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THE RATIONALE FOR CARBON DIOXIDE INJECTION INTO THE HIGH VISCOSITY OIL ROCK FORMATIONS

A. A. Makhmutov[1], R. U. Rabaev[1], M. O. Abdullah Neiser[2], Sh. Kh. Sultanov[1]*

[1]*Ufa State Petroleum Technological University, Ufa, Russia*

[2]*Yemen Oil and Minerals Investment Company, Sanaa, Yemen*

ABSTRACT

In this article the researchers have studied oil recovery processes under CO_2 injection into non-homogeneous production banks with the use of a compositional hydrodynamic model. GHDM calculations has shown that at the reservoir conditions there will be mutual dissolution of oil and gas while injecting carbon dioxide. Oil-to-gas and gas-to-oil partial mass transfer will occur during oil displacement. The operational benefit will come as a result of reduced oil viscosity, greater cover ratio (reduced water-to-oil phase fluidity), and displacement coefficient (reduced surface tension). This benefit will amount to 8.5 tons of extra oil recovered.

Keywords: porosity; boundary surface tension; geological hydrodynamic model; carbon dioxide.

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One of the most promising pathways in optimization of high viscosity oil field development and oil recovery improvement is carbon dioxide injection into pay zones. This can be attributed to the fact that while using CO_2, unlike other gases, the following processes take place [1-3, 6-8]:

- Oil viscosity reduction and stratum water viscosity increase (i.e. the effect of viscosity change);
- Oil volume gain (i.e. bulk effect);
- Capillary force weakening due to CO_2 and oil mixing (i.e. mixing and displacement effect);
- Surface tension reduction on the «oil-water» boundary (i.e. surface tension change effect), and so on.

Consequently, oil displacement under the effect of CO_2 injection is a complex process where effects, such as mass transfer, capillarity and gravitation greatly manifest themselves. Therefore, the necessity to adequately replicate the physicochemical processes that occur while injecting gases of various composition, naturally arise when obtaining a valid forecast of the dynamics of well operating parameters based on three dimensional geological hydrodynamic models. [4, 5].

One of the methods to formulate physicochemical processes, as practice shows, can be through utilizing compositional modelling which is widely employed for the modelling of multicomponent fluid filtration in oil deposits [9].

The tNavigator program environment with its «Compositional model» feature has been employed while elaborating the geological hydrodynamic model (GHDM) of a hydrocarbon deposit of the Ural-Volga region.

One of the most crucial steps in compositional modelling is creating an adequate PVT-model. The PTV-model has been tuned to laboratory work results through setting critical temperature and pressure, as well as mole fraction (fig. 1 and 2).

Oil recovery processes under CO_2 injection into the non-homogenous production formations have been studied based on the developed GHDM. Several recovery options have been considered. While modelling, it was assumed that the discharge and producing wells operate in a stationary production and injection mode. Production well operability was bound by bottomhole pressure, which was set to not be lower than oil saturation pressure. The injection well had another limitation which was the production recoup value of 1.2. Production here is meant to be recouped by injection. With these being set up, the conditions under which production wells could be stopped were both achieving saturated watercut of 98% and minimum production rate of 1 ton per day.

Thus, the following development options have been modelled (fig. 3 and 4):

- General case. Gas is not injected;
- In Case 1 it is considered that three banks will be subjects to injection. Injection of one bank lasts a year. The overall annual gas volume is 5 million m^3 (at standard temperature and pressure) (fig. 3);
- Case 2 implies utilizing Case 1 with the difference being a two-fold gas volume to be injected.

A comparison of operation indicators has been conducted in order to appraise the operation efficacy of the cases developed (fig. 5). It can be seen from the comparison that injecting three CO_2 banks results in oil recovery increase by 8,500 tons over the studied timespan.

A fragmented CO_2 molar density cube (fig. 6 and 7) was also considered for even more detailed understanding of CO_2 distribution within the formation. This allows one to establish the main formation impact zones and describe

