DNIPRO UNIVERSITY of TECHNOLOGY 1899

Mining of Mineral Deposits
ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)
Journal homepage http://mining.in.ua
Volume 13 (2019), Issue 4, pp. 107-113

UDC 622.276.4 https://doi.org/10.33271/mining13.04.107

ANALYSIS OF POSSIBILITIES TO INCREASE OIL RECOVERY WITH THE USE OF NITROGEN IN THE CONTEXT OF DEEP OIL DEPOSITS OF THE DNIPRO-DONETSK OIL-AND-GAS UKRAINIAN PROVINCE

O. Kondrat[1*], O. Lukin[2], L. Smolovyk[1]

[1]Ivano-Frankivsk National Technical University of Oil and Gas, Ivano-Frankivsk, Ukraine
[2]Scientific-Research and Design Institute PJSC "Ukrnafta", Ivano-Frankivsk, Ukraine
**Corresponding author: e-mail kondrat@nung.edu.ua, tel. +380342727141*

ABSTRACT

Purpose is to increase oil recovery of deep oil deposits of the Dnipro-Donetsk oil-and-gas Ukrainian province with the use of nitrogen.

Methods. Experiments, intended to residual oil displacement with the use of different driving agents, involved laboratory modeling of the process when a seam was simulated as such being close maximally to a real seam and samples of formation fluids were applied. The experiments, which materialized equilibrium displacement (without mass transfer), used seam models developed from cores of V-19n seam (Perekopivske deposit). 43 core samples were analyzed with 3.3 – $226.0 \cdot 10^{-3}$ μm^2 permeability.

Findings. Characteristics and applicability of nitrogen and flue gas to increase oil recovery have been analyzed. Theoretic prerequisites of the mechanism, aimed at oil displacement using nitrogen and flue gases, have been formulated. Results of the laboratory experiments of oil displacement by means of nitrogen within a porous environment have helped determine that minimum pressure of mutual oil and nitrogen dissolution is 36.0 – 38.0 MPa. In terms of mutual mixing of agents at 110 – 112°C temperature, 36.4 MPa gas injection pressure, and nitrogen pumping velocity being 1 cm^3 per 40 minutes, oil displacement ratio achieved 0.76 – 0.78.

Originality. For the first time, parameters of mixable oil displacement using nitrogen for the conditions of deep oil deposits of the Dnipro-Donetsk petroleum province in Ukraine have been determined. Efficiency of mixable nitrogen displacement to compare with water displacement and nitrogen displacement under equilibrium conditions has been proved.

Practical implications. The advanced technique of nitrogen use to improve oil recovery in the context of deep oil deposits has been proposed. The technique is applicable to extract residual oil from the depleted deposits.

Keywords: *oil recovery ratio, nitrogen, residual oil, displacement, injection pressure*

1. INTRODUCTION

International practices give following evidence of the increased oil recovery: 5 – 10% if gas methods are applied; 3 – 8% if physicochemical methods are applied; and 15 – 20% if thermal methods are applied (Evison & Gilchrist, 1992; Ermakova & Eremina, 1996; Behzadi & Towler, 2009). Thermal projects are 5% of extraction resulting from the implemented techniques intended to improve oil extraction; 45% – to inject nitrogen and CO_2; and chemical methods are 5% only. Gas methods and thermal methods are the most popular in the USA applies (Strpić, Miličević, & Kurevija, 2017). It should be noted that chemical methods are recommended for 2500 m wells and thermal methods are recommended for 1000 m wells. Gas methods are the only ones to increase oil recovery of deep deposits; among other things, the use of dioxide carbon, carbon, nitrogen, and flue gases is meant (Clancy, Gilchrist, & Kroll, 1981; Mungan, 2000; Indrupskiy, Zakirov, & Kondrat, 2013).

In the early 1980s, a number of companies (inclusive of Exxon and Chevron) experimented with nitrogen injection into a seam. There are nine operating projects and implementation objects of the method are almost equal to the objects where oil is displaced with the help of dioxide carbon (Ahmed, Menzie, & Crichlow, 1983; Stepanova & Tolokonskaya, 1983; Sayegh, Wang, & Najman, 1987). However, the carried out analysis of nitrogen use to increase oil recovery of seams has shown that in the practice of improvement of the current oil withdrawal from the depleted oil deposits, the method, relying upon the mixable displacement of residual oil with the help of nitrogen, did not turn out to be popular. The tendency is rather promising and will become commonly used (Glaso, 1990; Hudgins, Llave, & Chung, 1990; Jha & Chakma, 1991; Lyan, 2016).

