


Increasing hydrocarbon recovery of Hadiach field by means of CO₂ injection as a part of the decarbonization process of the energy sector in Ukraine

Serhii Matkivskiy¹✉

¹ JSC “Ukrgezvydobuvannia”, Kyiv, Ukraine

*Corresponding author: e-mail matkivskij@gmail.com

Abstract

Purpose is studying the efficiency of a carbon dioxide injection technology to control a water flooding process of the reservoir of the horizon V-16 of Hadiach oil and gas condensate field and displace the residual gas reserves trapped by the formation water involving numerical modelling.

Methods. A technology of carbon dioxide injection into the reservoir of the horizon V-16 of Hadiach oil and gas condensate field was tested in terms of numerical reservoir model with the use of basic modelling instruments.

Findings. The modelling results makes it possible to calculate the main technological indices of the development of the reservoir of the horizon V-16 of Hadiach oil and gas condensate field in terms of carbon dioxide injection and while developing for depletion. According to the results of the performed calculations, it is identified that there is considerable influence of the number of injection wells on the efficiency of the analyzed technology as for control of a water flooding process in the productive formation. It should be noted that while increasing the number of injection wells, more complete coverage of the gas-bearing area with carbon dioxide is provided; owing to that, the efficiency of blocking the formation water inflow into the production wells turns to be much higher. The implementation of the technology under study makes it possible to increase the final hydrocarbon recovery factors. In case of using wells ## 52, 101, 201, 202 for carbon dioxide injection, the highest final hydrocarbon recovery factors are provided. The predictive gas recovery factor grows by 2.95% and the condensate recovery factor increases by 1.24% comparing to the field development for depletion.

Originality. Basing on the research results, technological efficiency of the implementation of a carbon dioxide injection technology in terms of the reservoir of the horizon V-16 of Hadiach oil and gas condensate field is determined; that is aimed at increasing the hydrocarbon recovery within the field by controlling a water flooding process in the productive formations and production wells.

Practical implications. Application of the research results helps improve the current system of the development of productive formations of Hadiach oil and gas condensate field in terms of water drive. Implementation of such technologies stipulates the increase in final hydrocarbon recovery of the depleted fields and allows developing optimal ways of utilization of technogenic carbon dioxide in terms of the whole decarbonization process of the energy sector in Ukraine.

Keywords: 3D model, hydrocarbon field, gas condensate reservoir, water drive, carbon dioxide injection

1. Introduction

Development of human society is based on the production of material and spiritual benefits, which totality stipulates favourable conditions for human activities. Since the industrial revolution and up to now, coal, oil, and gas are still the main sources of energy generation [1].

Coal is a relatively cheap product being widely used for electric energy generation. Thermal power plants are characterized by high reliability; they produce about 40% of the world electric energy. However, combustion of fossil fuels results in harmful emissions of flue gases into the atmosphere – the gases with high carbon dioxide content [2].

Currently, the environmental problem is clearly seen being of great topicality as the environmental pollution with

industrial wastes has reached its peak. High concentration of carbon dioxide in the atmosphere deteriorates the risks for human health and activity.

One of the possible ways to reduce concentration of greenhouse gases in the atmosphere is the reduction of a share of fossil fuel in the process of electric energy generation and transition to the alternative renewable sources of energy. Nowadays, highly developed countries are basing their economies on the developing renewable energetics. Use of solar, wind, hydro- and electric plants is excluding gradually the traditional methods of electric energy production by fossil fuel combustion.

The renewable energy sources are the promising methods for reducing the level of environmental pollution and controlling all the negative aftereffects for humanity in general.

Received: 12 February 2021. Accepted: 22 February 2022. Available online: 30 March 2022

© 2022, S. Matkivskiy

Mining of Mineral Deposits. ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted reuse, distribution, and reproduction in any medium, provided the original work is properly cited.

Using various renewable energy sources, it is possible to get the amount of energy being several times more than it is necessary for consumption. That is the reason why such renewable energy sources should be considered in the short term as the main energy sources taking into account their reliability and safety for the humanity [3].

To reduce industrial emissions of carbon dioxide into the atmosphere, one should shorten energy consumption by investing into the increased energy efficiency and infrastructure development. Nevertheless, those measures will be not enough; thus, rapid capture and reliable storage of carbon dioxide are the obligatory conditions as well. There are numerous technologies of carbon dioxide capture characterized by high technological efficiency and being applied successfully worldwide [2].

Equipping of the large power-consuming enterprises with the technologies of carbon dioxide capture stipulates the necessity of searching for the ways of its utilization. A prospective method of carbon dioxide recovery is its injection into the depleted oil fields aimed at hydrocarbon recovery growth.

Most natural gas fields in Ukraine, which provide the main share of natural gas recovery, have entered their final stage of development [4], [5]. The specific features of the final development stage are represented by low formation pressure, selective water flooding of the productive formations, liquid accumulation on the well bottomhole, corrosion of ground and underground equipment etc. [6], [7].