**E-mail:* ssultanov@mail.ru

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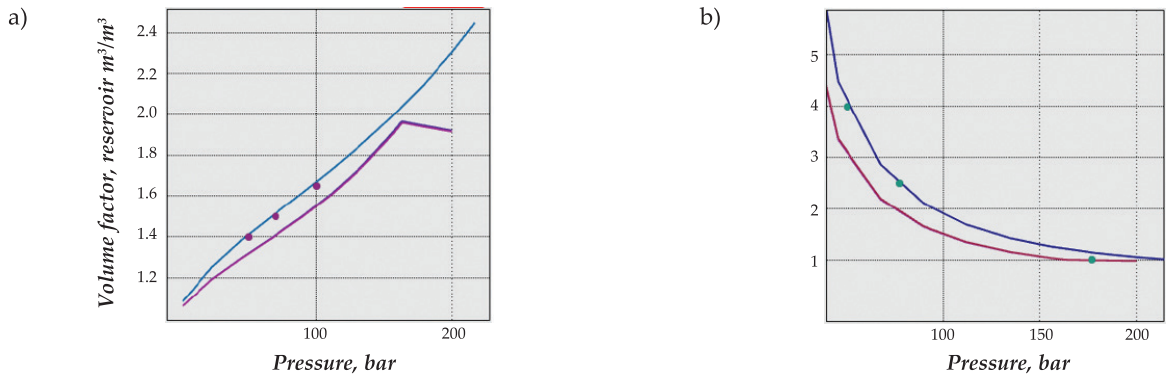

Fig. 1. Comparison of the results prior to and after CCE (a) and DLE (b) experiments adaptation

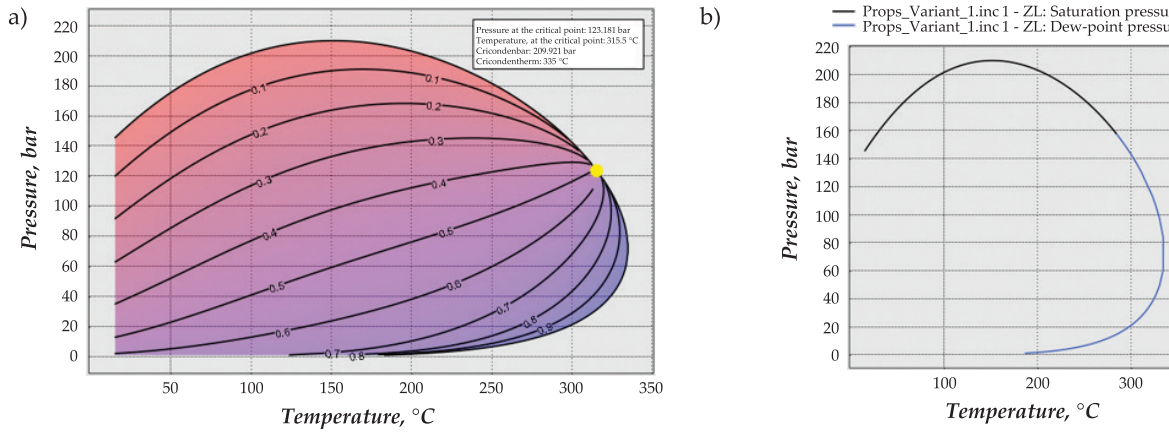

Fig. 2. Phase envelope (a) and saturation pressure curve (b)

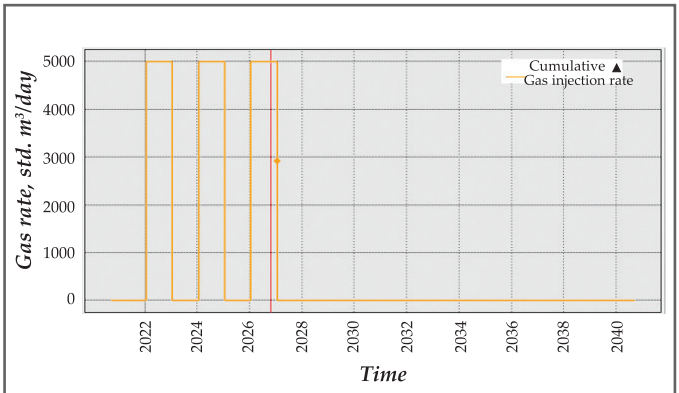

Fig. 3. Case 1 CO_2 injection (three cycles)