In the context of Ukrainian oil deposits being mainly depleted, the use of modern techniques to improve oil recovery is of current interest. Substantial quantity of such deposits is concentrated within the Dnipro-Donetsk oil-and-gas province of Ukraine (Law et al., 1998). Significant depth of productive strata exceeding 3000 m is characteristic feature of the deposits. Thus, it has become necessary to analyze use of nitrogen for the improvement of oil recovery of deep oil deposits of the Dnipro-Donetsk oil-and-gas province of Ukraine.

2. ANALYSIS OF USE OF NITROGEN AND FLUE GASES TO IMPROVE OIL RECOVERY OF SEAMS

Nitrogen and flue gases were the first applied to increase oil recovery of seams. Since oil dissolves nitrogen poorly, its industrial use was considered skeptically for a long time. Nitrogen dissolution is 35 – 45 m^3 in light oil, and 15 – 25 m^3 in heavy oil (Gurevich & Zazovskiy, 1987; Sinanan & Budri, 2012; Heucke, 2015). Nitrogen dissolves easily with methane and low-molecular carbohydrates. It is possible to mix up nitrogen with real oils if formation pressure is more than 35.0 MPa and oil contains significant amount of light hydrocarbons. It should be noted that sometimes complete mixing with light oils takes place under 25.0 MPa pressure; if CO_2 is involved, the pressure is 8.0 MPa (Entov & Zazovskiy, 1989; Yu & Sheng, 2016). In spite of the fact that in addition to nitrogen, flue gases contain 10 – 15% of dioxide carbon, they mix with oil little better than nitrogen.

The above mentioned speaks for worse technological efficiency of nitrogen to compare with other gas methods. However, injection of nitrogen and flue gases into a seam has a number of significant advantages offering the possibility to consider it as a promising method to increase oil recovery. Low cost of the agents and their availability are the key advantages. Since nitrogen compressibility is 3 times less than CO_2 compressibility and 1.5 times less than methane compressibility, its losses in seam will be 2 – 3 times less to compare with the use of other gases.

Taking into consideration the fact that nitrogen cost and its compressibility degree, expenditures connected nitrogen injection into a seam is 3 – 6 times less to compare with dioxide carbon injection into the seam. Moreover, it should be noted that nitrogen is noncorrosively active and injection of flue gases into a seam favours their utilization while mitigating environmental pollution (Kondrat, 2013; Heucke, 2015).

Proper application area has been determined for nitrogen and flue gases. Deep deposits ($h > 4000$ m) and ultradeep deposits ($h > 7500$ m) are meant. Generally, the deposits contain light low-viscosity oils characterized by high seam pressure (30.0 – 56.0 MPa) and temperature (68 – 125°C). Such conditions may help achieve complete oil-nitrogen mixing as well as maximum values of oil recovery ratio (Fahandezhsaadi, 2019).

Nitrogen may also substitute natural gas during the gas recirculation while developing gas-condensate deposits. If seam temperature is close to the initial boiling point, then natural gas can be successfully substituted by nitrogen or other available gases which provide effective support of the formation pressure as well as condensate transfer to the production well bottom. Economic arguments remain to be determining ones (Surguchev, 1989).

When a steep oil seam with an active water drive is under the development, certain oil share may remain in the neighbourhood of the seam roof. Drilling of extra wells is not expedient economically. The oil, remained within the seam upper part, can be extracted using gas displacement; the gas is injected through a single well. Again, nitrogen is more advantageous in this context.

At the initial extraction stage, gas from a gas cap is not mined for more complete oil exclusion. It is done not to decrease seam pressure. Gas cap blowdown starts when oil extraction is over i.e. many years after the development began. Under the conditions of high gas demand and its high cost, delay in a gas cap blowout may turn out to be undesirable, or even unprofitable. Nitrogen injection into a seam at an early stage of a deposit development makes it possible to recover gas from a gas cap with no decrease in the seam pressure. Currently, carbon dioxide becomes more and more popular as for the enhanced oil recovery. Carbon dioxide is efficient from the viewpoint of oil displacement but it is of high cost. Thus, to transfer a carbon dioxide share along a seam, nitrogen and water may be used alternately. The same is true for the solvent share transfer. Finally, simply mixable and unmixed (i.e. equilibrium) oil displacement by means of nitrogen is possible. Such a displacement depends upon the seam characteristics. The seam depth, upon which mixing pressure depends, and availability of sufficient amount of light fractions in oil are the determinant factors. Good mixing can be achieved when the seam depth is not less than 3000 m and the oil density is not more than 820 kg/m^3.

Maximum effect is possible in terms of a technique providing complete mixing (solubility, nonequilibrium) of the injected gas with oil within relatively homogenous seams; and equilibrium (i.e. unmixed) displacement during free gas transmission within nonhomogeneous seam is less efficient.

