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HYDRODYNAMIC SIMULATION OF THE STEAM-ASSISTED GRAVITY DRAINAGE METHOD FOR DIFFERENT RESERVOIR THICKNESSES USING ECLIPSE

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Abstract. The Steam-Assisted Gravity Drainage (SAGD) method is one of the most effective methods of oil recovery from low-permeability reservoirs with high-viscosity oil. Particularly for productive reservoirs with thicknesses of 25 and 30 meters, the SAGD method may be successfully applied under certain conditions. One of the main advantages of the SAGD method is the capability to recover oil from thin reservoirs that were previously inaccessible for production. In addition, the SAGD method may significantly boost the oil production ratio and minimize the negative impact on the environment, since it requires fewer wells than conventional production methods. However, the application of the SAGD method also has its limitations and drawbacks. In particular, the method requires considerable initial investment, as well as high-energy intensity. In addition, the SAGD method may not be effective under certain geological settings, such as a rough reservoir surface and the presence of geological checks. Thus, the successful application of the SAGD method for productive reservoirs with thicknesses of 25 and 30 meters requires a thorough study of the geological, hydrodynamic and economic conditions of the field. Besides, a detailed simulation of the SAGD process employing custom-made software tools, such as Eclipse, should be performed to optimize process parameters and maximize oil production.

Keywords: high-viscosity oil, bitumens, thermal methods, hydrodynamic simulation, ECLIPCE, SAGD

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ECLIPSE ПАЙДАЛАНУ АРНАЛҒАН ӨНІМДІ ПРОГРАММАЛАРДЫҢ ТҮРЛІ ҚАЛАНДЫҚТАРЫНДАҒЫ БУ ГРАВИТАЦИЯЛЫҚ ДРЕНАЖ ӘДІСІН ГИДРОДИНАМИЯЛЫҚ СИМУЛАУ

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Аннотация. Бу гравитациялық мұнай дренажы (SAGD) тығыз және тұтқыр қабаттардан мұнайды алудың ең тиімді әдістерінің бірі болып табылады. Атап айтқанда, қалыңдығы 25 және 30 метр болатын су қоймалары үшін SAGD әдісі белгілі бір жағдайларда сәтті қолданылуы мүмкін. SAGD әдісінің негізгі артықшылықтарының бірі - бұрын пайдалану мүмкін болмаған жұқа қабаттардан мұнай алу мүмкіндігі. Сонымен қатар, SAGD әдісі мұнай өндіру жылдамдығын айтарлықтай арттырып, қоршаған ортаға теріс әсерді азайта алады, өйткені ол дәстүрлі өндіру әдістеріне қарағанда аз ұңғымаларды қажет етеді. Дегенмен, SAGD әдісін қолданудың шектеулері мен кемшіліктері де бар. Мысалы, әдіс бастапқы кезеңде айтарлықтай инвестицияларды, сондай-ақ жоғары энергия сыйымдылығын талап етеді. Сонымен қатар, SAGD әдісі кейбір геологиялық жағдайларда тиімді болмауы мүмкін, мысалы, қабат бетінің біркелкі еместігі және геологиялық кедергілердің болуы. Осылайша, қалыңдығы 25 және 30 метр болатын су қоймалары үшін SAGD әдісін сәтті қолдану үшін кен орнының геологиялық, гидродинамикалық және экономикалық жағдайларын мұқият зерделеу қажет. Сонымен қатар, Eclipse сияқты арнайы бағдарламалық құралдарды пайдалана отырып, SAGD процесін егжей-тегжейлі модельдеу процесс параметрлерін оңтайландыру және мұнай беруді барынша арттыру үшін қажет.

Түйін сөздер: тұтқырлығы жоғары мұнай, битум, термиялық әдістер, гидродинамикалық модельдеу, ECLIPCE, SAGD

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ГИДРОДИНАМИЧЕСКОЕ МОДЕЛИРОВАНИЕ МЕТОДА ПАРОГРАВИТАЦИОННОГО ДРЕНИРОВАНИЯ ДЛЯ РАЗНЫХ ТОЛЩИН ПРОДУКТИВНОГО ПЛАСТА С ПРИМЕНЕНИЕМ ECLIPSE