Oil and gas fields are mainly multilayered consisting of reservoir seams being nonuniform in their permeability [8]. As the industrial practice of hydrocarbon deposit development shows, production wells are usually located nonuniformly within the gas-bearing area with their concentration in the central part. Under such conditions, one can observe nonuniform water influx into a water-saturated zone with the advancing movement of a displacement front in terms of the most permeable and drained formations. Within the watered part of the formations, there are certain sites with high gas saturations being not affected by the water [9], [10].

Along with the problem of control of edge water inflowing into a gas-saturated share of the formation, the trapped gas recovery from watered formations is quite a topical issue in the context of gas production increase [11].

Numerous studies have confirmed that the highest technical and economic indices of development can be reached in case of active influence on the water drive of the productive formation development. The recommended measures are to be implemented from the moment of the formation water showing in the well production. However, secondary hydrocarbon recovery from the depleted and watered formations is also one of the possible trends in hydrocarbon recovery improvement [12], [13].

Depleted gas and gas condensate fields are usually characterized by much lower reservoir pressure comparing to the pressure in a water drive system. Considerable differentiation of the reservoir pressures stipulates the formation water movement towards the lower resistance. Owing to that, even when the field development is over, one can observe water flooding of gas-saturated formations.

Such a process results in further compression of the residual micro- and macrotrapped gas in a porous medium due to reduced reservoir pressure and its decreased volume. Taking the aforementioned into consideration, a solution concerning the expediency of implementing secondary hydrocarbon recovery should be taken quickly as delay in the recommended measures results in the deteriorated efficiency of the technology being implemented and causes future production of great formation water volumes [7].

The results of laboratory and experimental studies have demonstrated high efficiency of secondary hydrocarbon recovery by injecting non-hydrocarbon gases (nitrogen, carbon dioxide, flue and exhaust gases, mixtures of different gases) into the productive formations [14]-[18].

A technology of carbon dioxide injection into productive formations is one of the effective techniques of hydrocarbon recovery [19]-[21].

The results of numerous studies concerning a process of carbon dioxide injection for deceleration of the edge water flow and residual gas displacement prove its efficiency. The implementation of non-hydrocarbon gas injection at any stage of deposit development under conditions of water drive mode helps provide the increased hydrocarbon recovery [22], [23].

First, carbon dioxide injection was performed in the USA (State of New-York) in 1949. The studies turned to be positive; thus, the research area was expanded for ten more USA hydrocarbon fields. Industrial studies were carried out mostly within the oil fields.

In 1964, the Union Oil Company implemented a technology of carbon dioxide injection into an oil field at Mead-Strawn field. The operation results helped reach the increased final factor of hydrocarbon recovery being 35% [24]. Since then, a technology of carbon dioxide injection into oil fields has been used successively worldwide.

Pilot projects as for implementation of carbon dioxide injection technology for increased oil recovery from Canadian fields were being implemented within the period of 1983-1984 at Weyburn and Joffre Viking deposits [25], [26].

Carbon dioxide as an injection agent started to be applied in Hungary at Budafa field in 1969 [27]. Norway uses the carbon dioxide injection technology to increase final coefficients of hydrocarbon recovery from the productive formations located under the Northern Sea floor [28].

In the USSR, industrial implementation of oil displacement by carbon dioxide started within the northern part of Tuimazinske field in 1971 and proved high efficiency of displacing residual hydrocarbon reserves by non-hydrocarbon gases [29].

As a rule, implementation of the technology of carbon dioxide injection does not require considerable costs as certain primary and secondary methods of hydrocarbon recovery have been already applied at most reservoirs. Consequently, the previously developed infrastructure can be used for the technologies of carbon dioxide injection as well.

To stabilize and improve the levels of natural gas recovery, a critical analysis of the depleted state of main fields of Dnieper-Donets Depression has been performed.

Hadiach oil and gas condensate field belongs to the prospective Ukrainian hydrocarbon fields characterized by the considerable energy potential and developed under conditions of water drive of the productive formation development.

According to the results of the analysis of Hadiach field development history, to implement the carbon dioxide injection technology it is recommended to use formations of reservoir of the horizon V-16; that is aimed at stabilization of hydrocarbon recovery and increase in final factors of hydrocarbon recovery.

The research objective is to study the efficiency of carbon dioxide injection technology to control a process of water flooding of the reservoir of the horizon V-16 of Hadiach oil and gas condensate field and displace residual gas involving numerical modelling.

To achieve the specified objective, it is necessary to solve the following problems:

1. To analyze the influence of a network of injection wells on the water drive activity in terms of carbon dioxide injection into the reservoir of the horizon V-16.
2. To study the effect of number of injection wells on the gas recovery factor of the reservoir of the horizon V-16 of Hadiach oil and gas condensate field.

2. Research methodology

The studies concerning the increase in final hydrocarbon recovery from the reservoir of the horizon V-16 of Hadiach field involved the tools of modelling Eclipse and Petrel by the Schlumberger Company (the USA). The studies are carried out on the simulation model of Hadiach oil and gas condensate field. A conceptual 3D model of the reservoir of the horizon V-16 of Hadiach oil and gas condensate field is represented in Figure 1.

