injection. [7]

The aforementioned predictive modelling evaluated the application of surfactants during the water flooding as the most effective production scenario [7]. This EOR method was previously the research objective at the Section of Exploration Technology (SET) under the Department of Geological Engineering, Faculty of Mining and Geology, VŠB – Technical University of Ostrava. Laboratory experiments in this field of interest were conducted on the MAF (Filtration Measurement Apparatus).

The analysis of the surfactant utilization in the EOR for the Ždánice crude oil case was proposed to be conducted at facilities of the SET and the Institute of Clean Technologies and Raw Materials Utilization (ICT) after the consultation with MND employees.

2 BASIS OF CHEMICAL FLOODING EOR METHOD

The history of oil recovery by means of chemical flooding reaches as far as 70 years of today with the first study patented by Detling (Shell) in 1944. The basic principle is the dynamic interaction of flooding agents with crude oil which is generally seized by the porous media of reservoir formation. The success of flooding operation depends especially on reservoir formation properties (i.e. anisotropy, wettability, porosity, permeability, fracture/pore geometry, etc.), formation fluids properties, injected slug characteristics. The properties of injected slugs are modified according to the reservoir conditions by a wide variety of chemicals. [1]

The chemicals used for flooding slug design are of a various character: surfactants, polymers, alkali, foaming agents, and acids. According to the aforementioned reservoir conditions, the injected fluid could be designed as a single component or multiple component solution. The surfactant flooding slug generally consists of water, surfactant, electrolyte, and solvents. The additional oil recovery achieved by this method could be up to approximately 30 % of residual oil in place. [8]

The main processes which enable additional oil recovery during chemical flooding are: 1) reduction of fluids interfacial tension; 2) oil dissolving; 3) crude oil emulsification into a mobile fluid phase; 4) formation rock wettability alteration; 5) improvement of water – oil mobility ratio. [8]

2.1 Monitoring effectiveness of the flooding agents for EOR under laboratory conditions

Laboratory experiments as well as mathematical modelling implemented during the search for a solution of the real field problems tend to yield not only important information, but also a certain degree of uncertainty caused by the necessary simplification of the real process as delivering the actual physical or mathematical model representing the real conditions is nearly impossible. The effort should be, therefore, made towards monitoring the single factor at the time instead of monitoring the whole heterogeneous and complex system at once. With this thought in mind, the laboratory simulations of surfactant flooding process were conducted.

In order to properly conduct the experiments, the following objectives and order of tasks were set:

- Selecting proper porous media representing the reservoir formation rock and selecting suitable fluids for injection slug design
- Conducting gravitation filtration experiments for further selecting applicable fluids
- Extended filtration experiments with an induced pressure thanks to the MAF VII apparatus and variety of fluids (i.e. brine, surfactant)
- Filtration EOR experiments simulating reservoir pressure and temperature conditions thanks to the BRP 350 apparatus
- Evaluating the best performing fluids

2.2 Selection of oil bearing formation rock model and selection of fluids

The real formation core sample of the 1^{st} Miocene horizon was not obtainable; therefore, the rock model had to be utilized. The main requirements were the effortless obtainability, intergranular hydraulically connected porosity and chemical inertness to the process fluids. For the first unconsolidated rock model design, we selected three fractions of silica sand (a grain diameter of 0.8-1.2 mm, a porosity of 36.2 %).

The second consolidated sample type was decided to be of Hořice sandstone (permeability of 213.04 mD at a 15.9MPa overburden pressure; a 7MPa pore pressure and a porosity of 27.83 % at a 15.9MPa overburden pressure). This sandstone is formed mainly by quartz clasts, with slight amount of feldspar clasts and clay grain cement. The grain diameter varies from 0.07 up to the 0.38 mm. [9, 10]

The base fluids for EOR experiments were the crude oil and brine provided by MND, water, and as the process fluids, four types of surfactants with process concentrations in water of 5 and 15 g/l (Tab. 1) were selected.