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Аннотация. Метод парогравитационного дренажа нефти (SAGD) является одним из наиболее эффективных методов добычи нефти из низкопроницаемых пластов с высоковязкой нефтью. В частности, для продуктивных пластов с толщинами 25 и 30 метров метод SAGD может быть успешно применен при определенных условиях. Одним из основных преимуществ метода SAGD является возможность добычи нефти из тонких пластов, которые ранее были недоступны для эксплуатации. Кроме того, метод SAGD может значительно увеличить коэффициент добычи нефти и сократить негативное воздействие на окружающую среду, так как он требует меньше скважин, чем традиционные методы добычи. Однако применение метода SAGD также имеет свои ограничения и недостатки. Например, метод требует значительных инвестиций на начальном этапе, а также высокой энергоемкости. Кроме того, метод SAGD может быть неэффективен при некоторых геологических условиях, таких как неровная поверхность пласта и наличие геологических препятствий. Таким образом, для успешного применения метода SAGD для продуктивных пластов с толщинами 25 и 30 метров, необходимо тщательно изучить геологические, гидродинамические и экономические условия месторождения. Кроме того, необходимо провести детальное моделирование процесса SAGD с использованием специализированных программных инструментов, таких как Eclipse, для оптимизации параметров процесса и максимизации добычи нефти.

Ключевые слова: высоковязкая нефть, битумы, тепловые методы, гидродинамическое моделирование, ECLIPCE, SAGD

Introduction

There are considerable challenges in the global oil and gas industry to actively develop huge reserves of high-viscosity oils and bitumens. Reserves of light oils are gradually depleted and there is a need for maximum possible recovery of high-viscosity oils and bitumens to replenish and strengthen the resource base of the fuel and energy complex.

Experience in developing fields of high-viscosity oils and bitumens has shown that the most effective and feasible recovery methods for heavy oils are thermal methods.

By now the global oil industry is developing rapidly and at a tremendous pace, new methods and technologies for recovery of heavy oils are appearing, making our options vast when choosing thermal methods for a particular field. Thus, some of the main and frequently used methods of thermal treatment are as follows: - steam-treatment, - in-situ combustion, - hot water injection, - steam-cyclic treatment of bottomhole zones of producing wells and combination of these methods with other physical and chemical methods (combined methods) (McLennan et al., 2006).

As evidenced in practice, the most widespread of all known arsenal of thermal methods are technologies, the essence of which is based on the heat transfer agent injection into the reservoir: the reservoir stimulation by pattern steam injection and steam-cycling treatment of producing wells.

Due to the above-mentioned technologies about 80 % of all high-viscosity oils and bitumens are produced in the world via state-of-the-art enhanced oil recovery methods (Karazhanova et al., 2023).

In order to select the optimal method of thermal treatment of the pay zone, it is necessary to study the geological and production characteristics of the productive reservoir, build a model of the reservoir, and calculate the expected well rates in the SAGD method for different reservoir thicknesses (Gotawala et al., 2010).

Meanwhile, it is necessary to build a model of the well, calculate its profile, and determine the length of the horizontal section to employ the SAGD method.

Methods

The mathematical model built in the Eclipse program allows determining the state of the simulated process at any time by its known initial state. By setting a change of this or that parameter, it is possible to draw conclusions about its overall effect on the process (Birrell et al., 2000).

In order to build a hydrodynamic model, the candidates of X field, characterized by high values of density and viscosity of oil, were selected. The characteristics of 2 productive reservoirs with a thickness of 25 and 30 m to build a hydrodynamic model were as follows:

- the density of oil is about 915 kg/m^3;
- the reservoir waters are of the calcium chloride type with a density of 1.095 g/cm^3 and mineralization of 95 g/l;

- the oil viscosity is 5.6 Pa*s, i.e. the oil in the field belongs to ultra-viscous.

The characteristics of a productive reservoir are as follows:

- the vertical thickness of pay zone is 25 and 30 m at depths of 903–936 m;
- the reservoir is composed of irregularly alternating sandy-siltstone and clayey rocks;
- pay zones in the field are represented by sandstones and siltstones, with a porosity of 23–29 % (open porosity);
- the permeability of rocks is 1500 mD;
- oil saturation factor is 0.5–0.6;
- the gas saturation factor is 0.32–0.69;
- initial reservoir pressure in reservoirs is 2.0–2.5 MPa;
- temperature is 25–35°C;
- oil flow rates are 26.4–62.1 m3/day.

Based on the set objectives, the first stage was built a mathematical model in the Eclipse program, which allows determining the state of the simulated process at any time by its known initial state (Chan et al., 2012). At the second stage according to SAGD method, the process of injection of highly heated steam into productive reservoir was simulated with the following injection regime: — steam temperature - 300°C, steam injection volume — 1600 kg/hour, for 15 days (Gladkov et al., 2012). By setting a change of one or another parameter in the ECLIPSE program, it is quite possible to draw conclusions about its effect on the process occurring in the reservoir as a whole (Zhao et al., 2013).

