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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ
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ИЗВЕСТИЯ

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Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

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©L. Nurshakhanova[1], S. Zakenov[1], A. Zakenova[2], 2024.
[1]Caspian university of technologies and engineering named after S. Yessenov, Aktau, Kazakhstan;
[2]Atyrau branch of «KMG Engineering» LLP, Atyrau, Kazakhstan.
E-mail: senbek.z@mail.ru

TECHNOLOGIES OF WATER-GAS IMPACT ON THE RESERVOIR USING SIMULTANEOUSLY PRODUCED PETROLEUM GAS

Nurshakhanova Lazzat - candidate of technical sciences, Caspian University of Technology and Engineering named after Sh.Yessenov, Aktau, Kazakhstan, E-mail: aitore2010@mail.ru, https://orcid.org/0000-0001-8745-9874;
Zakenov Sembigali - doktor of technical sciences, Caspian University of Technology and Engineering named after Sh.Yessenov, Aktau, Kazakhstan, E-mail: senbek.z@mail.ru, https://orcid.org/orcid.org/0000-0002-1225-3203;
Zakenova Amina - Atyrau branch of «KMG Engineering» LLP, Atyrau, Kazakhstan, E-mail: aminazakenova362@gmail.com, https://orcid.org/0009-0000-5078-5764.

Abstract. The current trend in the development of scientific research in the field of enhanced oil recovery is to achieve the maximum possible oil recovery coefficient in the conditions of development of hard-to-recover oil reserves.

The development and scientific justification of an innovative technology of water and gas exposure to increase oil recovery and reduce the carbon footprint is an urgent problem. Well-known technologies of water and gas exposure have, in addition to advantages, significant disadvantages (low stability of water and gas mixtures, irrational injection into wells unsuitable for exposure, insufficient research into the process of creating, pumping and filtering mixtures, the use of inefficient and unreliable injection equipment, lack of methodology for selecting optimal equipment).

The article provides a justification for the possibility of solving the problem by conducting research to develop a technology for "smart" water-gas impact on the reservoir when injecting stable water-gas mixtures with optimal physico-chemical and foaming properties to achieve maximum oil recovery into the most suitable wells with efficient and reliable pumping-ejector and pumping-compressor-ejector systems.

oil recovery coefficient, enhanced oil recovery, pumping-compressor-ejector systems and technologies.

©Л.Қ. Нұршаханова[1], С.Т. Зәкенов[1], А.С. Зәкенова[2], 2024.
[1]Ш. Есенов атындағы Каспий технологиялар және инжиниринг университеті, Ақтау, Қазақстан;
[2]«КМГ Инжиниринг» ЖШС Атырау филиалы, Атырау, Қазақстан.
E-mail: senbek.z@mail.ru

ІЛЕСПЕ МҰНАЙ ГАЗЫН ПАЙДАЛАНА ОТЫРЫП, ҚАБАТҚА СУ-ГАЗ ӘСЕР ЕТУ ТЕХНОЛОГИЯСЫ

Нұршаханова Ләззат – техника ғылымдарының кандидаты, Ш. Есенов атындағы Каспий технологиялар және инжиниринг университеті, Актау, Қазақстан, E-mail: aitore2010@mail.ru; https://orcid.org/0000-0001-8745-9874;
Зәкенов Сембіғали – техника ғылымдарының докторы, Ш. Есенов атындағы Каспий технологиялар және инжиниринг университеті, Актау, Қазақстан, E-mail: senbek.z@mail.ru; https://orcid.org/orcid.org/0000-0002-1225-3203;
Зәкенова Әмина – «КМГ Инжиниринг» ЖШС Атырау филиалы, Атырау, Қазақстан, E-mail: aminazakenova362@gmail.com; https://orcid.org/0009-0000-5078-5764.

Аннотация. Қабаттардың мұнай беруін арттыру саласындағы ғылыми зерттеулерді дамытудың қазіргі тенденциясы өндірілуі қиын мұнай қорларын игеру жағдайында мұнай алудың мүмкін болатын ең жоғары коэффициентіне қол жеткізу болып табылады.

Мұнай беруді арттыру және көміртегі ізін азайту үшін су-газ әсерінің инновациялық технологиясын әзірлеу және ғылыми негіздеу өзекті мәселе. Су-газ әсерінің белгілі технологияларының артықшылықтарынан басқа елеулі кемшіліктері бар (су-газ қоспаларының төмен тұрақтылығы, ұңғыманың әсеріне жарамсыз жерлерге ұтымсыз айдау, қоспаларды жасау, айдау және сүзу процесінің жеткіліксіз зерттелуі, айдау үшін тиімсіз және сенімсіз техниканы қолдану, оңтайлы жабдықты таңдау әдістемесінің болмауы).