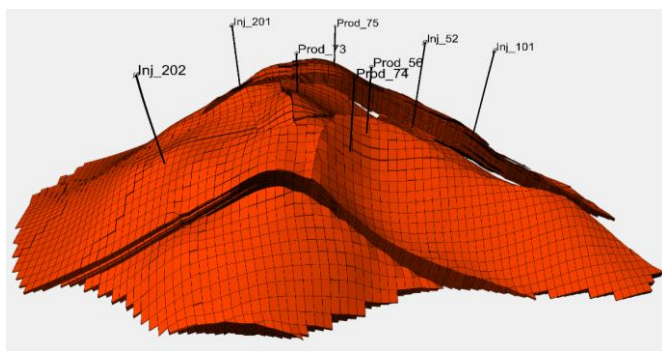


Figure 1. Conceptual 3D model of the reservoir of the horizon V-16 of Hadiach oil and gas condensate field

To represent physical processes occurring within the productive formation during the carbon dioxide injection, a compositional PVT-model has been developed with the use of PVTi module and Eclipse software [30].

A gas condensate formation is developed for depletion involving 4 production wells (## 56, 73, 74, 75). While applying a continuously acting technological model of Hadiach oil and gas condensate field, which is adapted for actual data of the development history, the localization of residual reserves of gas trapped by the formation water was defined. Having identified the sites of productive formation with high residual gas-bearing characteristics, a series of injection wells was selected, which use would help cover the greatest amount of residual trapped reserves of natural gas by means of displacement. Wells ## 52, 101, 201, 202 were selected for carbon dioxide injection. The non-hydrocarbon gas was pumped into a productive formation with the flow rate of 50 thousand m³/day per one well. The gas flow rate of a production well was 50 thousand m³/day.

Duration of a period of non-hydrocarbon gas injection is 16 months. A productive formation is being developed up to the moment of carbon dioxide breakthrough into the last production well.

To analyze the influence of different number of injection wells and their spatial location within the formation area on

the gas recovery factor, 5 case of productive formation development with carbon dioxide injection were elaborated:

- case 1 – carbon dioxide is injected into the reservoir of the horizon V-16 with the use of wells ## 52, 201;
- case 2 – carbon dioxide is injected into the reservoir of the horizon V-16 with the use of wells ## 52, 202;
- case 3 – carbon dioxide is injected into the reservoir of the horizon V-16 with the use of wells ## 101, 202;
- case 4 – carbon dioxide is injected into the reservoir of the horizon V-16 with the use of wells ## 201, 202;
- case 5 – carbon dioxide is injected into the reservoir of the horizon V-16 with the use of wells ## 52, 101, 201, 202;

Figure 2 represents a scheme of location of injection wells within the area of gas-bearing reservoir of the horizon V-16 of Hadiach oil and gas condensate field.

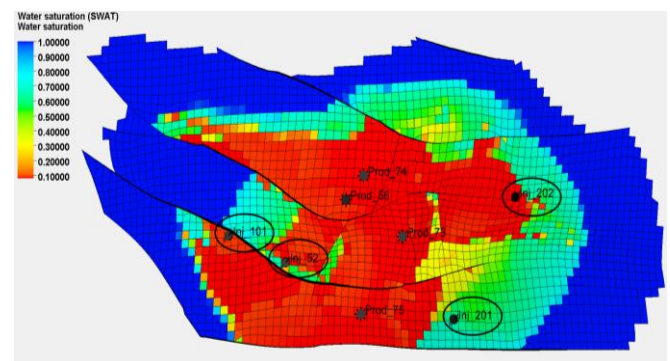


Figure 2. Scheme of location of injection and production wells within the area of gas-bearing reservoir of the horizon V-16 of Hadiach oil and gas condensate field

While studying the cases of non-hydrocarbon gas injection into the reservoir of the horizon V-16, a moment of carbon dioxide breakthrough into each of the production wells was recorded. Use of different number and spatial location of a network of injection wells stipulates different duration of the operating period of production wells up to the moment of carbon dioxide breakthrough. In case of the variant of productive formation development for depletion, productive wells stopped at the same moment of time like during the formation development with carbon dioxide injection. Taking into consideration the abovementioned for each case of the field development with carbon dioxide injection, a case of development for depletion was calculated according to the duration of the operating period of production wells stipulated by different density and location of a network of injection wells.

The results of conducted studies helped calculate the main technical indices of the development of a productive formation at the moment of carbon dioxide breakthrough into one of the production wells in terms of the value of recovered formation water at the moment of its breakthrough. The research results were processed in the form of table and graphic dependences of the parameters under consideration at the moment of carbon dioxide breakthrough depending on the number and spatial location of the injection wells.

3. Results and discussion

Applying a constantly functioning geological and technological model of Hadiach oil and gas condensate field, the efficiency of a technology of carbon dioxide injection for the conditions of the reservoir of the horizon V-16 has been studied.