We used the ECLIPSE 2003A_1 program version to build models (Schlumberger, ECLIPSE – 2003). In this program version, the following innovations are used to build the well model:

– Steam Assisted Gravity Drainage (SAGD) technology option is implemented, which allows determining the injection capacity of well, depending on the selection of neighboring wells of the scheme. This option is controlled by the WCONINJP keyword;

– connection D-factors for the inflow-dependent skin factor can be calculated from the expression defined by the WDFACCOR keyword. This expression is based on the correlation of the inertial resistance coefficient, which depends on the permeability and porosity of the connected grid units;

– wells and groups can now control their heat rate with new control modes and values/limits in the WCONPROD and GCONPROD keywords. The molar thermal equivalents must be defined with the CALVAL keyword before applying the new control mode;

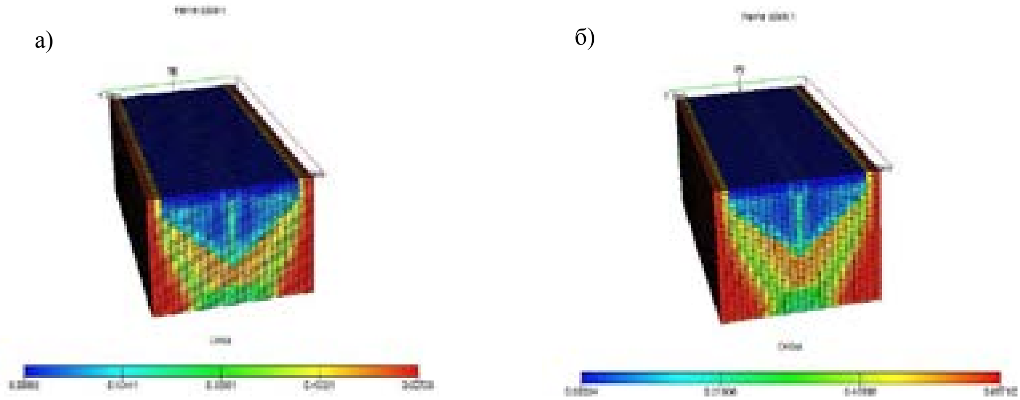
– the WINJMULT keyword can now be employed to enter multipliers for injection wells changing along with their bottomhole pressure value, or wellbore pressure adjacent to individual junctions.

Calculated hydrodynamic models of the SAGD method were built for productive reservoirs with vertical thickness of pay zone of 25 and 30 m and flow rate planning for the operation period of 10 years (Zhao et al., 2014).

Results and Discussion

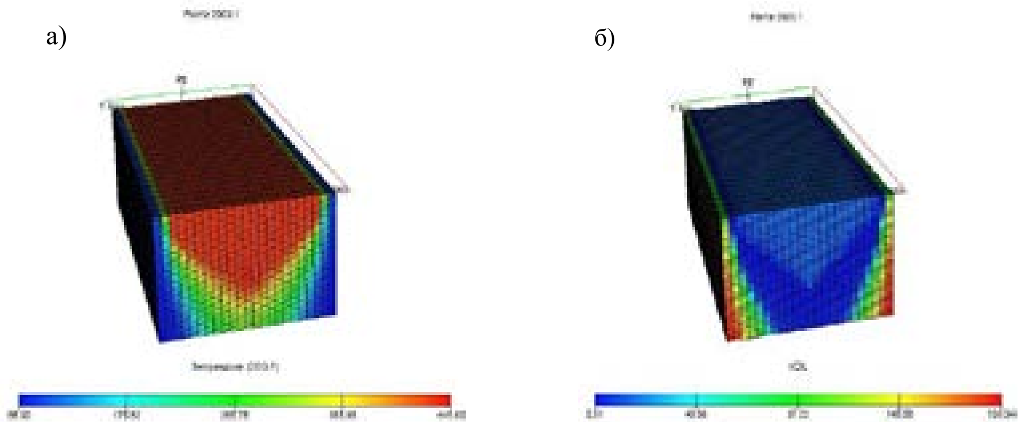
The oil saturation growth model shown in Figure 1a after the SAGD process shows a significant increase in oil saturation over time (the red zone turns to yellow and then to blue).