Currently, such an idea prevails that efficiency of flue gas injection into a seam is almost equal to pure nitrogen injection. CO_2 content in the flue gases is minor (i.e. 10 – 15%). CO_2 is the first thing being dissolved in oil contacting with it. As a result, pure nitrogen displaces oil and CO_2 lags behind the displacement front. It makes clear minimum mixing pressure of flue gases is equal to the minimum mixing pressure of pure nitrogen; thus, technological efficiency of the agents should be similar in terms of mixable displacement.

Additional effect, which has never been considered, arises if a mode of the unmixed (i.e. equilibrium) displacement in combination with flue gases-water injection takes place. Water, injected into a seam, dissolves CO_2

being a component of flue gases. Hence, combination of oil displacement by means of the carbonized water and water-nitrogen mixture occurs. Injection of such an amount of carbon dioxide and water into a seam, being sufficient for CO_2 to achieve a recovery line, should result in the increase of displacement ratio as well as of the sweep ratio. Degree of the increase has to be determined with the help of laboratory experiments. If the degree turns out to be rather significant, it will mean that alternate or synchronous injection of nitrogen with carbon dioxide may be applied efficiently when more viscous oil is displaced to compare with displacement with the use of nitrogen. Application of flue gases and nitrogen is restricted less than application of physicochemical and thermal methods. The mixable displacement needs deposits of relatively light oil; moreover, they should be deeper and with high gas injection pressure i.e. more than 35.0 – 40.0 MPa. When nitrogen disposes gas margins, oil should also be light.

3. MECHANISM TO DISPLACE OIL WITH THE HELP OF NITROGEN AND FLUE GASES

A process of the unmixed oil displacement using nitrogen is close to a piston-like one described in the large-scale approximation by a Buckley-Leverett theory.

Since low velocities within porous media are typical for gas-liquid systems, it is possible to assume that interphase mass exchange will be close to equilibrium one under formation conditions.

In the context of mixable oil displacement using nitrogen, a multicontact process is observed when nitrogen, combining with formation oil, is enriched by methane, n-butane, and vapours of light oil fractions. Conversely, the gas mixture dissolves in the oil being displaced. As a result, small transition area of the gas-liquid mixture is formed within which active interphase migration of the components takes place. On the one hand, if the injected nitrogen exceeds oil saturation pressure, its dissolution happens; on the other hand, light hydrocarbon oil components vapour out to nitrogen. During nitrogen motion over a seam, its enrichment by hydrocarbon components will become more and more intensive. At the end of the process, gas, containing hydrocarbon components and nitrogen, will flow within the displacement front. Their ratio will be constant depending upon the initial displacement conditions. On the one hand, the gas is consumed, while dissolving within oil, displaced by it, which saturation pressure is less than displacement pressure; on the other hand, its amount increases owing to transition of methane, n-butane, and vapours of light oil fractions from oil to the gas phase. Dissolution of such a gas mixture within the formation oil increases the number of light components in it. The decreased density of the formation oil may result in the complete mixability of oil and the enriched hydrocarbon components of gas flowing over the displacement front. Even if the complete mixture is not achieved, the displacement coefficient is rather high owing to the following: first, gas transfers light fractions from the residual oil to the nondisplaced oil; and second, oil amount increases since such a gas, enriched by hydrocarbons, dissolves in it.

4. LABORATORY EXPERIMENTS INTENDED TO ANALYZE A PROCESS OF OIL DISPLACEMENT USING NITROGEN AND FLUE GASES

Generally, selection of one or another method to improve oil recovery coefficient, involves laboratory simulation process; i.e. laboratory environment is used to model a seam being close maximally to a real seam. The key objective of such experiments is to evaluate efficiency of the methods. According to the current technique to evaluate methods of seam recovery improvement, operational effect by the method implementation is evaluated using comparison of actual results with basic alternative of the object development (oil recovery improvement method is not used).

Watering is considered as a basic method to determine the effect by the influence of gas methods upon a seam. Hence, such a comparison involves experiments carried out for both basic development alternative and for the methods proposed for implementation. Information, concerning experiments intended to oil displacements using nitrogen and flue gases, is almost nonavailable. In the first place, the fact can be explained by the lack of laboratory facilities for such experimentation. Only a group of AUISR researchers (G.G. Vakhitov, A.Yu. Namiot, V.G. Skripka and A.A. Faktulin) carried out experiments for oil displacement by means of nitrogen and flue gases. A.A. Faktulin demonstrated their basic findings in his PhD thesis and several publications.

Resulting from the calculations of a process of oil-gas intersolubility, data, concerning both composition and characteristics of gas phase and liquid phase at each stage of such multicontact mixing, were obtained.

It has been determined that at 25.0 – 32.7 MPa pressures and 117°C temperature, displacement process is characterized by the limited mutual solubility, and the complete mutual formation oil-nitrogen solubility is observed when 33.0 MPa pressure is achieved.

