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THEORETICAL JUSTIFICATION OF THE THERMAL METHOD – STEAM CYCLIC TREATMENT OF WELLS OF THE X DEPOSIT



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Enhanced oil recovery from active fields is equivalent to the discovery of new fields, making this issue critical to all oil-producing countries around the world.

Of course, among all modern methods of increasing oil recovery from reservoirs, thermal methods are the most technically and technologically prepared. They make it possible to extract oil with a viscosity of up to 100 MPa and at the same time increase the final oil recovery by 30-50%. In particular, the thermal steam method is widely used both in fields in the CIS countries and abroad.

The main factors that determine the growth of oil production using thermal methods include:

Availability of significant resources of high-viscosity oil.

Application of highly effective technologies for influencing oil deposits.

Availability of necessary heat and power equipment.

Use of heat-resistant equipment for wells and on the surface.

Effective control and regulation of processes inside wells.

The widespread development of methods for thermal oil production is associated with the solution of a complex set of scientific and technical problems. Among these tasks, special attention is paid to:

The study of oil recovery mechanisms in various geological and physical conditions.

The determination of opportunities for effective use of the features of the geological structure of specific fields.

The development of combined methods for increasing oil recovery, including thermal methods and others, in order to improve technological processes and achieve high oil recovery rates at the level of 50-60%.

The aim of this article is to analyze and justify the choice of a specific thermal oil production technology, namely the method of steam-cyclic well treatment, which is especially relevant for the production of high-viscosity oils.

***KEY WORDS:** steam treatment, well, enhanced oil recovery, production, object, deposit.*

Х КЕН ОРНЫНЫҢ ҰҢҒЫМАЛАРЫН БУ-ЦИКЛДІК ӘДІСПЕН ӨҢДЕУ – ЖЫЛУ ӘДІСІНІҢ ТЕОРИЯЛЫҚ НЕГІЗДЕМЕСІ

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Белсенді игеріліп жатқан кен орындарында мұнай берудің артуы жаңа кен орындарының ашылуына тең, бұл бүкіл әлем бойынша мұнай өндірумен айналысатын барлық елдер үшін бұл проблеманы аса маңызды етеді.

Әрине, қабаттардан мұнай алуды арттырудың барлық заманауи әдістерінің ішінде термиялық әдістер ең техникалық және технологиялық тұрғыдан дайындалған. Олар тұтқырлығы 100 МПа-ға дейінгі мұнайды алуға мүмкіндік береді және сонымен бірге соңғы мұнай шығаруды 30-50%-ға арттырады. Атап айтқанда, бу-жылу әсер ету әдісі ТМД елдерінде де, одан тыс жерлерде де кең таралған.

Термиялық әдістерді қолдану кезінде мұнай өндірудің өсуін анықтайтын негізгі факторларға мыналар жатады:

-тұтқырлығы жоғары мұнайдың маңызды ресурстарының болуы;

-мұнай кен орындарына әсер етудің жоғары тиімді технологияларын қолдану;

-қажетті жылу энергетикалық жабдықтың болуы;

-ұңғымалар үшін және бетінде ыстыққа төзімді жабдықты пайдалану;

-ұңғымалар ішіндегі процестерді тиімді бақылау және реттеу.

Мұнайды термиялық өндіру әдістерінің кең дамуы ғылыми және техникалық міндеттердің күрделі кешенін шешумен байланысты. Осы міндеттердің ішінде ерекше назар аударылады:

-әр түрлі геологиялық-физикалық жағдайларда қабаттардың мұнай беру механизмдерін зерттеу;

-нақты кен орындарының геологиялық құрылымының ерекшеліктерін тиімді пайдалану мүмкіндіктерін анықтау;

-технологиялық процестерді жақсарту және 50-60% деңгейінде мұнай берудің жоғары коэффициенттеріне қол жеткізу мақсатында жылу әдістерін және басқаларын қоса алғанда, мұнай беруді арттырудың аралас әдістерін әзірлеу.