While analyzing the modelling results, it is determined that carbon dioxide injection into the reservoir of the horizon V-16 of Hadiach oil and gas condensate field involving different number of injection wells helps support the reservoir pressure at much higher level comparing with the field development for depletion. According to the calculation results, the highest values of the reservoir pressure are reached at carbon dioxide injection with the use of 4 injection wells (## 52, 101, 201, 202). The reservoir pressure dynamics for different injection wells while carbon dioxide injecting into the reservoir of the horizon V-16 is represented in Figure 3.

The nature of reservoir pressure dynamics in time depending on the number of injection wells is stipulated by intense advance of formation water into the formation and disconnection of production wells due to water flooding or carbon dioxide breakthrough. In case of well shutdown due to one of the indicated reasons, extraction of natural gas from the formation is reduced resulting in decreased rate of the reservoir pressure drop. While analyzing the reservoir pressure dynamics, it should be noted that when the last production well stops, the reservoir pressure experiences its increase in time. Such a nature of the dependences is stipulated by further advance of edge water into the gas-saturated formations of the productive formation and balancing of a hydrodynamic system.

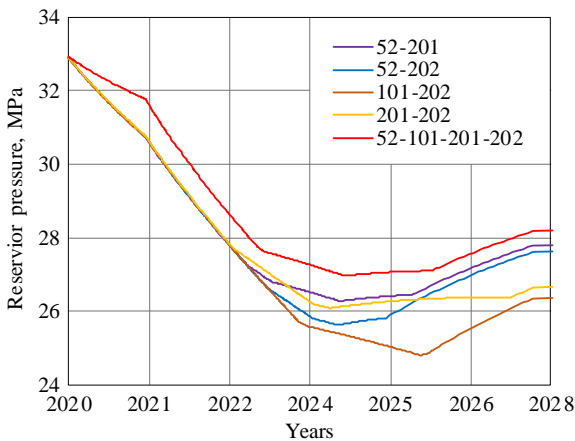


Figure 3. Dynamics of the reservoir pressure while injecting carbon dioxide into the reservoir of the horizon V-16 of Hadiach oil and gas condensate field for different number of injection wells

Basing on the performed calculations of the main technological parameters of the reservoir of the horizon V-16 development, the influence of the number of injection wells on the water drive system activity has been analyzed.

Figure 4 shows the dynamics of the cumulative water production while carbon dioxide injecting into the reservoir of the horizon V-16 for different number of injection wells.

According to the calculation results, it has been defined that the least amount of water is produced in case of using wells ## 52, 202 for injection; it is 8.52 thousand m³. If wells ## 52, 201 are used for injection, then the highest water production is provided being 9.89 thousand m³.

The obtained results of the dynamics of cumulative formation water production are explained by different water flooding degree of the zone, into which non-hydrocarbon gas is injected. Different location of injection wells within the gas-bearing area relative to current gas-water contact stipulates different volumes of formation water in front of the injection front.

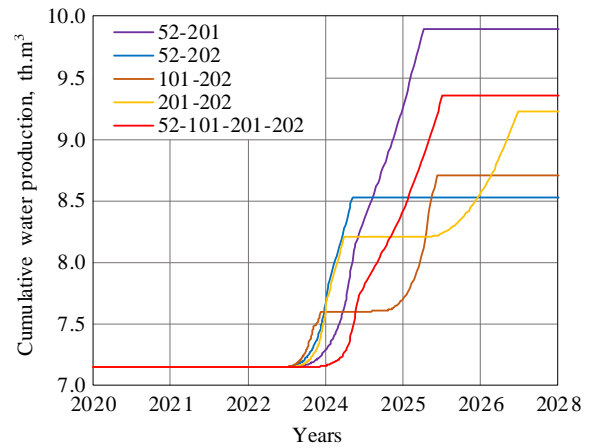


Figure 4. Dynamics of the cumulative formation water production while carbon dioxide injecting into the reservoir of the horizon V-16 of Hadiach oil and gas condensate field for different number of injection wells

The farther the injection well is from the current gas-water contact, the more water with the trapped gas is displaced owing to the carbon dioxide injection.

The results of the conducted studies have helped identify that different number of injection wells while carbon dioxide injecting into the formation influences considerably the duration of operating period of production wells up to its breakthrough.

While analyzing the results of calculations of technological indices of the reservoir of the horizon V-16 development, it has been determined that the ratio of distances between production and injection wells has great effect on the duration of production wells operation. The closer the production well is to the injection one, the faster the injection agent breakthrough happens.

The research results make it possible to state that number of injection wells influences significantly the natural gas and condensate recovery. Basing on the modelling results, predictive factors of gas and condensate recovery were calculated at the moment of carbon dioxide breakthrough into the production wells and while field developing for depletion. The predictive coefficients of hydrocarbon recovery were calculated in terms of the value of formation water production at the moment of carbon dioxide breakthrough into the production wells.