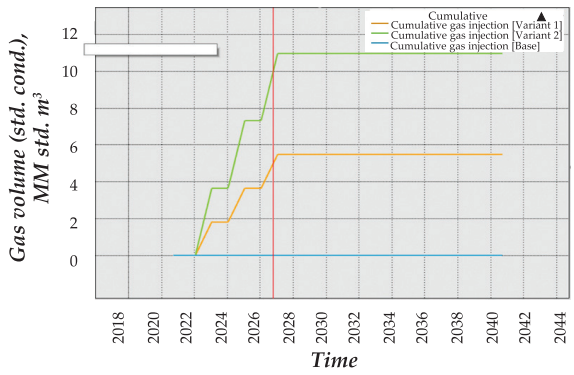

Fig. 4. CO_2 volume at standard temperature and pressure

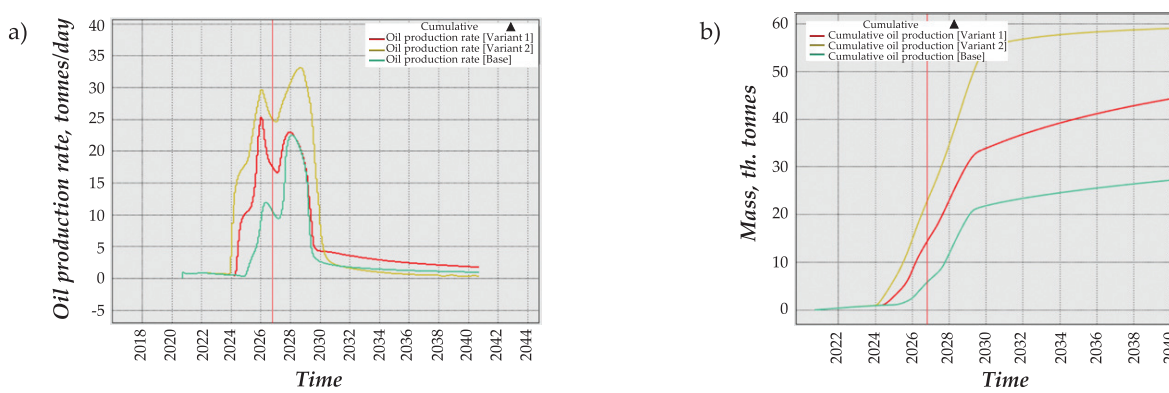

Fig. 5. Oil yield (a) and aggregated oil production (b)

the physicochemical processes that take place during CO_2 injection in more depth.

The following conclusion can be made, having all the modelling results summed up. The injection gas mainly dissolves into the oil (fig. 8). As a result, oil viscosity decreases in the areas of CO_2 distribution (fig. 9).

Consequently, hydrodynamic calculations has illustrated that mutual dissolution of oil and gas and vice versa occur when injecting CO_2 into the formation being studied. Oil displacement will be complemented with partial mass transfer between oil and gas phases. Improved operational effectiveness will result from lower oil viscosity, greater cover ratio (reduced water-to-oil phase fluidity), and displacement coefficient (reduced surface tension).

For this oil formation, therefore, the determining factors upon which the success of such a technological approach