Бұл мақаланың мақсаты – термиялық мұнай өндірудің нақты технологиясын, атап айтқанда, әсіресе тұтқырлығы жоғары мұнай өндіруге қатысты ұңғымаларды бу-циклдік өңдеу әдісін таңдауды талдау және негіздеу.

ТҮЙІН СӨЗДЕР: *бумен өңдеу, ұңғымалар, мұнай беруді арттыру, өндіру, объект, кен орны.*

ТЕОРЕТИЧЕСКОЕ ОБОСНОВАНИЕ ТЕПЛОВОГО МЕТОДА – ПАРОЦИКЛИЧЕСКОЙ ОБРАБОТКИ СКВАЖИН МЕСТОРОЖДЕНИЯ Х

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Повышение нефтеотдачи на активно разрабатываемых месторождениях эквивалентно открытию новых месторождений, что делает эту проблему критически важной для всех стран, занимающихся добычей нефти по всему миру.

Безусловно, среди всех современных методов увеличения извлечения нефти из пластов наиболее технически и технологически подготовленными являются термические методы. Они позволяют извлекать нефть с вязкостью до 100 МПа и в то же время увеличивать конечную нефтеотдачу на 30-50%. В частности, метод паротеплового воздействия широко распространен как на месторождениях в странах СНГ, так и за ее пределами.

Основные факторы, которые определяют рост объема добычи нефти при использовании термических методов, включают:

- наличие значительных ресурсов высоковязкой нефти;
- применение высокоэффективных технологий воздействия на нефтяные залежи;
- наличие необходимого теплоэнергетического оборудования;
- использование термостойкого оборудования для скважин и на поверхности;
- эффективный контроль и регулирование процессов внутри скважин.

Широкое развитие методов термической добычи нефти связано с решением сложного комплекса научных и технических задач. Среди этих задач особое внимание уделяется:

- исследованию механизмов нефтеотдачи пластов в разнообразных геолого-физических условиях;
-определению возможностей эффективного использования особенностей геологической структуры конкретных месторождений;
- разработке комбинированных методов повышения нефтеотдачи, включая тепловые методы и другие, с целью улучшения технологических процессов и достижения высоких коэффициентов нефтеотдачи на уровне 50-60%.

Цель данной статьи – провести анализ и обоснование выбора конкретной технологии термической добычи нефти, а именно метода пароциклической обработки скважин, особенно актуального для добычи высоковязких нефтей.

КЛЮЧЕВЫЕ СЛОВА: *паровая обработка, скважина, повышение нефтеотдачи, добыча, объект, месторождение.*

Introduction. During the exploitation of fields with heavy paraffinic oils at reservoir temperatures close to the beginning of paraffin crystallization or below it, the oil permeability of bottomhole zones within a radius of up to 1.5 m, and sometimes up to 3 m, deteriorates. This is caused by the formation of paraffin deposits and polymolecular colloidal adsorption-solvation layers from the active components of oil (resins, asphaltenes, organic acids) on the surface of the pore channels. The near-wellbore zone may also contain sludge deposits and water barriers remaining after drilling and completion of the well, which impair oil permeability [1].

To reduce the filtration resistance of the bottomhole zone, thermal effects are successfully used. Heat can be introduced into the collector by two methods: 1) heat transfer through the rock skeleton and saturating fluid from a heat source located in the well (by conductive heating method) and 2) forced heat and mass transfer through the reservoir due to the injection of coolants into the formation (saturated or superheated steam, hot water, etc.).

The mechanism of influence on the reservoir of each method has some differences. The choice of method is determined by the specific geological conditions of the area of application. The method of conductive heating of the bottomhole zone can be carried out periodically in a shut-in well (periodic well heating method) or stationary during operation (stationary well heating method). The main advantages of this method are the simplicity of the technology and, as a rule, low cost.

Unlike other treatment methods, no foreign substances are introduced into the bottomhole zone, which can cause irreversible negative consequences. The disadvantages of the method include the impossibility of introducing large amounts of heat into the formation in a short period of time. This is due to the low values of effective thermal conductivity of rocks [2,3]. In this regard, during conductive heating, the radius of the heated zone, as a rule, does not exceed 1 m.