Tab. 1 The selected process surfactants and their abbreviations (* commercially distributed surfactants were selected intentionally to assess their effect compared to Slovanik 3040 which is utilized in the oil industry)

Surfactant	Abbreviation
Slovanik 3040	PAL 1
Henkel – Pur*	PAL 2
Jar*	PAL 3
Tesco*	PAL 4

3 FILTRATION EXPERIMENTS EVALUATION

The vast number of surfactants and their concentrations in process slug had to be reduced by inexpensive, less time consuming means as all slugs could not be tested in induced filtration experiments under reservoir conditions. As a first screening option, the gravitational filtration experiment was selected.

3.1 Gravitational filtration experiments for surfactant evaluation

The measurement consisted of placing the unconsolidated rock model into the gravitational filtration testing apparatus (TARGF) (Fig. 2). The rock model was saturated with crude oil provided by MND. Then the secondary method of water flooding with the brine was simulated. Subsequently, the surfactants (PAL 1 – 4) were used for oil displacement from the rock model.

Fig. 2 Gravitational filtration testing apparatus (TARGF)

The resulting filtration curves of recovered oil after the certain volume of slug injected were produced. The residual oil saturation and the primary recovery effectiveness was used to set succeeding steps. This experiment reduced the amount of surfactants to the two with the best performance which were selected for additional testing. The best oil recovery after the injection of 3 pore volumes of process fluid was held by the surfactants PAL 1 and PAL 3 with 89.2 % and 76.6 % respectively. The worst performing by means of oil recovery was showed by the brine (9 %) (Fig. 3).

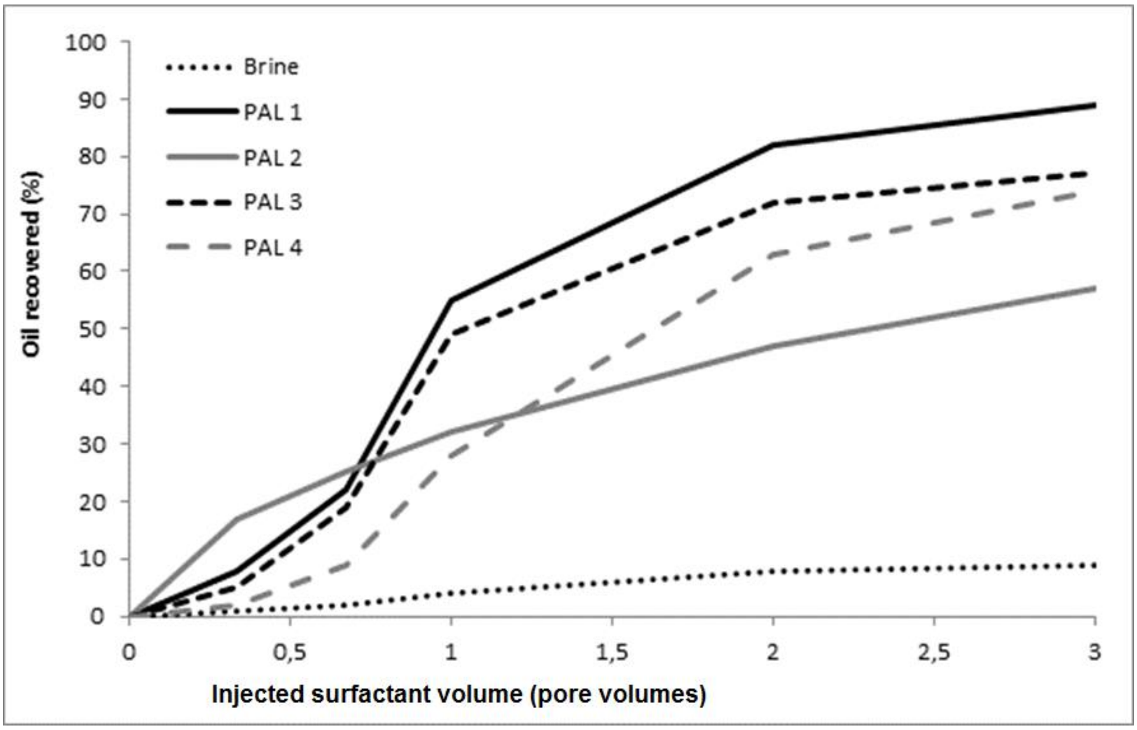

Fig. 3 Graphical record of oil production to the injected fluid volume for PAL 1 – 4 and brine