The research has helped understand that minimum pressure of dynamic mixing (MPDM) for homogenous seam is 33.6 MPa. It has also been substantiated that, in terms of macro nonhomogenous formation, seam pressure should exceed MPDM by 2.0 – 3.0 MPa. Thus, it has been concluded that it is possible to inject nitrogen into V-19n seam of Perekopivske deposit if more than 35.0 MPa pressure is produced. Processes of oil displacement from a porous environment involving mutual mi-xing (mutual dissolving) of the agents within a seam are rather complicated. Size of a transition area (i.e. mixing area) is extremely important for the processes since it foresees the use of long experimental seam models, which, in turn, makes it possible to form rather extended transition area in the context of the experiments. The model length should not be less than 7.0 m.

Since the experiments, analyzing processes of mutual fluid mixing within a porous environment, develop rather extended mixing area, their implementation needs long bulk seam models.

Deficit of rock from Perekopivske deposit to disintegrate it and fill tubes was compensated by the rock from an open pit located in a village of Pasichna, Nadvirna District.

The disintegrated rock was separated into following fractions: up to 0.00005; 0.00005 – 0.00014; 0.00014 – 0.000315; 0.000315 – 0.00063; 0.00063 – 0.00125; and 0.00125 – 0.0025 m.

As the practice shows, mixture of the first five fractions with equal volume forms the most compact packing of grains. Absolute permeability of the seam models, used during experiments with mutual agent dissolving, was $718 \cdot 10^{-3} – 2100 \cdot 10^{-3}$ μm^2.

The experiments, implemented equal displacement (with no mass transfer), applied seam models, developed using cores of V-19n seam (Perekopivske deposit). 43 core samples have been analyzed; their permeability was $3.3 – 226.0 \cdot 10^{-3}$ μm^2. 32 analyses of the extracted core porometry have been carried out according to which open porosity was 6.5 – 17.2%, and permeability was $6.7 – 166.0 \cdot 10^{-3}$ μm^2.

Permeability of the seam models, used to carry out oil displacement using water and gas, was $67 – 145 \cdot 10^{-3}$ μm^2.

The experiments were carried out with the help of a device which principal scheme is represented in Figure 1. The device makes it possible to experiment under the conditions providing mutual agent mixing within the porous environment.

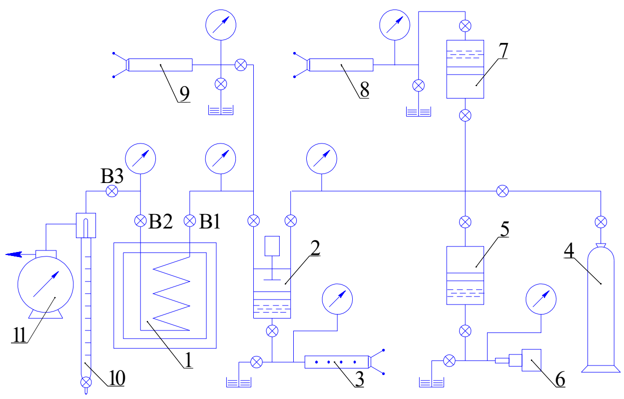

Figure 1. Principal scheme of a device to experiment processes of oil displacement using different agents: 1 – seam model; 2 – container; 3 – hand-operated press; 4 – high pressure source (balloon); 5 – container for gas compression; 6 – pump; 7 – container for liquid; 8 and 9 – presses; 10 – burette; 11 – gas meter; B1, B2 and B3 – valves

As the scheme demonstrates, first stainless steel coil *1* was used as the seam model. Further, it was replaced by a direct seam model. Valve B1 was mounted at the model inlet; B2 and B3 valves for fine (accurate) fluid-flow rate control were mounted at its outlet.

If twisted bend tube, filled up with rock of proper fractions, was used as the seam model, then the former was placed within air bath making it possible to carry out experiments at up to 150°C temperature. When a direct tube was the seam model, electrical heating was used with a special control unit.

Container *2* with a hand-operated press *3* is applied to prepare (recombinate) oil and to supply it to the model. The container is equipped with a magnetic mixer.

Gas supplying system consists of balloon *4*, container for gas compression *5*, and pump *6*. A system to supply liquid to the seam involves container *7* and press *8*.

The device may have another design when, for instance, hand-operated presses are replaced by device presses of CPMU (Core Permeability Measurement Unit) type equipped additionally with multiplying gears to develop high pressures since such facilities can build up to 30.0 MPa pressures.

As it has been mentioned, steel tubes were used to develop seam model. The tubes had to withstand conditions under which mutual oil-nitrogen mixture took place. However, early experiment, carried out at 40.0 MPa pressure, was not completed due to gaps in the wall of the spiral model tube. After liquidation of the gaps, we managed to carry out two more experiments not complying with all the parameters set. During the period, the seam model became inapplicable for further activities.