The mechanism of action in the periodic method of heating a well is reduced to the melting of paraffin and asphalt-resin deposits in the bottom-hole zone, which are removed from the formation during subsequent operation. Moreover, with the resumption of operation, intensive cooling of the formation occurs and re-processing of the face is required to restore the permeability of the rocks.

The mechanism of action during stationary heating boils down to the fact that during operation, a ring zone with a radius of up to 1 m is created around the well in the formation, where a sufficiently high temperature is stationarily maintained. In this zone, the high oil permeability of the reservoir does not decrease during operation, and the viscosity of the oil is significantly reduced.

Heating of the near-wellbore zone of the formation by introducing coolant into the formation can be carried out a considerable distance deep into the formation (up to 20 m). However, this method, as a rule, leads to a significant water cut in the product. In addition, it can cause minor consequences in the near-wellbore zone, for example, the formation of persistent emulsions and water cones inside the formation, the destruction of a loose reservoir, as well as the swelling of lyophilic clays in the formation, if any [4].

The mechanism of influence on the reservoir during injection of coolants also comes down to the effect on the viscosity of oil and the oil permeability of the reservoir. However, in this case, the decrease in oil viscosity is caused not only by the temperature factor, but also by the effect of oil dilution by hot condensate. In addition, this method of treating the bottomhole zone promotes the active dissolution of paraffin-resinous deposits, loosening of sludge deposits and the elimination of water barriers. As a result, the oil permeability of the reservoir is not only restored, but often becomes higher than at the beginning of the well’s operation [5]. After treatment, the surface of the pore channels is lyophobized (covered with a film of hot condensate), which, combined with long-term preservation of elevated temperature in the reservoir, greatly slows down the mechanism of re-accumulation of paraffin-resinous deposits.

Assessing the prospects for oil production in the world, we can state that the era of cheap and easily produced oil is over. Heavy oils and gas hydrates, in the context of depletion of traditional energy resources, are becoming increasingly important in the global economy. They are of particular importance in Kazakhstan, where light oil deposits are more than half depleted, and at the same time, existing and potential refiners in most cases do not have direct access to resources. Operating costs for the production of heavy oil and natural bitumen are 3-4 times higher than the costs for the production of light oil, which is associated not only with the higher density and viscosity of heavy oils, but also with the insufficient development of the technology for its production and processing in our country.

The presence of high-viscosity oil (HVO) deposits in Kazakhstan with large concentrations of associated elements has not contributed to the increase in production of this type of petroleum feedstock for a long time due to its high cost. Moreover, chemical compounds of high-viscosity oil have a negative impact on oil refining processes, reduce the performance of petroleum products, and corrode equipment [6]. In this regard, reduction of the HVO cost necessitates the introduction of new innovative technologies and methods for its extraction.

The Moldabek Vostochny section of the Kenbai deposit began development in 1999. There are 10 productive formations under development, 3 of which are confined to Cretaceous deposits, 7 to Jurassic ones. All layers are combined into 7 development objects. The main production at the field is provided by facilities in Jurassic deposits (Figure 1.1). At the beginning of this year, production from purely chalk deposits is ~16% of total production, while the current stock of producing wells in chalk (objects I and II) is ~44%. The development of Cretaceous horizons is complicated due to the high viscosity of oil: its average value over the horizons exceeds 200 cP [7,8].

Theoretical justification.

The average fluid flow rate as a result of processing is determined by the formula

$$q_{cp} = \frac{\left(\frac{k_e}{k_a} ln\frac{r_a}{r_e} + ln\frac{r_e}{r_a}\right) q_0}{\frac{\mu_0}{\mu_e} ln\frac{r_0}{r_e} + \frac{k_e}{k_a} ln\frac{r_a}{r_0} + ln\frac{r_e}{r_a}}$$

Here μ_e, μ_o are the dynamic viscosities of oil under reservoir conditions and at the average temperature in the heated zone in mPa·s.