3.2 Surfactant evaluation by means of experiments under reservoir conditions

One of the previously best performing surfactants PAL 3 was selected for oil displacement filtration under the reservoir conditions thanks to the BRP 350 apparatus (Fig. 4) at the facilities of the Laboratory of Wells and Hydrocarbon Deposits Stimulation, under the ICT. The second type of rock model was utilized in the form of the core plug which has 37.4 mm in diameter and 54.1 mm in length. The sample was originally saturated with brine and subsequently put under a confining pressure of 15.9 MPa and a pore pressure of 7 MPa at a laboratory temperature of 23 °C. The drainage of brine with oil was conducted afterwards to put the sample into the most representative saturation state. The PT and saturation conditions very well represented the in situ conditions of the 1st lower Miocene horizon of the Ždánice Miocene deposit.

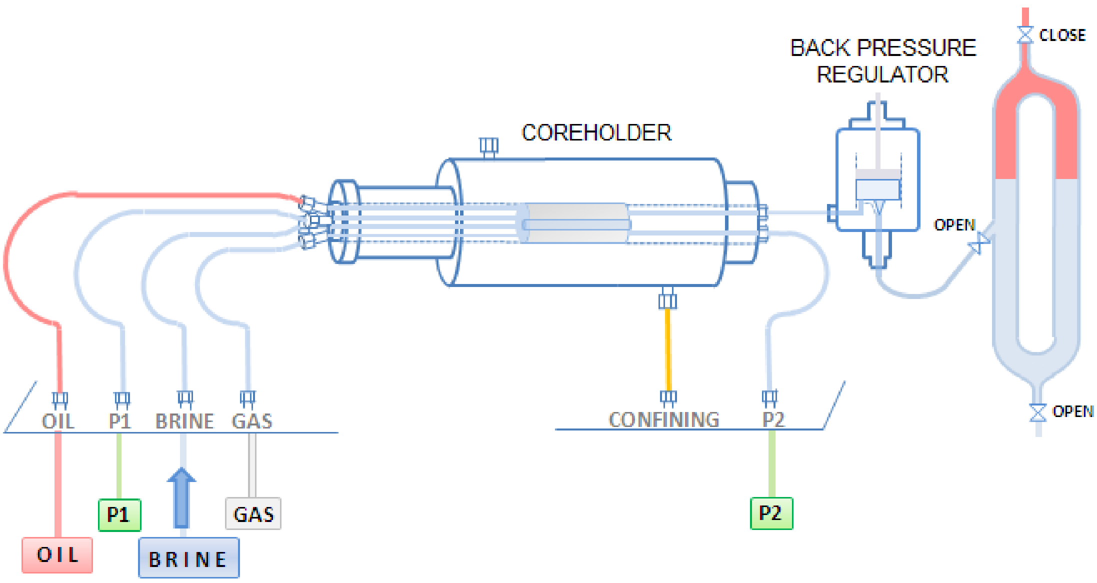

Fig. 4 Scheme of the BRP 350 apparatus (OIL, BRINE, GAS – lines for injection; P1, P2 – lines for inlet and outlet pressure measurements respectively; CONFINING – line for confinement of core sample; BACK PRESSURE REGULATOR – for regulating pore pressure)

The imbibition by brine injection was then performed to simulate a secondary water flooding method of production. The oil recovery at exact pore volume of brine injected was measured, and after the oil volume level stabilization in measurement burette, the recovery by the brine injection was considered done. The oil recovery by brine imbibition was 23.87 %, if the initial oil saturation after the 3.8 pore volumes of brine were injected.