Мақалада тиімді және сенімді сорғы-эжекторлық және сорғы-компрессорлық-эжекторлық жүйелермен ең қолайлы ұңғымаларға мұнай алудың максималды коэффициентіне қол жеткізу үшін оңтайлы физика-химиялық және көбік түзетін қасиеттері бар тұрақты су-газ қоспаларын айдау кезінде қабатқа "ақылды" су-газды әсер ету технологиясын әзірлеу үшін зерттеулер жүргізу арқылы мәселені шешу мүмкіндігінің негіздемесі келтірілген.

Түйін сөздер: Су-газ әсері, ілеспе мұнай газы, газ технологиялары, мұнай алу коэффициенті, мұнай беруді арттыру, сорғы-компрессорлық-эжекторлық жүйелер мен технологиялар.

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[1]Каспийский университет технологий и инжиниринга имени Ш. Есенова, Актау, Казахстан;
[2]Атырауский филиал ТОО «КМГ Инжиниринг», Атырау, Казахстан.
E-mail: senbek.z@mail.ru

ТЕХНОЛОГИИ ВОДОГАЗОВОГО ВОЗДЕЙСТВИЯ НА ПЛАСТ С ИСПОЛЬЗОВАНИЕМ ПОПУТНО ДОБЫВАЕМОГО НЕФТЯНОГО ГАЗА

Нуршаханова Лаззат – кандидат технических наук, Каспийский университет технологий и инжиниринга имени Ш. Есенова, Актау, Казахстан, E-mail: aitore2010@mail.ru; https://orcid.org/0000-0001-8745-9874;
Закенов Сембигали – доктор технических наук, Каспийский университет технологий и инжиниринга имени Ш. Есенова, Актау, Казахстан, E-mail: senbek.z@mail.ru; https://orcid.org/orcid.org/0000-0002-1225-3203;
Закенова Амина – Атырауский филиал ТОО «КМГ Инжиниринг», Атырау, Казахстан, E-mail: aminazakenova362@gmail.com; https://orcid.org/0009-0000-5078-5764.

Аннотация. Современной тенденцией развития научных исследований в области повышения нефтеотдачи пластов является достижение максимально возможного коэффициента извлечения нефти в условиях разработки трудноизвлекаемых запасов.

Разработка и научное обоснование инновационной технологии водогазового воздействия для повышения нефтеотдачи и снижения углеродного следа является актуальной проблемой. Известные технологии водогазового воздействия имеют, помимо достоинств, существенные недостатки (невысокая устойчивость водогазовых смесей, нерациональная закачка в неподходящие для воздействия скважины, недостаточная исследованность процесса создания, нагнетания и фильтрации смесей, применение неэффективной и ненадежной техники для закачки, отсутствие методики подбора оптимального оборудования).

В статье приводится обоснование возможности решения проблемы путем проведения исследований для разработки технологии «умного» водогазового воздействия на пласт при нагнетании устойчивых водогазовых смесей с оптимальными физико-химическими и пенообразующими свойствами для достижения максимального коэффициента извлечения нефти в наиболее подходящие скважины эффективными и надежными насосно-эжекторными и насосно-компрессорно-эжекторными системами.

Ключевые слова: водогазовое воздействие, попутный нефтяной газ, газовые технологии, коэффициент извлечения нефти, повышение нефтеотдачи, насосно-компрессорно-эжекторные системы и технологии.

Introduction

Many oil fields are developed using flooding. At the same time, 30-70 % of the initial oil reserves remain unrecovered in the subsurface. There is a negative trend in the oil recovery coefficient (ORK). In general, the ORK value of 30-32% seems realistic for all stocks (Mikhailov, et al., 2019). The decline in ORK in many countries of the world is objective, given by nature and there is a downward trend in project ORK. Therefore, there is a need to use other methods of exposure that increase oil recovery. Among the most promising technologies, gas methods, including water-gas exposure, should be noted (Zakenov, et al., 2022).

It can be used at any stage of field development when injecting associated petroleum and industrial gases (flue, exhaust, etc.) together with water, which allows, along with increasing oil recovery, to improve the environmen tal situation and reduce the carbon footprint.

Materials and methods.