The main indicators when designing steam-thermal treatment are: injection rate, injection duration, rate of increase in flow rate and duration of well operation at increased flow rate.

The duration of injection and the radius of the heated zone are determined by the nomogram (*Figure 1*), if the linear flow rate of dry steam per meter of productive strata and the coefficient characterizing the specific enthalpy of the formation (φ) are known. The rules for using the nomogram are explained by the diagram shown in the same figure.

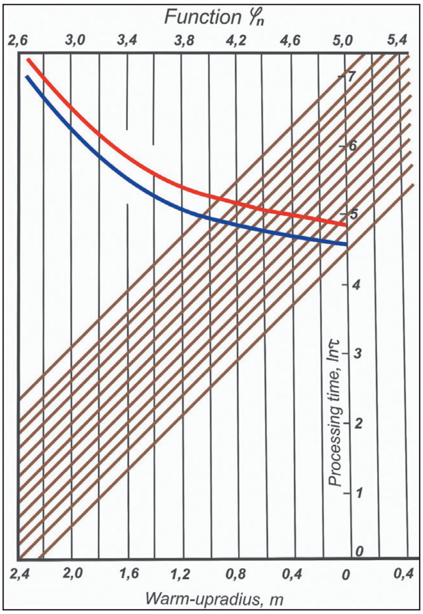

Figure 1 – **Nomogram for determining the parameters of periodic electrothermal treatment of wells**

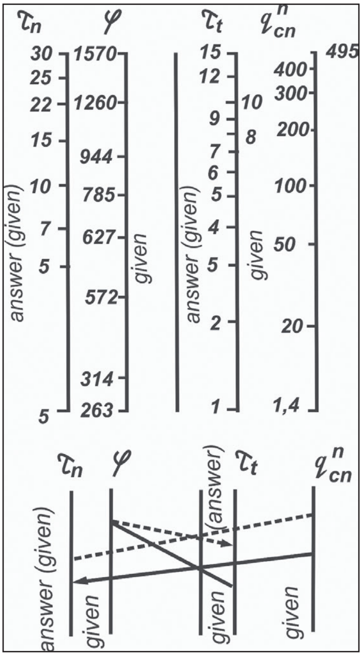

Figure 2 – **Nomogram for determining the duration of steam injection.**

Here $q^h_{СП} = \frac{q_{СП}}{h}$ is the linear flow rate of dry steam in kg/(h·m); $q_{СП}$ - dry steam consumption in kg/h; h - reservoir thickness;

$$\varphi = \pi\left[m(1 - S_В)\rho_{НП}x_П + (1 - m)c_М\rho_М\frac{t_П - t_{ПЛ}}{i_П} + mS_Вc_В\rho_В\frac{t_П - t_{ПЛ}}{i_П}\right];$$

$$\rho_{НП} = \frac{1}{\frac{x_П}{\rho_{СП}} + \frac{1 - x_П}{\rho_В}},$$

where $S_В$ is the water saturation of the formation in fractions of a unit; $\rho_{НП}$ - density of wet and saturated steam at the bottom in kg/m^3; m - formation porosity in fractions of a unit; $X_П$ - steam dryness at the bottom in fractions of a unit; $c_М$, $\rho_М$ – heat capacity and density of the formation rock mineral in kJ/(kg·^{0}C) and kg/m^3; $i_П$ - latent heat of vaporization in kJ/kg; $c_В$, $\rho_В$ – specific heat capacity and density of condensate at the bottom in kJ/(kg·^{0}C) and kg/m^3; $t_П$ - steam temperature at the bottom is ^{0}C; $t_{ПЛ}$ – reservoir temperature at ^{0}C.

The duration of well operation at increased flow rate as a result of treatment is determined by the formula

$$\tau_{эф} = \frac{\pi r_t^2 hC_П}{q_{ср}C_ж} ln\frac{t_П}{60}$$

where r_t is the radius of the heated zone; $C_П$, $C_Ж$ – the volumetric heat capacity of the formation and liquid, respectively, in kJ/(m^3·^{0}C). The value $q_{СР}$ is determined from *fig. 2.*

Study. The current production of chalk reserves is very low; recovery under the current development scheme will most likely not exceed 5% of the initial recoverable reserves, while it is the chalk deposits that have the maximum geological and recoverable reserves. The approved design oil recovery factor (hereinafter referred to as the ORF) of object I is 38% and assumes the full-scale use of thermal development methods (*Figure 3*).