Tables 1-2 demonstrate the generalized results of calculation of hydrocarbon recovery factors while carbon dioxide injecting into the reservoir of the horizon V-16 of Hadiach oil and gas condensate field and while developing the formation for depletion according to the considered cases of development.

Basing on the generalized results of the calculations as for the considered development cases, it has been defined that the final gas recovery factor in terms of residual gas while carbon dioxide injecting into the reservoir of the horizon V-16 varies from 31.71 to 37.42%; the condensate recovery factor varies from 7.44 to 8.23%.

While developing the reservoir of the horizon V-16 for depletion under these conditions, lower values of hydrocarbon recovery factors are reached: the final factor of gas recovery is 29.57-36.11%; the condensate recovery factor is 6.68-7.69%. The research results indicate the technological efficiency of the implementation of carbon dioxide injection for the Hadiach field conditions.

Table 1. Results of calculations of the gas recovery factors while carbon dioxide injecting into the reservoir of the horizon V-16 of Hadiach oil and gas condensate field and while developing the formation for depletion

Cases	List of injection wells	Gas recovery factor (from the residual reserves), %		Δ , %	Gas recovery factor (from the initial reserves), %		Δ , %
		Injection	Depletion		Injection	Depletion	
1	52, 201	31.71	29.57	2.14	76.03	75.28	0.75
2	52, 202	32.82	31.49	1.33	76.42	75.95	0.47
3	101, 202	37.42	36.11	1.31	78.04	77.57	0.47
4	201, 202	35.33	34.21	1.12	77.30	76.91	0.39
5	52, 101, 201, 202	32.56	29.61	2.95	76.33	75.29	1.04

Table 2. Results of calculations of the condensate recovery factors while carbon dioxide injecting into the reservoir of the horizon V-16 of Hadiach oil and gas condensate field and while developing the formation for depletion

Cases	List of injection wells	Condensate recovery factor (from the residual reserves), %		Δ , %	Condensate recovery factor (from the initial reserves), %		Δ , %
		Injection	Depletion		Injection	Depletion	
1	52, 201	7.44	6.68	0.76	41.31	40.83	0.48
2	52, 202	7.50	6.97	0.53	41.35	41.02	0.34
3	101, 202	8.23	7.69	0.54	41.81	41.47	0.34
4	201, 202	8.12	7.50	0.62	41.74	41.35	0.40
5	52, 101, 201, 202	7.92	6.68	1.24	41.62	40.83	0.79

According to the performed calculations for the first case of development at carbon dioxide injection involving injection wells ## 52, 201, the technology under consideration provides the effect at the level of 2.14% from the value of residual gas reserves. The condensate recovery factor in this context increases by 0.76% from the value of residual condensate reserves.

While analyzing the second case involving wells ## 52, 202 for injection, it has been determined that the carbon dioxide injection into the reservoir of the horizon V-16 helps increase a gas recovery factor by 1.33% and a condensate recovery factor – by 0.53% in terms of the residual reserves.

The third case of the horizon V-16 means carbon dioxide injection with the use of wells ## 101, 202. According to this case, the predictive effect from the technology implementation is 1.31% in terms of the residual gas reserves. Owing to carbon dioxide injection into the formation and maintenance of the reservoir pressure at a higher level comparing to the development for depletion, it is possible to increase the condensate recovery factor by 0.54% from the value of the residual condensate reserves.

The carried out calculations of the fourth case of the development of the horizon V-16 field with the use of injection wells ## 201, 202 has made it possible to provide 1.12% increase in the predictive gas recovery factor and 0.62 increase in the condensate recovery factor in terms of the residual hydrocarbon reserves.

According to the fifth case of development, carbon dioxide is injected into the formation involving four injection wells (# 52, 101, 201, 202). Having analyzed the calculation results, it is identified that carbon dioxide injection makes it possible to increase the final gas recovery factor by 2.95% comparing to the case of deposit development for depletion. In this context, the final condensate recovery factor grows by 1.24%.

Generalizing the main technological parameters of the development of the reservoir of the horizon V-16 of Hadiach oil and gas condensate field that differ in the number of injection wells, it has been defined that the fifth case demonstrates the greatest technological efficiency of carbon dioxide injection into a productive gas condensate formation.

Figures 5 and 6 show dynamics of gas and condensate recovery while carbon dioxide injecting in terms of the fifth case of development and during the development for depletion.