Currently, the output of old oil fields, which are basic for the industry, is decreasing worldwide. Investments in the development of oil production are decreasing. The structure of oil reserves has changed significantly in recent years. The largest highly productive fields, which provided high volumes of oil production in previous years, are now significantly depleted. The share of hard-to-recover reserves (HRR) has increased in the total volume of current oil reserves, the development of which is largely associated with the further development of the oil industry.

The design values of oil recovery of fields being put into development are set lower and lower. The average oil recovery coefficient in Russia is only about 36% according to the work (Poddubny, et al., 2020). At the same time, there is a negative trend in the oil recovery coefficient.

According to the documents of the Central Commission for the Development of Minerals, the average ORK in Russia is fixed at 38%. At the same time, according to Yu.A. Poddubny (Poddubny, et al., 2020), the ORK value of 38% refers to good reserves, excluding HRR, as explicitly stated in the latest Energy Strategy of Russia for the period up to 2035. In general, the ORK value of 30-32% seems realistic for all reserves, and there is a downward trend in project ORK. The fall of the ORK in Russia, as in many countries of the world, primarily in the United States, is objective, given by nature.

Yu.A. Poddubny also notes the mythical values of ORK, which are published with enviable regularity in Russia (there is no such thing in the West, it seems, they trust professionals more), when they fantasize about the average ORK of 40% in the United States (in fact, at the level of 34%, and without shale oil) or in the world – that's- here will be the level of 50% (in fact, the global achievable ORK is estimated at 29%, the possible achievability of 32% is being discussed, and this is without heavy oil and bitumen). And in Norway it is said about 50-60% ORK in the best fields (Poddubny, et al., 2020: Pestov, et al., 2019).

Another aspect of the problem that the project is aimed at solving is reducing the flaring of associated petroleum gas (APG), CO_2 carbon dioxide emissions into the atmosphere, improving the environment and reducing the carbon footprint (decarbonization).

The reasons for the irrational use of APG are related to a number of factors: the remoteness of the fields from the infrastructure for collecting and transporting petroleum gas; limited access to the main gas pipeline system; lack of local consumers of APG processing products, etc.

The problem is so global that it is being considered at the global level at the UN. In April 2015, UN Secretary-General Ban Ki-moon and World Bank President Jim Yong Kim announced the launch of a joint initiative "Complete cessation of regular flaring of APG by 2030" (Zero Routine Flaring by 2030 Initiative), which aims to end unproductive burning of APG. Despite the adoption of such a program, APG flaring increased by 2019.

According to the World Bank, in 2019, the volume of APG flared increased by 5 billion compared to the previous year. cubic meters — up to 150 billion m^3. The largest growth was recorded in Syria (by 35%) and the United States (by 23%), followed by Venezuela (16%) and Russia (9%). Statistics on the volume of burned APG over the past 5 years are presented in Table 1. Russia is in first place in terms of irrational APG combustion in 2019, Iraq is in second, and the United States is in third (Global Gas Flaring Tracker Report, 2020).

Table 1 - Dynamics of volumes of burned associated petroleum gas in various countries and around the world for 2015-2019 according to the World Bank's Global Partnership to Reduce Associated Gas Combustion

Countries	2015	2016	2017	2018	2019	Change for 2018-2019
	billion m^3					
Russia	19,62	22,37	19,92	21,28	23,21	1,93
Iraq	16,21	17,73	17,84	17,82	17,91	0,09
USA	11,85	8,86	9,48	14,07	17,29	3,22
Iran	12,10	16,41	17,67	17,28	13,78	-3.50
Venezuela	9,33	9,35	7,00	8,22	9,54	1,32
Algeria	9,13	9,10	8,80	9,01	9,34	0,33
Nigeria	7,66	7,31	7,65	7,44	7,83	0,39
Libya	2,61	2,35	3,91	4,67	5,12	0,45
Mexico	5,00	4,78	3,79	3,89	4,48	0,59
Everything in the world	146	148	141	145	150	5,0

In the first quarter of 2020, according to (Global Gas Flaring Tracker Report, 2020), the total combustion of APG decreased by about 10%, with a decrease observed in the 30 most irrationally burning gas countries. This is mainly due to a decrease in oil production due to falling oil prices and the crisis associated with the coronavirus pandemic. APG utilization increased during this period only in the

USA. After overcoming the crisis and restoring the global economy, a new increase in flaring gas should be expected if effective technologies for its disposal are not introduced.