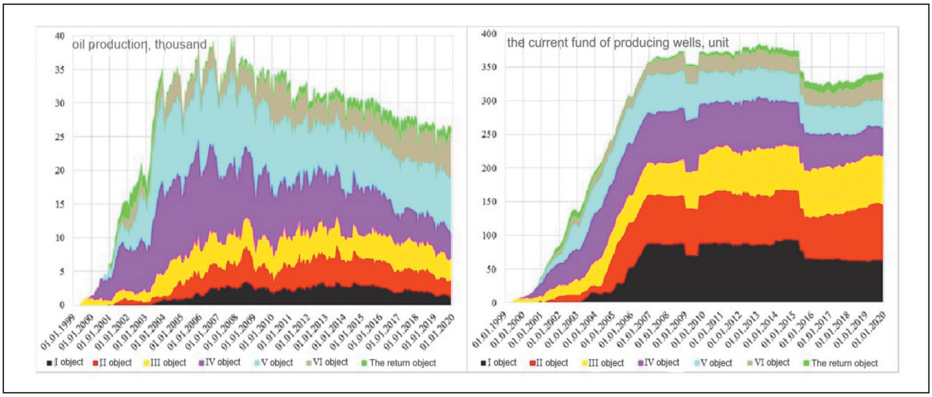

Figure 3 – **Oil production and operating stock of production wells by facility [1]**

Thermal development technologies are one of the most effective methods of influencing the formation in order to intensify oil production and increase oil recovery. Currently, various methods of thermal influence based on the injection of hot water, steam or the creation of an in-situ combustion center have found widespread use [9,10]. The best coolant from among those technically possible for use is water vapor. In this regard, improving the efficiency of using this technology is of direct practical importance.

In recent years, certain progress has been achieved in the development of oil fields with high-viscosity oils in the Republic of Kazakhstan and abroad [11]. One of the achievements for Kazakhstan is the use of thermal methods technology, namely the injection of water vapor at the Kenkiyak and Karazhanbas fields. For these fields, the experience of using thermal effects on the formation was reviewed.

The first SHT section includes eight injection wells №№ 6001, 6002, 6003, 6006, 6008, 6009, T-1249, T-1251, all wells are located in block III. Thermal impact measures at this site have been ongoing since 2003. As of the reporting date, a total of 2,284 thousand tons of steam were pumped into the site. When pumping steam into productive formations, the following conditions were observed:

• injection capacity of one injection well is 65 t/day. • pressure at the mouth – 2.1 MPa; • temperature at the mouth – 213.3 °C;

• steam dryness – 78%.

To determine the effectiveness of the ongoing constant steam injection at eight steam injection wells, an analysis of the operation of nearby reacting wells was carried out. *Figure 1* shows a map of the location of reacting wells (*Figure 4*).

Cumulative oil production at the site amounted to 757.2 thousand tons, liquid production – 2490.7 thousand tons. A total of 50 wells were in production. Additional oil production is estimated at 135.2 thousand tons. After five years, the radius of the heating zone increases, but the oil saturation decreases and becomes close to residual. Accordingly, reacting wells that fall into the zone of oil saturation close to residual are characterized as low-yield and high-water-cut. The steam-oil ratio is 8.9 t/t.