Other two spiral models were developed for new experiments; however, they failed the tests. It has been suspected that the seam models are of a spiral shape, deformations, resulting from extra tension load, arise. Hence, further experiments used stainless steel seam models with 10.01 m length, 0.01 m internal diameter, and 0.003 m width of tube wall.

Electric heating developed necessary temperature within the model, for which purpose a special control unit was designed. Heating elements and corresponding potentiometer controlled the temperature.

To carry out the experiments, steel tubes were mounted vertically on the bulk seam models. They were filled up with specific mixture of disintegrated rock, which was compacted by means of the tube vibration. Filters were mounted at the ends of the tube to prevent rock grains from precipitating and pipe connection tamping.

Communication tubes with valves, manometers, and filters to hold containers, presses, and other facilities, required to carry out comprehensive experiments, are fixed to the pipe connections. Then, the model was pressurized by air at 50.0 MPa pressure; its absolute permeability was determined. Further model preparation was to determine pore volume, to develop initial water saturation (residual water); to determine water volume in the pores; and saturation of the model by formation (or recombined) oil. Like further oil displacement, the operations are performed in accordance with the branch standard.

Depending upon the problems, put by the researchers, pore volume of the seam model are either filled up by oil at once, or they start from the development of the initial water saturation as it took place in the context of the described experiments.

The fluids, displaced from the model, were caught by burette *10*, considered by gas meter *11*, and recorded in the measurement registry.

Such an order of experiments where oil was displaced in terms of different conditions and with the use of different displacement agents is applied for bulk seam models as well as for seam models made from natural cores. In this context, pore media differ.

If it is required, the experiments, concerning a process of mutual oil-displacement agent dissolving, apply relatively long bulk seam models making it possible to form within them transition areas (i.e. mixing areas) effecting drastically the displacement process as well as a degree of oil recovery from a pore medium.

5. RESULTS AND DISCUSSIONS

The section explains findings concerning mixable and equilibrium oil displacement in the context of Perekopivske deposit. The laboratory results of oil displacement within pore medium using nitrogen have helped determine minimum pressure of mutual oil dissolving i.e. 36.0 – 38.0 MPa.

Figure 2 demonstrates a graph characterizing a process of oil displacement using nitrogen under the conditions of mutual agent mixing at 110 – 112°C temperature, 36.4 MPa pressure of gas injection, and nitrogen injection velocity being 1 cm^3 per 40 minutes. Under such conditions, oil displacement ratio achieved 0.76 – 0.78 value.

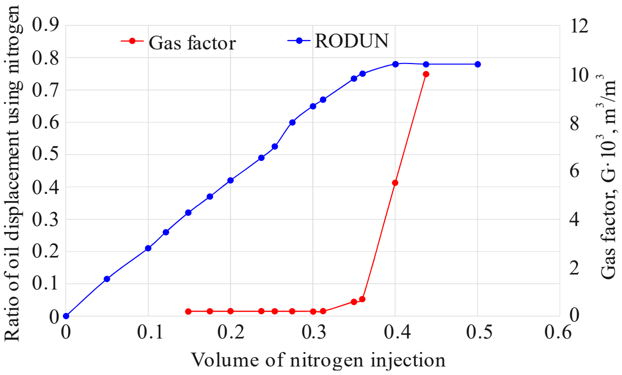

Figure 2. Dependence of the ratio of oil displacement using (RODUN) nitrogen and gas factor in the context of agent mutual dissolving (inclusive of mass transfer)

Figure 2 also demonstrates a graph of changes in a gas factor, and in composition of gas extracted from the seam model during oil displacement using nitrogen in the context of mutual dissolution of agents.

The experiment implemented simultaneously equilibrium oil displacement using nitrogen. Under such conditions, oil displacement ratio differs significantly from that one obtained in the context of experiments during mutual dissolving. It achieves 0.33 – 0.35 value (Fig. 3).

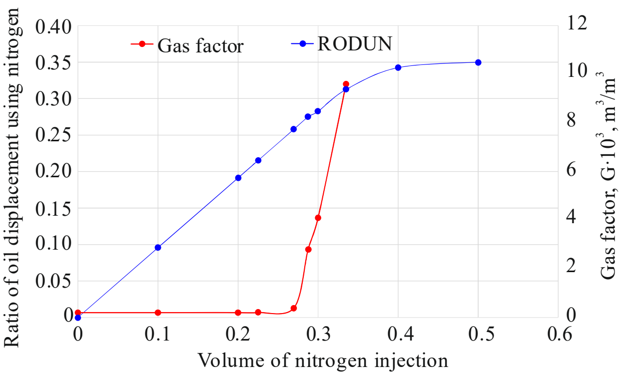

Figure 3. Dependence of the ratio of oil displacement using nitrogen (RODUN) under equilibrium conditions