The main directions of qualified use of APG include gas processing (production of dry and liquefied gas, liquid fuel), combustion in power plants for the production of electric and thermal energy, as well as cycling process and injection into the reservoir, including with the aim of increasing oil recovery (Drozdov, 2014: Berge, et al., 2002: Zheng, et al., 2013: Alvarado, et al., 2010).

At the same time, the volume of APG use through processing and combustion for energy generation will increase slightly in the future. Technologies aimed at increasing oil recovery have the best prospects in the field of increasing the degree of APG use (Drid, et al., 2004: Samba, et al., 2018: Kinate, et al., 2022).

Results and discussion.

The systematization of projects of methods for increasing oil recovery (IOR) in the world by technology shows that today gas IOR prevail. If we take a conservative estimate (347-375 projects) as a basis, then projects with gas IOR occupy 47%, thermal projects – 44%, chemical and other technologies – 9%. According to the most radical estimate, the share of IOR gas projects is estimated at 56%, while the share of thermal projects is only 32-41% (Afzali, et al., 2018: Christensen, et al., 2001: Khizhnyak, et al., 2016).

The United States, Brazil and Canada occupy the leading positions in IOR gas technologies. Moreover, the United States dominates here with production volumes of over 75% of the global total for this group of IOR. However, about 60% of the known technologies for increasing oil recovery are still insufficiently studied for a reasonable and large-scale commercial application.

IOR are becoming more and more in demand. The basis for their implementation is hydrodynamic development systems, in which physico-chemical, physical, microbiological, water-gas methods work effectively.

In particular, technologies of water-alternating-gas (WAG) are currently being actively developed, while the injection of finely dispersed water-gas mixtures is the most promising.

An analysis of the field experience shows that various WAG technologies have previously been used in more than a hundred fields around the world. Numerous studies have been conducted that have shown that in complicated mining and geological conditions, one of the most promising methods of increasing oil recovery is water-gas exposure.

WAG technologies can be classified: by the method of pumping water and gas, by the ratio of displacing agents to each other, by the type and composition of the gas, by the gas source, by the place of formation of the water-gas mixture, by the displacement mode, by the choice of technological equipment for the implementation of the technology, by the type of object selected for exposure.

Alternating injection of water and gas into the reservoir, known as WAGI (Water

Alternating Gas Injection) technology, is an earlier method of WAG. In it, water and gas are pumped into the reservoir cyclically, in rims. Another method is the joint (simultaneous) injection of water and gas into the reservoir, known as SWAGI (Simultaneous Water and Gas Injection) technology. In this case, water and gas enter the reservoir in the form of a water-gas mixture.

Most of the fields where water and gas exposure has been applied are located in North and South America, as well as in Norway. When exposed, hydrocarbon gases, dry or enriched, as well as carbon dioxide are usually injected. Most often, an increase in oil recovery at WAG is reported by about 5%, but, as noted in some fields, oil recovery can increase by 20%. The WAG method has almost always been used as a tertiary method of oil production. It was only in later cases in the North Sea that the water-gas effect was carried out from the very beginning of development. It turned out to be highly effective there in increasing oil recovery in many fields.

Almost all publications note a significant increase in oil recovery achieved due to water and gas exposure (Drozdov, et al., 2020: Faisal, et al., 2009: Kang, et al., 2016: Wang, et al., 2015: Ainge 2019: Hosseini, et al., 2021).

However, it should be noted that many works in Russia on water and gas exposure were then discontinued (at Samotlor, New Year, Sovetsky and other fields), mainly due to technical and technological problems, insufficient efficiency and complications in the operation of equipment.

In world practice, complex and expensive equipment is used for the implementation of HBV, requiring large capital investments, high–quality maintenance and competent operation - gas treatment plants, high-pressure pumps and compressors.

The use of WAG technologies using high-pressure compressors at the Samotlor and New Year fields was discontinued due to a number of problems. These WAG technologies require the purchase of sophisticated equipment, huge capital investments at the initial stage of construction and significant operating costs during the exposure process.

In addition to compressor stations, it is necessary to build gas treatment plants. The drying of gas for the normal operation of compressors leads to the removal of fatty fractions from the gas, which cannot be disposed of everywhere, and the use of dry gas in the WAG process is less effective from the point of view of oil recovery than fatty.

Finally, with the sequential injection of water and gas fringes into the reservoir, practiced in compressor technologies, large volumes of gas may break through to the faces of producing wells, which leads to the cessation of their normal operation and losses in oil production, the formation of hydrates and other complications.