The first group of wells (sections) is characterized by the presence of a direct connection between liquid withdrawals and steam injection, which manifests itself in a decrease in liquid levels immediately after the cessation of steam injection, a decrease in

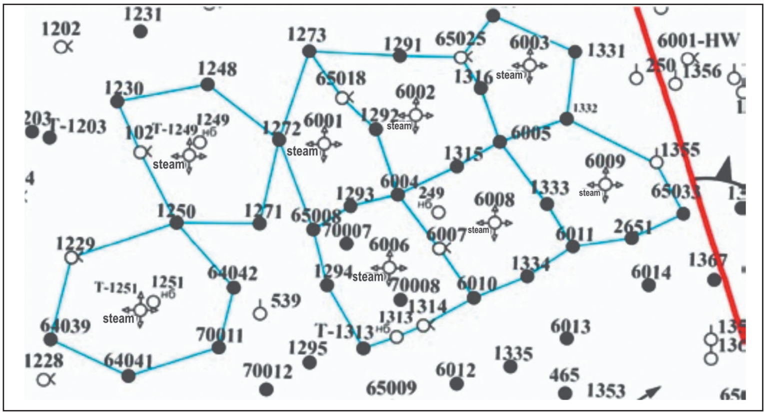

Figure 4 – **Map of reacting wells of SHT section №1* [1]**

water cut, and, accordingly, an increase in the share of produced oil. After steam injection is resumed, liquid levels begin to rise along with water cut. Thus, the above-described dynamics of indicators takes the form of harmonic oscillations, presented in *Figure 2*, using the example of the reacting environment of well 2724, where the injection period corresponds to an increase in liquid and water cut, respectively, the idle period corresponds to a decrease in liquid levels and water cut [12-14].

- The second group of wells (areas) is characterized by the absence of dependence between steam injection and liquid extraction. All wells in this group are located in the southern marginal part of reservoir 3, where the active influence of peripheral injection is observed. *Figure 3* shows the characteristic dynamics of indicators for wells of the second group using the example of the reacting environment of well 4415.

The second SHT section includes nine injection wells №№ 61028, 61040, 61051, 61062, 61026, 61024, 61038, 61050, 61060, (*Figure 5-6*) which are located in block I-2.

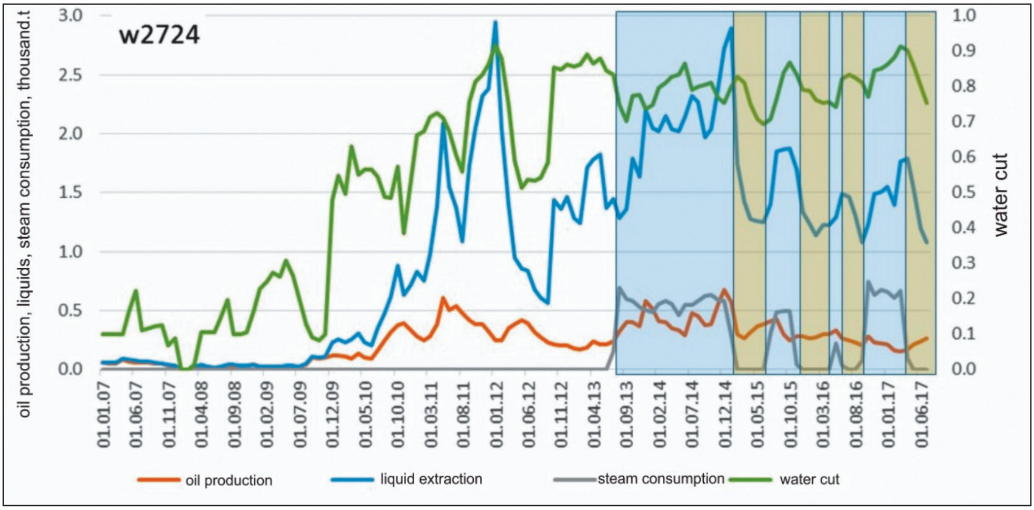

Figure 5 – **Dynamics of technological indicators in the reacting environment of well 2724 [1]**