Subsequently, the imbibition by surfactant slug was conducted and the produced oil, in other words the additional oil recovery, was measured. The resulting filtration curves of recovered oil after the certain volume of slug injected were produced (Fig. 5). The slug consisted of brine and 15 g/l PAL 3 concentration held the additional oil recovery at 30.23% residual oil saturation, which means 54.10% recovery of initial oil in place.

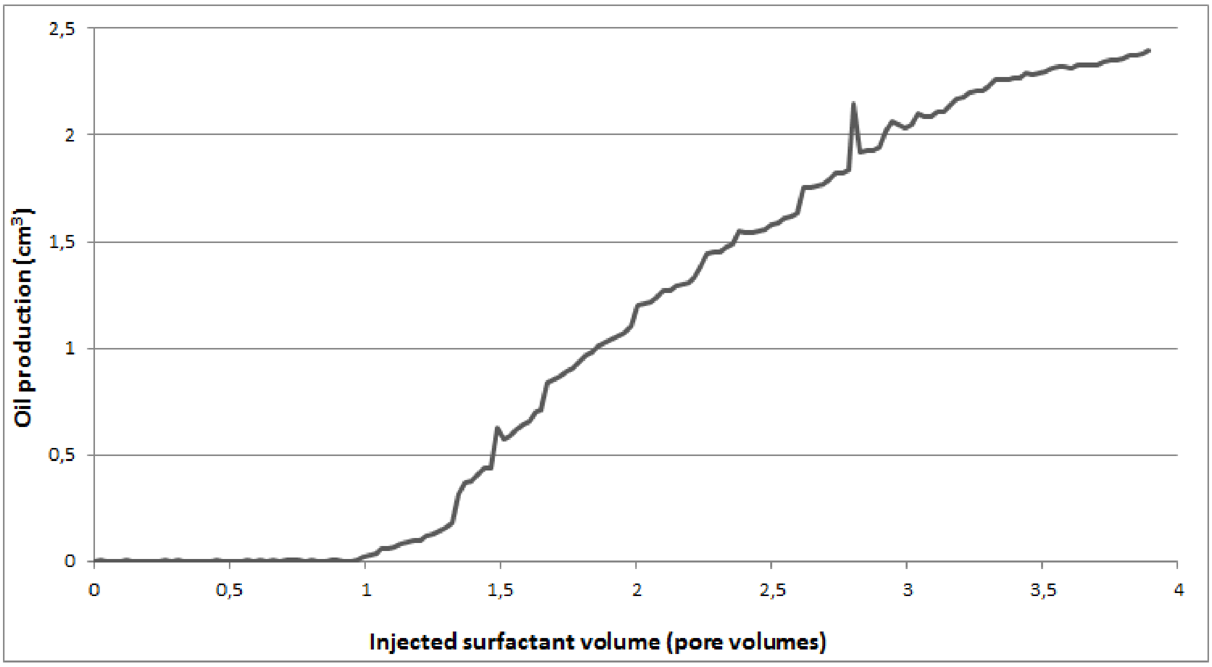

Fig. 5 The filtration curve of recovered oil after the certain volume of slug injected

4 CONCLUSION

The percentage of recovered oil by surfactant injection is quite high and tempting, therefore, this EOR method seems appropriate, however much more testing has to be done in this particular case. The obtained results so far will be used as the screening method for reducing possible injection fluids variety to the most effective one. The surfactants PAL 1 and PAL 3 will be evaluated by the filtration experiments under the reservoir conditions by the utilization of the MAF and BRP 350 apparatuses.

ACKNOWLEDGEMENT

The article has been done in connection with the project of the Institute of Clean Technologies for mining and utilizing raw materials for energy use, reg. no. CZ.1.05/2.1.00/03.0082 supported by the Research and Development for Innovations Operational Programme financed by the Structural Founds of the European Union and from the means of the state budget of the Czech Republic.

REFERENCES

[1] GREEN, D. W. WILLHITE, G. *Enhanced Oil Recovery*. 2st ed. Texas, 2003. 545 pp. ISBN 1-55563-096-0.

[2] HIRASAKI, G. & MILLER, C. & PUERTO, M.. *Recent Advances in Surfactant EOR*. SPE Journal. 2011, vol. 16, issue 4, s. 889-907. DOI: 10.2118/115386-PA.