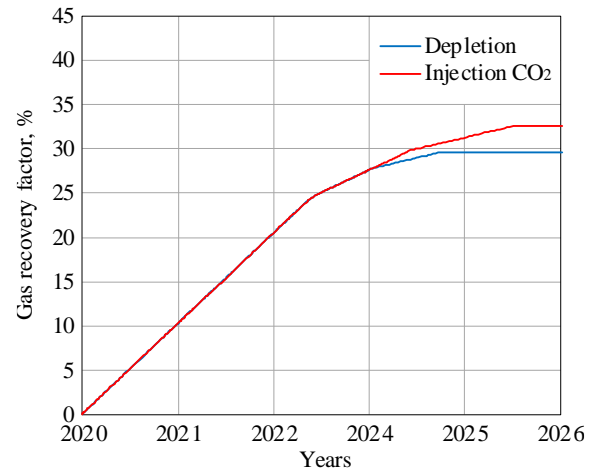


Figure 5. Dynamics of the gas recovery factor while carbon dioxide injecting into the reservoir of the horizon V-16 according to the fifth case and during the development for depletion

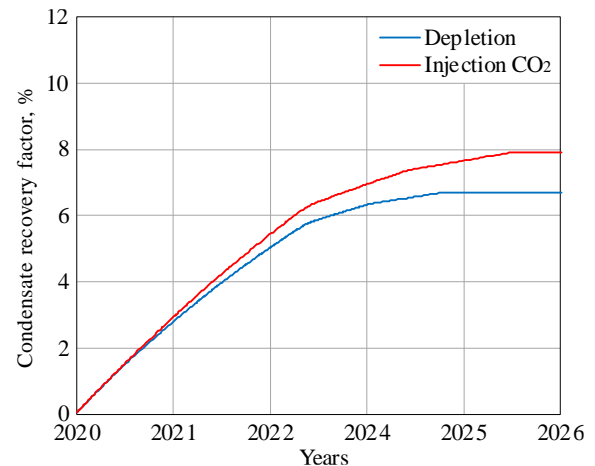


Figure 6. Dynamics of the condensate recovery factor while carbon dioxide injecting into the reservoir of the horizon V-16 according to the fifth case and during the development for depletion

The results of conducted studies demonstrate high technological efficiency of the implementation of secondary technologies to increase the final hydrocarbon recovery factor of depleted oil and gas fields with the use of carbon dioxide.

4. Conclusions

Application of the modelling instruments has helped analyze the efficiency of implementation of primary and secondary methods to increase the final hydrocarbon recovery from the depleted oil and gas fields involving carbon dioxide.

The research results based on a 3D model of Hadiach oil and gas condensate field demonstrate high technological efficiency of carbon dioxide injection into the reservoir of the horizon V-16 aimed at its increased hydrocarbon recovery by controlling a process of water flooding in the production wells. Owing to the technology implementation, it is possible to create both hydrodynamic and artificial barrier on the way of the formation water flow within the area of carbon dioxide injection. Thus, one can obtain reduced cumulative formation water production along with the continuing period of stable waterless operation of the production wells.

According to the modelling results, it has been identified that the denser a network of injection wells is, the greater the gas-bearing area covered with carbon dioxide is; consequently, the much higher efficiency of the analyzed technology is, concerning the blocking of a process of formation water inflow into a productive formation.

The calculation results has helped specify that implementation of the technology of carbon dioxide injection into the reservoir of the horizon V-16 of Hadiach oil and gas condensate field provides increase in final hydrocarbon recovery comparing to the reservoir development for depletion. According to the calculation results, the final natural gas recovery factor grows by 2.95% and the condensate recovery factor increases by 1.24% in terms of the value of residual hydrocarbon reserves.

The world practice of the application of carbon dioxide injection confirms the efficiency of this method for increasing hydrocarbon recovery of depleted oil and gas fields if there is some reliable source of its supply.

As for Ukraine, it has numerous energy-intensive enterprises producing the combustion products with high carbon dioxide content with further considerable environmental impact. Relying on the fact that climatic norms are growing much tighter and harder year by year, in the future it is necessary to capture technogenic carbon dioxide and develop optimal methods of its utilization.

Use of carbon dioxide in oil and gas field is a promising trend within the whole process of decarbonization of Ukrainian energy sector. It should be noted that in this case carbon dioxide acts as a useful product that helps increase the final hydrocarbon recovery factors.

Injection of technogenic carbon dioxide into the productive formations in terms of different technological schemes will make it possible to increase final hydrocarbon recovery of depleted oil fields and reduce the environmental load.

Acknowledgements

The research results were obtained without any support in the form of grants or projects. The authors express their gratitude to the company JSC "UkrGasvydobuvannya" for the possibility to carry out the research, which results are represented in this paper.

References

[1] Uiriski, K. (2013). *Ulovlivannia ta zberihannia vuhletsiu: Ukrainski perspektivy dlia promyslovosti ta zabezpechennia enerhetychnoi bezpeky*. Oslo, Norvehiia: Mizhnarodne ekolohichne obiednannia "Bil-lona", 48 s.

[2] Kuzovkin, V.V. (2001). Modelirovaniye protsessov vybrosov SO₂ i zakhroneniya ughleroda pri neenergeticheskom ispol'zovanii topliva. *Zashchita Okruzhayushchey Sredy v Neftegazovom Komplekse*, (1), 34-38.

[3] Kudria, S.A. (2015). Stan ta perspektivy rozvytku vidnovlyuvanoi enerhetyky v Ukraini. *Visnyk NAN Ukrainy*, (12), 19-26.