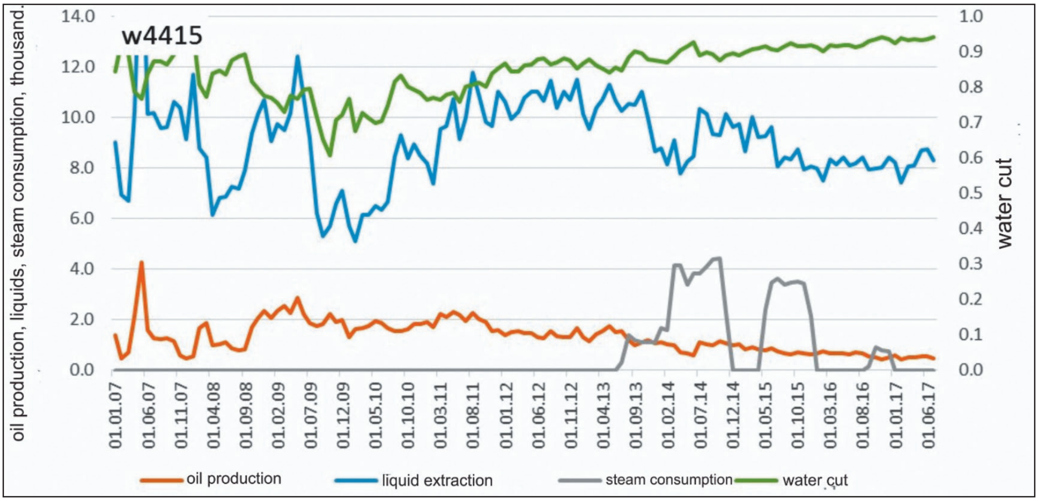

Figure 6 – **Dynamics of technological indicators in the reacting environment of well 4415 [1]**

Continuous injection of steam in this area has been carried out since June 2010; before that, SCTW and hot water injection were carried out at these wells.

When analyzing development in areas with periodic operation, it was possible to identify the following patterns, identifying two groups of injection wells with characteristic behavior of liquid production in reacting wells 4415:

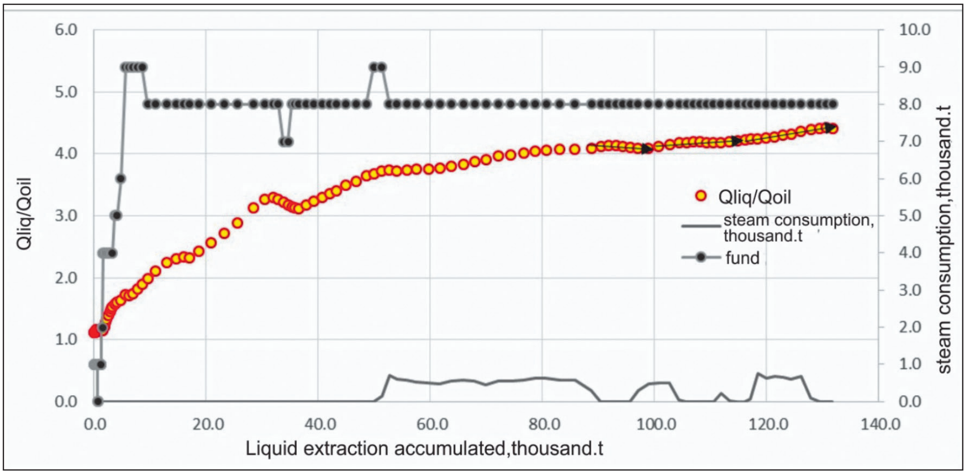

Figure 7 – **Dependence of Ql/Qo on Ql for the reacting environment of well 2724 [1]**

To assess technological efficiency, the dependence of the liquid-oil factor (Ql/Qo(Ql)) on the accumulated liquid production was analyzed. As the dependence for group 1 of wells shows, this development method makes it possible to increase the involved reserves of the reacting environment. This follows from the behavior of the Ql/Qo curves in *Figure 7*, where during periods of downtime there is a decrease in the angle of inclination of the curve relative to the X axis, which is not observed in *Figure 8*, which characterizes the operation of group 2 of wells.