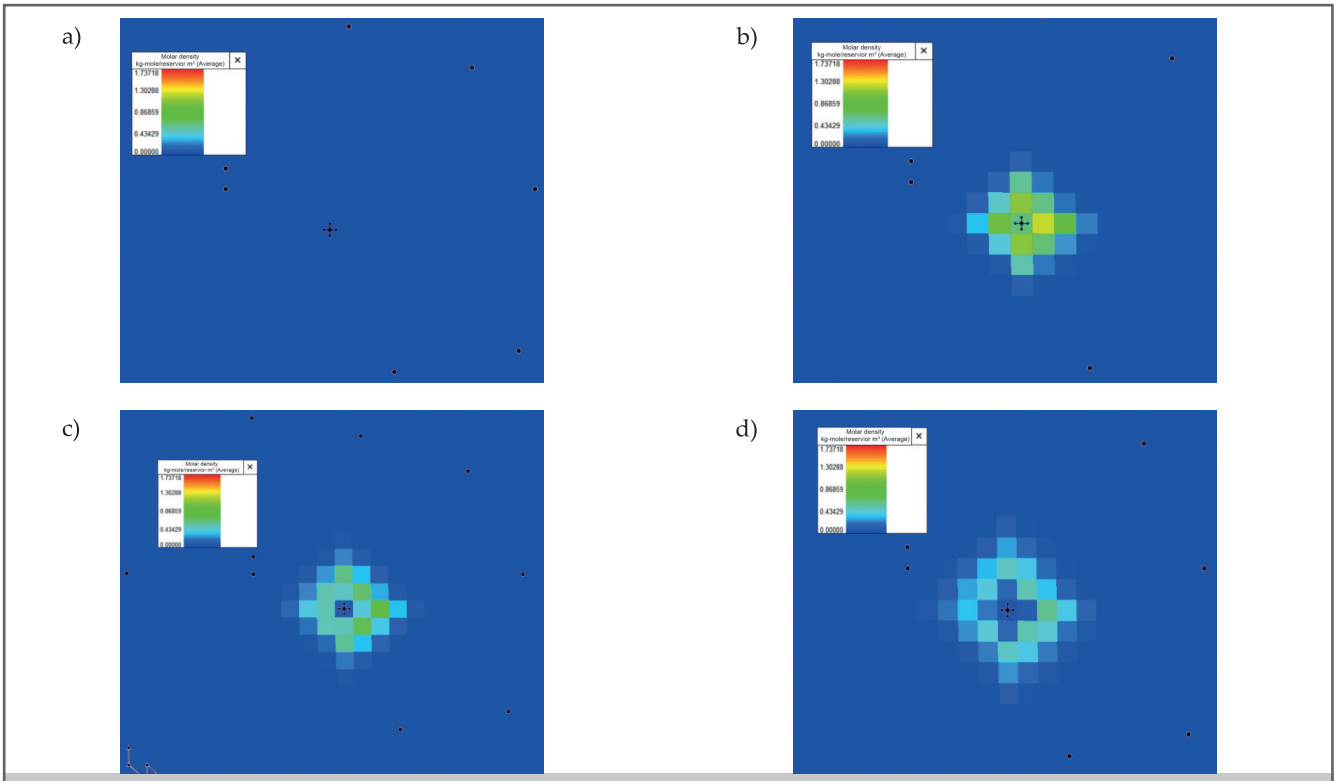

Fig. 6. Elements of the CO_2 molar density cube: a) prior injection b)CO_2 bank injection c) water injection d) CO_2 bank being forced through by injected water

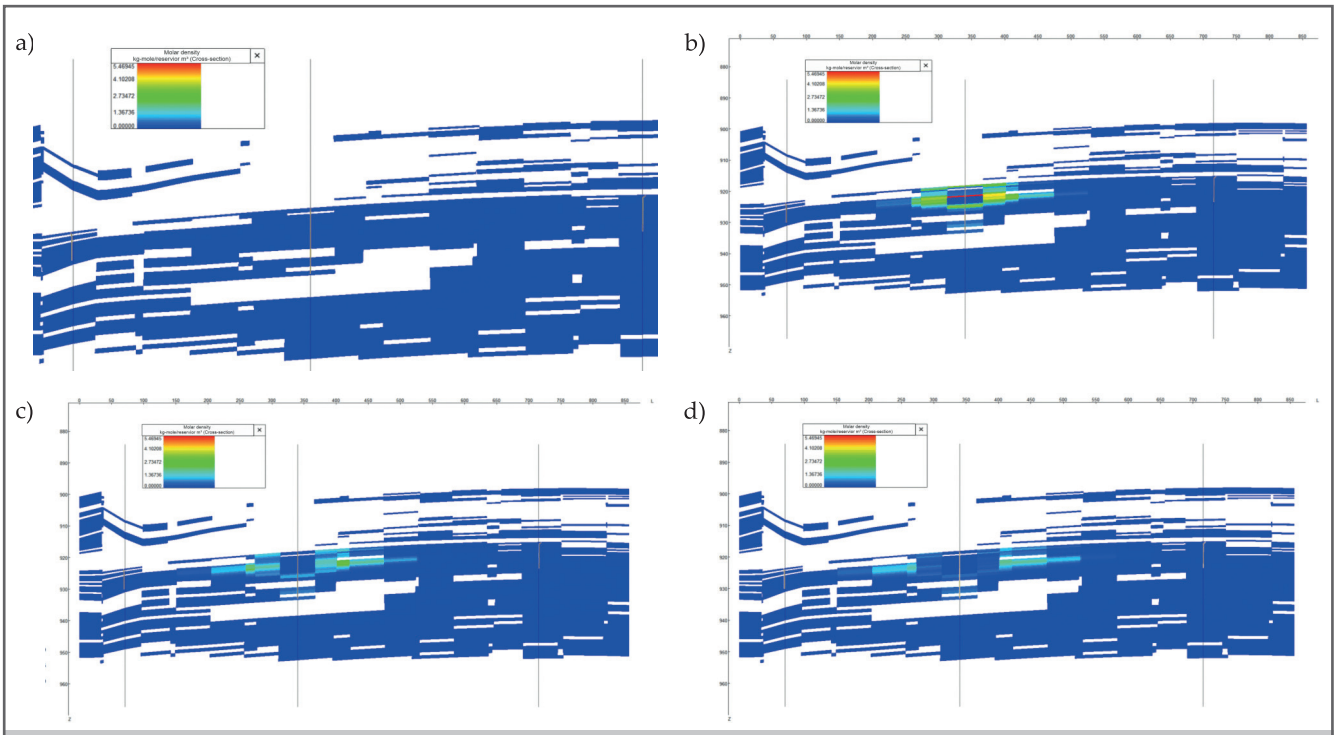

Fig. 7. Cut-outs of the CO_2 mole density cube: a) prior injection b)CO_2 bank injection c) water injection d) CO_2 bank being forced through by injected water