However, determination of a degree of oil extraction from a seam using one of the methods (in this case, if mutual dissolving and equal importance of oil and nitrogen agents take place), cannot provide complete idea of its efficiency. Such an idea can be obtained after research implements different methods of oil recovery, and comparison of the findings. Oil displacement using water is one of the methods compared generally with others. Such a displacement was performed using seam models developed with the help of natural cores which permeability is 67 – 145·10^{-3} μm^2 under the conditions resembling maximally seam conditions of Perekopivske deposit (i.e. rock, formation fluids, seam pressure, rock pressure, and temperature). The experimental results have shown that for the moment of water inrush, the ratio of oil displacement using water is 0.52 – 0.54, achieving 0.56 value by the end of the displacement.

6. CONCLUSIONS

The experiments intended to analyze residual oil displacement using nitrogen have helped understand that in the context of oil deposits of the Dnipro-Donetsk oil-and-gas Ukrainian province, inclusive of Perekopivske deposit, mixing displacement of oil using nitrogen is the most efficient method. Moreover, it has been determined that minimum pressure of mutual oil-nitrogen dissolving is 36.0 – 38.0 MPa at 110 – 112°C temperature. Nitrogen use makes it possible to achieve high ratios of residual oil displacement, which were 0.76 – 0.78 for bulk seam models, and 0.52 – 0.56 in the context of oil displacement using water, if seam models, resembling formation conditions of Perekopivske deposit (i.e. rock, formation fluids, seam pressure, rock pressure, and temperature) were used. Such high oil displacement ratios (when average oil extraction ratio is not more than 0.3 in the context of Ukrainian oil deposits) supports extra efficiency of nitrogen use for deep oil deposits as well as the necessity to apply the proposed method at the experimental site of one of the oil deposits within the Dnipro-Donetsk oil-and-gas province in Ukraine.

ACKNOWLEDGEMENTS

The research results have been obtained with no support in the form of grants of projects. The authors express thanks to PJSC "Ukrnafta" for the possibility to carry out the experiments, which findings are represented by the paper, on the basis of Scientific-Research and Design Institute PJSC "Ukrnafta".

REFERENCES

Ahmed, T., Menzie, D., & Crichlow, H. (1983). Preliminary experimental results of high-pressure nitrogen injection for EOR systems. *Society of Petroleum Engineers Journal*, *23*(02), 339-348. https://doi.org/10.2118/10273-pa

Behzadi, S., & Towler, B.F. (2009). A new EOR method. *SPE Annual Technical Conference and Exhibition*. https://doi.org/10.2118/123866-ms

Clancy, J.P., Gilchrist, R.E., & Kroll, D.E. (1981). Nitrogen for the enhanced recovery of oil and gas. *Proceedings of SPE California Regional Meeting*, SPE-9912-MS. https://doi.org/10.2118/9912-ms

Entov, V., & Zazovskiy, A. (1989). *Gidrodinamika protsessov povysheniya nefteotdachi*. Moskva, Rossiya: Nedra.

Ermakova, P., & Eremina, N. (1996). Nagnetanie azota v poristye sredy dlya uvelicheniya nefteotdachi. *Geologiya, Geofizika i Razrabotka Neftyanykh Mestorozhdeniy*, (11), 45-51.