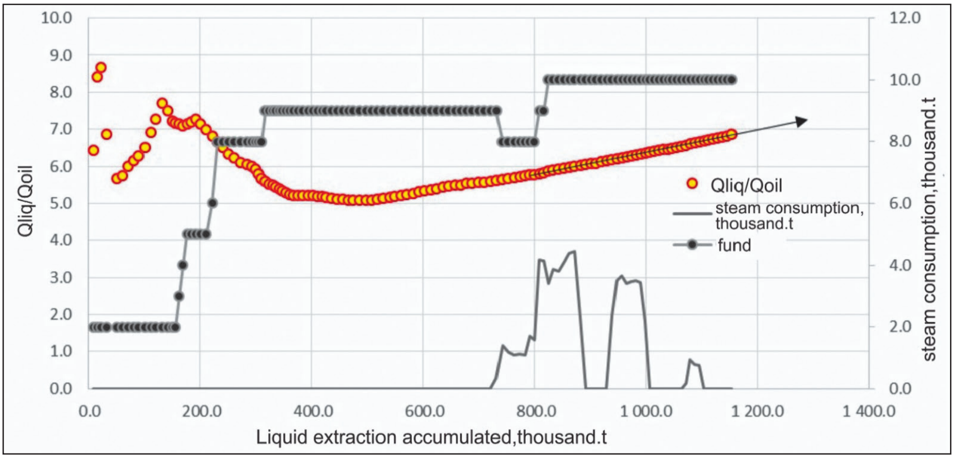

Figure 8 – **Dependence of Ql/Qo on Ql for the reacting environment of well 5116 [1]**

At the initial stage of applying steam injection technology (2-5 years) in the eastern section of the facilities, an increase in oil flow rate per well was observed, then its decrease and stabilization in the east of object 1, a constant decrease in the east of object 2, initially a sharp, then less intense drop in the east of object 3 is recorded. In the northern block, with the introduction of the SHT system, the previous rate of decline in flow rate is reduced.

With the beginning of the use of steam injection technology in all areas, the growth rate of water cut was reduced; over the past three years, the water cut rate has stabilized at around 75-80%.

The volume of steam required to extract 1 ton of oil (steam-oil factor) in SHT areas over the last five years of development has increased from 2.1 to 4.5 t/t, therefore, the volume of oil per ton of injected steam has decreased.

Low steam dryness at the bottom of most steam injection wells and low temperatures in production wells indicate a decrease in the quality of the agent used in the field conditions, which leads to a violation of the thermodynamic state of the interwell space and a decrease in the efficiency of the technology itself. The wellhead temperatures of the main number of injection wells do not correspond to the required parameters, which also indicates non-compliance with the technology and, accordingly, low steam quality;

In steam injection areas, oil production levels have been stable in recent years - in the northern block and growing in the eastern section of the 1st facility, which is supported by the commissioning of new project wells. In the eastern sections of objects 2 and 3, oil production decreases annually due to a drop in average flow rates with insignificant drilling volumes. With the beginning of the use of steam injection technology, the rate of increase in water cut was reduced in all areas;

The temperature front in the steam injection areas is distributed unevenly; in individual production wells located in the steam injection zone, according to deep measurements, the temperature does not exceed (+30°C);

The volume of steam required to extract 1 ton of oil (steam-oil factor) in SHT areas over the past five years of development has increased from 2.1 to 4.5 t/t;

The use of the technology of alternating steam and water injection in 6 cells of the western section since April 2016 shows positive technological efficiency over 1.5 years, expressed by an additional total increase in oil in the amount of 28,376 tons.

Conclusion. When analyzing the dynamics of technological indicators of the sites, it was found that in most cases the periods of downtime and steam injection had different durations (from 1 to 6 months), which obviously affected the drop in liquid production levels. In order to fully replenish the decreased fluid levels and reservoir pressure during the downtime period, it is necessary to maintain an equal level of compensation for injection extraction during each injection cycle, as well as equal duration of the downtime and injection cycles.

Thus, this method of regulating development with proper control over development makes it possible to maintain the level of oil production at a constant level, reducing the rate of watering and the likelihood of steam breakthrough, which is typical for areas with constant steam injection, while reducing the cost of steam production.

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