[4] Matkivskiyi, S., & Burachok, O. (2022). Impact of reservoir heterogeneity on the control of water encroachment into gas-condensate reservoirs during CO₂ injection. *Management Systems in Production Engineering*, 30(1), 62-68. <https://doi.org/10.2478/mspe-2022-0008>

[5] Kondrat, R.M., Doroshenko, V.M., & Kondrat, O.R. (2007). Osoblyvosti zavershalnoi stadii rozrobky rodovyschch nafty i hazu. *Naftohazova Enerhetyka*, (1), 17-21.

[6] Matkivskiyi, S., & Khaidarova, L. (2021). Increasing the productivity of gas wells in conditions of high water factors. In *Materials of the Eastern Europe Subsurface Conference* (pp. 1-16). Kyiv, Ukraine. <https://doi.org/10.2118/208564-MS>

[7] Kondrat, R.M. (1992). *Hazokondensatootdacha plastov*. Moskva, Rossiya: Nedra, 255 s.

[8] Romi, A., Burachok, O., Nistor, M.L., Spyrou, C., Seilov, Y., Djuraev, O., & Matkivskiyi, S. (2020). Advantage of stochastic facies distribution modeling for history matching of multi-stacked highly-heterogeneous field of Dnieper-Donetsk basin. *Petroleum Geostatistics*, (2019), 1-5. <https://doi.org/10.3997/2214-4609.201902188>

[9] Kondrat, R.M. (2005). Aktyvnyi vplyv na protsesy rozrobky rodovyschch pryrodnykh haziv z vodonapirnym rezhymom dlia zbilshennia hazokondensatovyluchennia. *Nauka ta Innovatsiyyi*, 1(5), 12-23. <https://doi.org/10.15407/scin1.05.012>

[10] Boyko, V.S., Kondrat, R.M., & Yaremychuk, R.S. (1996). *Dovidnyk z naftohazovoi spravy*. Lviv, Ukraina: Svit, 620 s.

[11] Rassokhin, G.V. (1997). *Zavershayushchaya stadiya razrobki gazovykh i gazokondensatnykh mestorozhdeniy*. Moskva, Rossiya: Nedra, 184 s.

[12] Zakirov, S.N., Korotayev, Yu.P., Vyakhirev, R.N., Kondrat, R.M., & Gordon, V.Ya. (1981). *Aktivnoe vozdeystvie na vodonapirnyy rezhim s tsellyu uvelicheniya komponentootdachi plasta*. Moskva, Rossiya: VNIIE Gazprom, 34 s.

[13] Zakirov, S.N. (1989). *Teoriya i proyektirovanie razrobki gazovykh i gazokondensatnykh mestorozhdeniy*. Moskva-Leningrad, Rossiya: Nedra, 334 s.

[14] Matkivskiyi, S., & Kondrat, O. (2021). The influence of nitrogen injection duration at the initial gas-water contact on the gas recovery factor. *Eastern-European Journal of Enterprise Technologies*, 1(6(109)), 77-84. <https://doi.org/10.15587/1729-4061.2021.224244>

[15] Yeske, G.A., & Volik, A.I. (2015). Issledovanie vliyaniya zakachki vykhopnykh gazov na koeffitsient izvlecheniya kondensata. *Neftegazovoye Delo*, 13(2), 94-99.

[16] Sim, S.S.K., Brunelle, P., Turta, A.T., & Singhal, A.K. (2008). Enhanced gas recovery and CO₂ sequestration by injection of exhaust gases from combustion of bitumen. *SPE Symposium on Improved Oil Recovery*. <https://doi.org/10.2118/113468-MS>

[17] Sim, S.S.K., Turtata, A.T., Singhal, A.K., & Hawkins, B.F. (2008). Enhanced gas recovery: Factors affecting gas-gas displacement efficiency. *Canada International Petroleum Conference*, 1-14. <https://doi.org/10.2118/2008-145>

[18] Mamora, D.D., & Seo, J.G. (2002). Enhanced gas recovery by carbon dioxide sequestration in depleted gas reservoirs. *SPE Technical Conference and Exhibition*, 1-9. <https://doi.org/10.2118/77347-MS>

[19] Matkivskiyi, S., & Kondrat O. (2021). Studying the influence of the carbon dioxide injection period duration on the gas recovery factor during the gas condensate fields development under water drive. *Mining of Mineral Deposits*, 15(2), 95-101. <https://doi.org/10.33271/mining15.02.095>

[20] Oldenburg, C.M., Law, D.H., Gallo, Y.L., & White, S.P. (2003). Mixing of CO₂ and CH₄ in gas reservoirs: Code comparison studies. *Greenhouse Gas Control Technologies – 6th International Conference*, 443-448. <https://doi.org/10.1016/B978-008044276-1/50071-4>

[21] Matkivskiyi, S., Kondrat, O., & Burachok, O. (2020). Investigation of the influence of the carbon dioxide (CO₂) injection rate on the activity of the water pressure system during gas condensate fields development. *E3S Web of Conferences*, (230), 01011. <https://doi.org/10.1051/e3sconf/202123001011>