[3] BOŠÁCKY, P. *Ložisková simulácia – ťažby na ložisku Ždánice*. Bratislava, SPP 02 Výzkum a vyhledávanie nafty a plynu, Bratislava, 1997.

[4] DOHNAL, K. & HAMRŠMÍD, B. & ZÁDRABA, M. Intraformační slepenec v sedimentech spodního miocénu v oblasti Ždánického lesa. In *Nové výsledky v terciéru Západních Karpat II*. Knihovnička zemního plynu a nafty 1995.

[5] DUDEK, A. *The crystalline basement block of the Outer Carpathians in Moravia: Bruno-Vistulicum*. Praha : Čs.Akad. Věd, 1980.

[6] BOŠÁCKY, P. *Ložisková simulácia primárnej ťažby a aplikácia druhotných ťažobných metód na ropných ložiskách Ždánice – miocén a Kloboučky*. Bratislava, SPP 02 Výzkum a vyhledávanie nafty a plynu, Bratislava, 1997.

[7] BOŠÁCKY, P. *Optimalizácia ťažby ropy na ložisku Ždánice 1. spodní miocén*. Final Report, EURO-GEOLOGIC, a.s., Bratislava, 1997.

[8] SHENG, J. *Modern Chemical Enhanced Oil Recovery: Theory and Practice*. 1st ed. Burlington : Gulf Professional Publishing, USA 2011. ISBN 978-1-85617-745-0.

[9] HALATOVÁ, M. *Laboratorní stanovení petrofyzikální charakteristiky vybraných vzorku vrtného jádra.* Bachelors thesis.. Ostrava : VŠB-TU Ostrava, 2013.

[10] VONDROUŠOVÁ, S. *Petrografie a využití hořických pískovců*. Bachelors thesis.. Ostrava : VŠB-TU Ostrava, 2009.

RESUMÉ

Tento výzkum se zabývá problematikou zvyšování výtěžnosti ropy pomocí rozšířeného zavodňování chemikáliemi, z nichž je věnována největší pozornost povrchově aktivním látkám. Dlouhodobým hlavním cílem tohoto výzkumu je aplikace těchto metod v podmínkách české republiky, konkrétně na ložisku Ždánice – miocén, kde vlastnosti obsažené ropy, jako je viskozita a objemová hmotnost, neumožňují použití klasických těžebních metod. Pro vhodnost použití jsme v laboratorních podmínkách simulovaly procesy probíhající při těžbě ropy za ložiskových podmínek a hodnotili vliv jednotlivých povrchově aktivních látek na výtěžnost těžké ropy.

Laboratorní výstupy navazují na prediktivní modely společnosti MND, a.s., které vyhodnotily nejperspektivnější metody těžby na ložisku Ždánice – 1. spodnomiocenní obzor. Matematické modelování považuje použití rozšířeného zavodňování s chemikáliemi, jako nejlepší variantu z běžně užívaných metod zvyšování výtěžnosti ropy (EOR). V laboratořích Institutu čistých technologií těžby a užití nerostných surovin navazujeme na náš předešlý výzkum, který hodnotí řadu povrchově aktivních látek (PAL), z hlediska jejich vhodnosti jako příměs pro EOR v podmínkách Ždánického ložiska. Byly vybrány PAL, které se jevily nejefektivnější a byly provedeny testy gravitační filtrace, nucené filtrace a nucené filtrace za navozených ložiskových podmínek v laboratorním prostředí. Použitá metoda vykazuje velmi slibné výsledky a bude nadále zkoumána formou testování nejvhodnějších PAL a jejich kombinaci s dalšími vhodnými tekutinami, jako jsou polymery, etc.

Článek byl vypracován v rámci projektu Institut čistých technologií těžby a užití energetických surovin, reg. č. CZ.1.05/2.1.00/03.0082 podporovaného Operačním programem Výzkum a vývoj pro Inovace, financovaného ze strukturálních fondů EU a ze státního rozpočtu ČR.