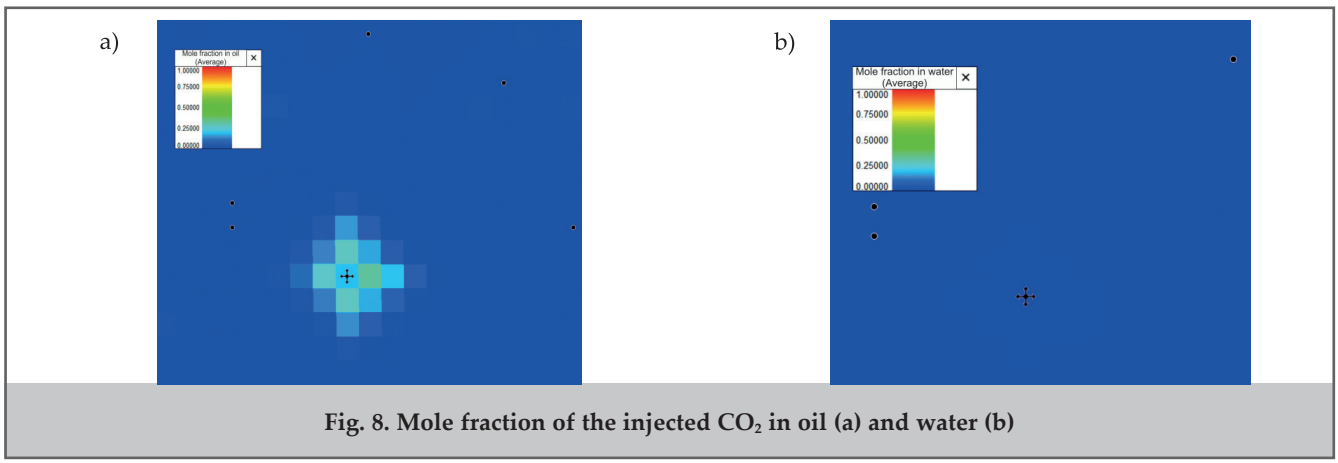

Fig. 8. Mole fraction of the injected CO_2 in oil (a) and water (b)

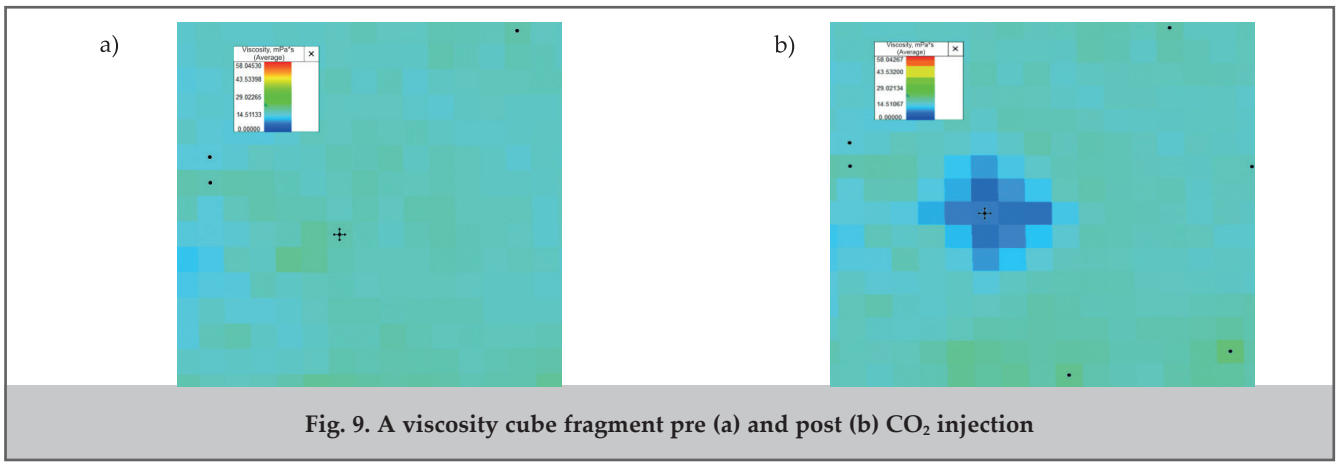

Fig. 9. A viscosity cube fragment pre (a) and post (b) CO_2 injection

rests are in situ temperature-pressure conditions, as well as the composition of the oil and injection gas.