[22] Al-Hashami, A., Ren, S.R., & Tohidi, B. (2005). CO₂ injection for enhanced gas recovery and geo-storage: Reservoir simulation and economics. *All Days*, 1-7. <https://doi.org/10.2118/94129-MS>

[23] Turta, A.T., Sim, K., Singhal, A.K., & Hawkins, B.F. (2008). Basic investigations on enhanced recovery by gas-gas displacement. *Journal of Canada Petroleum Technology*, 47(10), 1-6. <https://doi.org/10.2118/08-10-39>

[24] Holm, L.W., & O'Brien, L.J. (1971). Carbon dioxide test at the Mead-Strawn field. *Journal of Petroleum Technology*, 23(04), 431-442. <https://doi.org/10.2118/3103-PA>

- [25] Malik, Q.M., & Islam, M.R. (2000). CO₂ injection in the Weyburn field of Canada: Optimization of enhanced oil recovery and greenhouse gas storage with horizontal wells. *Journal of Canada Petroleum Technology*, 39(09), 1-7. <https://doi.org/10.2118/00-09-01>
- [26] Pyo, K., Damian-Diaz, N., Powell, M., & Van Nieuwkerk, J. (2003). CO₂ flooding in Joffre Viking pool. *Canadian International Petroleum Conference*, 1-30. <https://doi.org/10.2118/2003-109>
- [27] Doleschall, S., Szittar, A., & Udvardi, G. (1992). Review of the 30 years' experience of the CO₂ imported oil recovery projects in Hungary. *International Meeting on Petroleum Engineering*. <https://doi.org/10.2118/22362-MS>
- [28] Agustssen, H., & Grinestaff, G.H. (2004). A study of IOR by CO₂ injection in the Gullfaks Field, Offshore Norway. *All Days*, 1-14. <https://doi.org/10.2118/89338-MS>
- [29] Zhuze, T.P. (1981). *Rol' szhatykh gazov kak rastvoriteley*. Moskva, Rossiya: Nedra, 165 s.
- [30] Whitson, C.H., & Brule, M.R. (2000). *Phase behavior*. Richardson, United States: SPE Monograph Series. <https://doi.org/10.2118/3103-PA>

Підвищення вуглеводневилучення Гадяцького родовища шляхом нагнітання CO₂ в рамках процесу декарбонізації енергетичного сектору України

С. Матківський

Мета. Дослідження ефективності технології нагнітання діоксиду вуглецю для регулювання процесу обводнення покладу горизонту В-16 Гадяцького нафтогазоконденсатного родовища та витіснення залишкових запасів газу защемлених пластовою водою із використанням чисельного моделювання.

Методика. Апробація технології нагнітання діоксиду вуглецю у поклад горизонту В-16 Гадяцького нафтогазоконденсатного родовища проводилася на основі постійно діючої геолого-технологічної моделі родовища з використанням основних інструментів цифрового моделювання.

Результати. На основі результатів моделювання здійснено розрахунок основних технологічних показників розробки покладу горизонту В-16 Гадяцького нафтогазоконденсатного родовища при нагнітанні діоксиду вуглецю та при розробці на виснаження. За результатами проведених розрахунків встановлено значний вплив щільності сітки нагнітальних свердловин на ефективність досліджуваної технології щодо регулювання процесу обводнення продуктивного покладу. Варто зазначити, при збільшенні щільності сітки нагнітальних свердловин забезпечується більш повне охоплення площі газоносності діоксидом вуглецю, внаслідок чого проявляється значна ефективність блокування процесу надходження пластової води до видобувних свердловин. Завдяки впровадженню досліджуваної технології забезпечується підвищення кінцевих коефіцієнтів вуглеводневилучення. У випадку використання для нагнітання діоксиду вуглецю свердловин №№ 52, 101, 201, 202 забезпечуються найвищі кінцеві коефіцієнти вуглеводневилучення. Прогнозний коефіцієнт вилучення газу збільшується на 2.95%, а коефіцієнт вилучення конденсату – на 1.24% порівняно з розробкою покладу на виснаження.

Наукова новизна. На основі результатів проведених досліджень встановлено технологічну ефективність впровадження технології нагнітання діоксиду вуглецю для умов покладу горизонту В-16 Гадяцького нафтогазоконденсатного родовища з метою підвищення його вуглеводневилучення шляхом регулювання процесу обводнення продуктивних пластів та видобувних свердловин.

Практична значимість. Використання результатів проведених досліджень дозволяє вдосконалити існуючу систему розробки продуктивних покладів Гадяцького нафтогазоконденсатного родовища в умовах прояву водонапірного режиму. Впровадження такого роду технологій обумовлює підвищення кінцевого вуглеводневилучення виснажених родовищ та дозволяє напрацювати оптимальні шляхи утилізації техногенного діоксиду вуглецю в рамках всього процесу декарбонізації енергетичного сектору України.

Ключові слова: 3D модель, родовище вуглеводнів, газоконденсатний поклад, водонапірний режим, нагнітання діоксиду вуглецю