Evison, B., & Gilchrist, R.E. (1992). New developments in nitrogen in the oil industry. *SPE Mid-Continent Gas Symposium*, SPE-24313-MS. https://doi.org/10.2118/24313-MS
Fahandezhsaadi, M., Amooie, M.A., Hemmati-Sarapardeh, A., Ayatollahi, S., Schaffie, M., & Ranjbar, M. (2019). Laboratory evaluation of nitrogen injection for enhanced oil recovery: Effects of pressure and induced fractures. *Fuel*, (253), 607-614. https://doi.org/10.1016/j.fuel.2019.05.039
Glaso, O. (1990). Miscible displacement: Recovery tests with nitrogen. *SPE Reservoir Engineering*, *5*(01), 61-68. https://doi.org/10.2118/17378-pa
Gurevich, G., & Zazovskiy, A. (1987). Matematicheskoe modelirovanie protsessa vytesneniya nefti dymovym gazom. *Izvestiya Vysshikh Uchebnykh Zavedeniy. Neft' i Gaz*, (98), 49-54.
Heucke, U. (2015). Nitrogen injection as IOR/EOR solution for North African oil fields. *SPE North Africa Technical Conference and Exhibition*, 1-12. https://doi.org/10.2118/175730-ms
Hudgins, D.A., Llave, F.M., & Chung, F.T.H. (1990). Nitrogen miscible displacement of light crude oil: A laboratory study. *SPE Reservoir Engineering*, *5*(01), 100-106. https://doi.org/10.2118/17372-pa
Indrupskiy, I., Zakirov, E., & Kondrat, A. (2013). K povysheniyu effektivnosti uplotneniya setki skvazhin. *Neft', Gaz i Biznes*, (10), 46-52.
Jha, K.N., & Chakma, A. (1991). Nitrogen injection with horizontal wells for enhancing heavy-oil recovery: 2D and 3D model studies. *SPE Asia-Pacific Conference*, 1-10. https://doi.org/10.2118/23029-ms
Kondrat, O. (2013). The enhancement of hydrocarbon recovery from depleted gas and gas-condensate fields. *Annual Scientific-Technical Collection – Mining of Mineral Deposits 2013*, 143-148. https://doi.org/10.1201/b16354-24
Law, B.E., Ulmishek, G.F., Clayton, J.L., Kabyshev, B.P., Pashova, N.T., & Krivosheya, V.A. (1998). Basin-centered gas evaluated in Dnipro-Donetsk basin, Donbas foldbelt, Ukraine. *Oil and Gas Journal*, *96*(47), 74-78.
Lyan, M. (2016). *Fizicheskoe modelirovanie vytesneniya nefti gazom (rastvoritelem) s ispol'zovaniem kernovykh modeley plasta i slim tube*. Dissertatsiya na soiskanie uchenoy stepeni kandidata tekhnicheskikh nauk.
Mungan, N. (2000). Enhanced oil recovery with high pressure nitrogen injection, *SPE/AAPG Western Regional Meeting*, SPE-62547-MS. https://doi.org/10.2118/62547-MS
Sayegh, S.G., Wang, S.T., & Najman, J. (1987). Multiple contact phase behaviour in the displacement of crude oil with nitrogen and enriched nitrogen. *Journal of Canadian Petroleum Technology*, *26*(06), 1-10. https://doi.org/10.2118/87-06-02
Sinanan, B.S., & Budri, M. (2012). Nitrogen injection application for oil recovery in trinidad. *SPETT 2012 Energy Conference and Exhibition*, 1-11. https://doi.org/10.2118/156924-ms
Stepanova, G., & Tolokonskaya, L. (1983). Issledovanie usloviy vzaimorastvoryaimosti v nefti gazokondensatnykh sistemakh. *Trudy VNII*, (84), 115-120.
Strpić, K., Miličević, M., & Kurevija, T. (2017). Development of tight oil resources in the USA: Exploitation costs and effect of macroeconomic indicators in a volatile oil price environment. *Rudarsko Geolosko Naftni Zbornik*, *32*(3), 23-33. https://doi.org/10.17794/rgn.2017.3.3
Surguchev, M. (1989). Perspektivy primeneniya azota i dymovykh gazov dlya uvelicheniya nefteotdachi plastov. *Neftyanoe Khozyaystvo*, (2), 75-77.
Yu, Y., & Sheng, J.J. (2016). Experimental evaluation of shale oil recovery from eagle ford core samples by nitrogen gas flooding. *SPE Improved Oil Recovery Conference*, 1-8. https://doi.org/10.2118/179547-ms

ВИВЧЕННЯ МОЖЛИВОСТЕЙ ЗБІЛЬШЕННЯ КОЕФІЦІЄНТА НАФТОВИЛУЧЕННЯ ІЗ ВИКОРИСТАННЯМ АЗОТУ ДЛЯ УМОВ ГЛИБОКОЗАЛЯГАЮЧИХ НАФТОВИХ РОДОВИЩ ДНІПРОВСЬКО-ДОНЕЦЬКОЇ НАФТОГАЗОНОСНОЇ ПРОВІНЦІЇ УКРАЇНИ

О. Кондрат, О. Лукін, Л. Смоловик

Мета. Підвищення нафтовилучення глибоких нафтових родовищ Дніпровсько-Донецької нафтогазоносної провінції України з використанням азоту.

Методика. Експериментальні дослідження витіснення залишкової нафти різними витіснювальними агентами проводили шляхом лабораторного моделювання процесу зі створенням зразків пласта, максимально наближених до реального пласту, і використанням зразків пластових флюїдів. В експериментах, в яких реалізувалося рівноважне витіснення (без масопереносу), використовувалися моделі пласта, які споруджувалися з кернового матеріалу пласта В-19н Перекоповського родовища. Було досліджено 43 зразки керна, проникність сягала в межах 3.3 – $226.0 \cdot 10^{-3}$ мкм^2.