However, calculations done by the hydrodynamic simulator have proved that CO_2 injection efficacy depends on the selection of the CO_2 injection well and its influence on the surrounding production wells. In the case of absence of hydrodynamic connectivity between the production and injection wells this effect can be negated. It is, therefore, recommended to conduct a thorough study on the geological structure and operating indicators of the wells in order to select injection wells having satisfactory geological connectivity with the surrounding wells.

Conclusion

1. The viability of introduction of such a technology has been rationalized with the employment of a three dimensional compositional hydrodynamic model.
2. Based on gas oil relative permeability-to-water saturation dependency established through test core experiments, the model type of the reservoir and fluids within it for an oil reservoir of the Ural-Volga region have been justified.
3. The following have been done using tNavigator software: model physicochemical characteristics of reservoir fluids rationalized, composition set and phase equilibrium calculated.
4. With the use of the three dimensional compositional hydrodynamic modelling it was attainable to study highly viscous oil recovery processes while injecting CO_2 into non-homogeneous formations. It was also established that for the reservoir under consideration and conditions pertaining to it, injected CO_2 and oil are bound to mutually dissolve. Oil-to-gas and gas-to-oil partial mass transfer is innate to oil displacement in this case. The operational benefit will come as a result of reduced oil viscosity, greater cover ratio (reduced water-to-oil phase fluidity), and displacement coefficient (reduced surface tension).

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Обоснование закачки углекислого газа в пласты высоковязких нефтяных пород

А. А. Махмутов[1], Р. У. Рабаев[1], М. О. Абдулла Нейзер[2], Ш. Х. Султанов[1]
[1]Уфимский государственный нефтяной технический университет, Уфа, Россия
[2]Yemen Oil and Minerals Investment Company, Санаа, Йемен

Реферат

В данной статье исследованы процессы нефтеотдачи при закачке CO_2 в неоднородные продуктивные пласты с использованием композиционной гидродинамической модели. Расчеты по ГГДМ показали, что в пластовых условиях при закачке диоксида углерода будет происходить взаимное растворение нефти и газа. При вытеснении нефти будет происходить частичный массоперенос нефти в газ и газа в нефть. Эксплуатационный эффект будет получен за счет снижения вязкости нефти, увеличения коэффициента покрытия (уменьшение текучести фазы вода-нефть) и коэффициента вытеснения (снижение поверхностного натяжения). Этот эффект составит 8.5 тонн дополнительно добытой нефти.

Ключевые слова: пористость; граничное поверхностное натяжение; геологическая гидродинамическая модель; углекислый газ.

Yüksək özlülüklü neft süxurları laylarına karbon qazının vurulmasının əsaslandırılması

A. A. Maxmutov[1], R. U. Rabayev[1], M. O. Abdulla Neyzer[2], Ş. X. Sultanov[1]
[1]Ufa Dövlət Neft Texniki Universiteti, Ufa, Rusiya
[2]Yəmən Neft və Minerallar İnvestisiya Şirkəti, Sanaa, Yəmən

Xülasə

Məqalədə kompozisiya hidrodinamik modelinin istifadəsi ilə, CO_2-nin geyri-bircinsli məhsuldar laylarına vurulması zamanı neftvermə prosesləri tədqiq edilmişdir. GHDM hesablamaları, lay şəraitində karbon dioksid vurulduqda neft və qazın qarşılıqlı həllinin baş verməsini göstərmişdir. Neftin sıxışdırılması zamanı neftin qaza və qazın neftə qismən kütləvi ötürülməsi baş verəcəkdir. İstismar effekti neftin özlülüyünün azalması, örtük əmsalının artması (su-neft fazasının axıcılığının azalması) və sıxışdırılma əmsalı (səthi gərilmənin azalması) ilə əldə ediləcəkdir. Bu effekt 8.5 ton əlavə hasil olunan neft təşkil edəcək.

Açar sözlər: məsaməlik; hüdud səthi gərilmə; geoloji hidrodinamik modeli; karbon qazı.