In Russia, in addition to compressor stations, booster systems were used for the introduction of WAG, which, unlike compressors, do not require careful gas preparation. However, the use of complex volumetric booster pumps-compressors (pumping and booster units) for the purposes of WAG is impossible without creating high gas pressures at reception and is also an expensive undertaking.

Booster pumps cannot provide the high performance required for the implementation of HCV in the entire field as a whole, and not in a small pilot site. The reliability of volumetric pumps in reservoir pressure maintenance systems is also lower than that of dynamic pumps.

For pumping and ejector technology of water and gas exposure of JSC «RITEK», it is necessary to have a gas source - a gas cap at relatively low values of the injection pressure of the mixture. The extraction of gas from the gas cap for HCV at the Kotovsk field subsequently led to a significant decrease in reservoir pressure and the cessation of water-gas exposure using this technology.

Therefore, the main problem situation is that the widespread use of water-gas exposure, which allows not only to utilize associated petroleum gas, but also to increase oil recovery, requires the creation of efficient, reliable and easy-to-maintain equipment and technology for the preparation and injection of a water-gas mixture into injection wells, and this is an urgent topic for oil production.

Pumping and ejector systems include vane pumps, ejectors and pipe fittings.

The water-alternating-gas on the reservoir using this system is carried out as follows.

The water-gas mixture created by the ejector is pumped into injection wells and foaming surfactants (surfactants) are added to the water-gas mixture. To do this, a power pump along the water injection line supplies pressurized water to the working nozzle of the ejector. When water flows through the working nozzle at high speed, a vacuum is created in the ejector intake chamber, where gas is sucked through the gas supply line. At the same time, foaming surfactants are fed into the receiving chamber of the ejector. In the flow part of the ejector, the flows are mixed and a water-gas mixture is formed.

At the outlet of the ejector, the water-gas mixture has some increased pressure, which, however, is not enough to pump the water-gas mixture into injection wells. Therefore, after the ejector, the water-gas mixture is pumped out with a pump and pumped under high pressure into injection wells.

In order to avoid a decrease in the performance of the booster pump due to the harmful effects of free gas, the content of free gas in the mixture at the pump intake is maintained no higher than the critical gas content of the cavitation-free operation of the pump on a water-gas mixture.

In order to achieve the highest effect on increasing oil recovery, the water-gas effect must be carried out in the area of optimal gas contents of the mixture.

The process of creating a finely dispersed water-gas mixture is also one of the fundamental features of the proposed pumping-ejector technology. The fact is that with conventional mixing of water and gas, the mixture is stable only in a narrow range of pressures and temperatures, and after a while it stratifies, which causes a significant increase in hydraulic resistances in aqueducts and injection wells.

Therefore, when creating a finely dispersed water-gas mixture, appropriate pairs of cations and anions are selected, and foaming surfactants are added, which stably hold free gas bubbles in water, preventing them from merging (coalescing).

When implementing the technology, the existing infrastructure of the reservoir pressure maintenance system (PMS) can be used. It does not require the construction of separate high-pressure gas pipelines and gas injection wells of complex design with wellhead and underground equipment necessary for high pressures. When pumping a water-gas mixture with a pumping-ejector installation, a significantly lower injection pressure is required than when pumping gas with a compressor, and several times higher injection pressure of the water-gas mixture is achieved compared to known ejector technologies. The technology also solves the problem of hydrate formation and it is possible to maintain not only reservoir pressure, but also reservoir temperature.

Suppression of coalescence in the "water – gas microbubbles" system by selecting pairs of cations, anions and surfactants makes it possible to avoid stratification of the water-gas mixture in pipelines and injection wells and significantly reduces the required injection pressures of the water-gas mixture.

Conclusion

An analysis of the experience of operating the system in the fields and previous studies have also made it possible to outline measures – new technical solutions to improve the technology and technique of water-gas impact on the reservoir using pumping and ejector systems.

The first of these solutions will increase the efficiency of the water-gas impact on the deposit by organizing separate individual concentrated injection of the water-gas mixture into the most suitable geological and field characteristics for water-gas impact in order to increase oil recovery.

Another technical solution will increase the reliability and productivity of the gas installation by providing additional gas ejection, which expands the scope of application in the implementation of water-gas effects on the reservoir.

The third technical solution will increase the efficiency of oil production by increasing the consumption of associated petroleum gas directed to create a water-gas mixture, reducing pressure in the oil collector, as well as creating effective non-stationary wave operating modes while reducing capital investments and operating costs.

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