Результати. Проаналізовано особливості та умови застосування азоту й димових газів для підвищення нафтовіддачі пластів. Сформульовано теоретичні передумови механізму витіснення нафти з пласта азотом і димовими газами. Встановлено за результатами лабораторних досліджень витіснення нафти азотом у пористому середовищі мінімальний тиск взаємного розчинення нафти та азоту, котрий становить 36.0 – 38.0 МПа. В умовах взаємного змішування агентів при температурі 110 – 112°C, тиску нагнітання газу 36.4 МПа і швидкості нагнітання азоту 1 см^3 за 40 хвилин коефіцієнт витіснення нафти досягав величини 0.76 – 0.78.

Наукова новизна. Вперше встановлені параметри змішуваного витіснення нафти азотом для умов глибоких нафтових родовищ Дніпровсько-Донецької нафтогазоносної провінції України. Доведено високу ефективність змішуваного витіснення азотом в порівнянні з витісненням водою і витісненням азотом при рівноважних умовах.

Практична значимість. Запропоновано удосконалену технологію використання азоту для підвищення нафтовилучення глибоких нафтових родовищ, яка може бути використана для виснажених нафтових родовищ.

Ключові слова: *коефіцієнт нафтовилучення, азот, залишкова нафта, витіснення, тиск нагнітання*

ИЗУЧЕНИЕ ВОЗМОЖНОСТЕЙ УВЕЛИЧЕНИЯ КОЭФФИЦИЕНТА НЕФТЕОТДАЧИ С ИСПОЛЬЗОВАНИЕМ АЗОТА ДЛЯ УСЛОВИЙ ГЛУБОКОЗАЛЕГАЮЩИХ НЕФТЯНЫХ МЕСТОРОЖДЕНИЙ ДНЕПРОВСКО-ДОНЕЦКОЙ НЕФТЕГАЗОНОСНОЙ ПРОВИНЦИИ УКРАИНЫ

А. Кондрат, А. Лукин, Л. Смоловик

Цель. Увеличение нефтеотдачи глубокозалегающих нефтяных месторождений Днепровско-Донецкой нефтегазоносной провинции Украины с использованием азота.

Методика. Экспериментальные исследования вытеснения остаточной нефти разными вытесняющими агентами проводили путем лабораторного моделирования процесса с созданием образцов пласта, максимально приближенных к реальному пласту, и использованием образцов пластовых флюидов. В экспериментах, в которых реализовалось равновесное вытеснение (без масопереноса), использовались модели пласта, которые сооружались из кернового материала пласта В-19н Перекоповского месторождения. Были исследованы 43 образца керна, проницаемость находилась в пределах 3.3 – $226.0 \cdot 10^{-3}$ мкм^2.

Результаты. Проанализированы особенности и условия применения азота и дымовых газов для повышения нефтеотдачи пластов. Сформулированы теоретические предпосылки механизма вытеснения нефти из пласта азотом и дымовыми газами. Установлено по результатам лабораторных исследований вытеснения нефти азотом в пористой среде минимальное давление взаимного растворения нефти и азота, которое составляет 36.0 – 38.0 МПа. В условиях взаимного смешивания агентов при температуре 110 – 112°C, давлении нагнетания газа 36.4 МПа и скорости нагнетания азота 1 см^3 за 40 минут коэффициент вытеснения нефти достигал величины 0.76 – 0.78.

Научная новизна. Впервые установлены параметры смешиваемого вытеснения нефти азотом для условий глубокозалегающих нефтяных месторождений Днепровско-Донецкой нефтегазоносной провинции Украины. Доказана высокая эффективность смешиваемого вытеснения азотом по сравнению с вытеснением водой и вытеснением азотом при равновесных условиях.

Практическая значимость. Предложена усовершенствованная технология использования азота для повышения нефтеотдачи глубокозалегающих нефтяных месторождений, которая может быть использована для истощенных нефтяных месторождений.

Ключевые слова: *коэффициент нефтеотдачи, азот, остаточная нефть, вытеснение, давление нагнетания*

ARTICLE INFO

Received: 27 July 2019
Accepted: 11 November 2019
Available online: 4 December 2019

ABOUT AUTHORS

Oleksandr Kondrat, Doctor of Technical Sciences, Professor of the Petroleum Production Department, Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska St, 76019, Ivano-Frankivsk, Ukraine. E-mail: kondrat@nung.edu.ua

Oleksandr Lukin, PhD Student, Engineer of the Scientific-Research and Design Institute PJSC “Ukrnafta”, 2 Pivnichnyi Bulvar St, 76019, Ivano-Frankivsk, Ukraine. E-mail: alelukinnn@gmail.com

Liana Smolovyk, Candidate of Technical Sciences, Associate Professor of the Petroleum Production Department, Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska St, 76019, Ivano-Frankivsk, Ukraine. E-mail: smolovyk@gmail.com