Figure 1b shows the growth of reservoir rock temperature surrounding the steam chamber in the reservoir, which allows concluding that the temperature of the productive reservoir increases over time and has a positive effect on reducing oil viscosity and increasing the oil recovery factor (ORF) - the blue zone gradually turns into red.



- growth of oil saturation in the reservoir at h = 25 m (a) and at h = 30 m (b).

Fig. 1 - Computational model of oil saturation growth for productive reservoirs at h = 25 m and h = 30 m

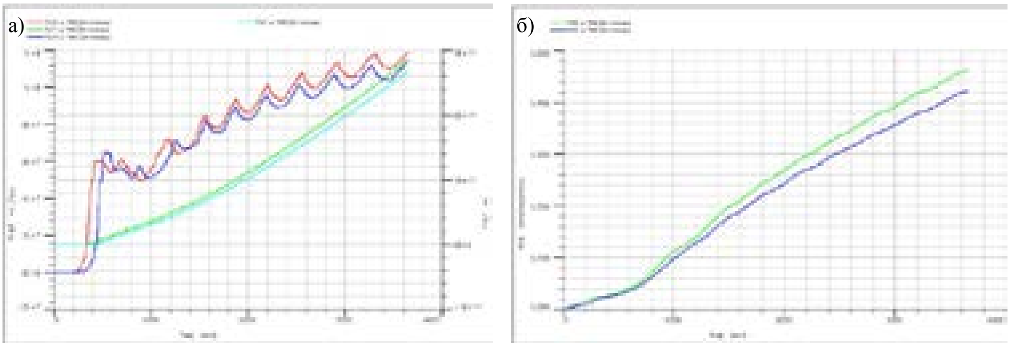


- visualization of steam chamber impact on the productive reservoir at h = 25 m (a) and at h = 30 m (b)

Fig. 2 - Visualization of oil volume change process under the steam impact at h = 25 m and h = 30 m

From the analysis of reservoir models, shown in Figure 2, it follows that the oil viscosity of the productive reservoir decreases significantly during the exposure time (the red zone gradually turns into a blue zone) and the heating of the reservoir zone increases, which positively affects both reducing oil viscosity and increasing the oil recovery factor.

From the graph in Figure 3a it follows that the total heat loss increases over time (blue and green lines) due to an increase in the steam chamber and, consequently, the heating area of the cap rock. Heating the upper part of the reservoir to the temperature of steam is undesirable because of the high heat loss in the surface, as well as because of the high heat requirements of the chamber. Losses in the covering layers also increase due to the fact that the steam chamber advances under the side of the reservoir roof and all the generated heat goes to heating the cap rock and the baren zone above the oil-saturated reservoir.



Instantaneous values of heat loss at h=30 m	Initial oil reserves at h = 25 m
Instantaneous values of heat loss at h=25 m	Initial oil reserves at h = 30 m
Total heat loss at h=25 m	
Total heat loss at h=30 m	

Fig.3 - Total heat loss and instantaneous heat loss (a) and initial oil reserves (b) at h = 25 and 30 m

In 10 years the ORF will reach a value of 0.36, which follows from the graph in Figure 3b (Butler et al., 1985). The graph corresponds to the graph built according to Butler theory (Butler et al., 1994) (Figure 4a).

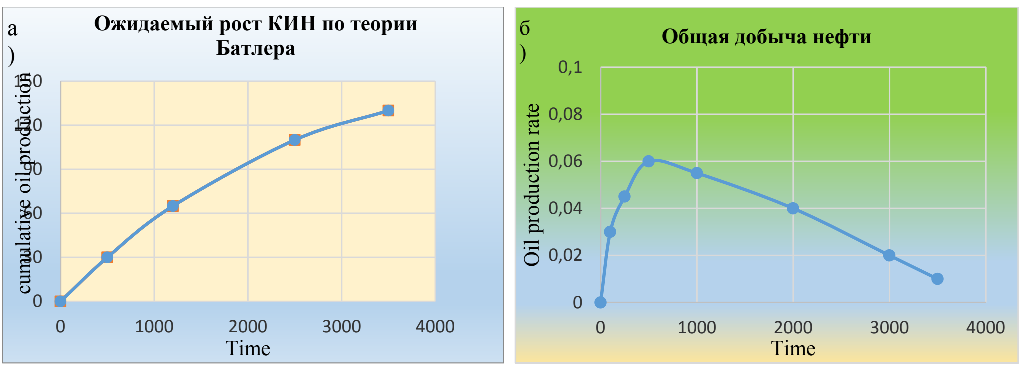
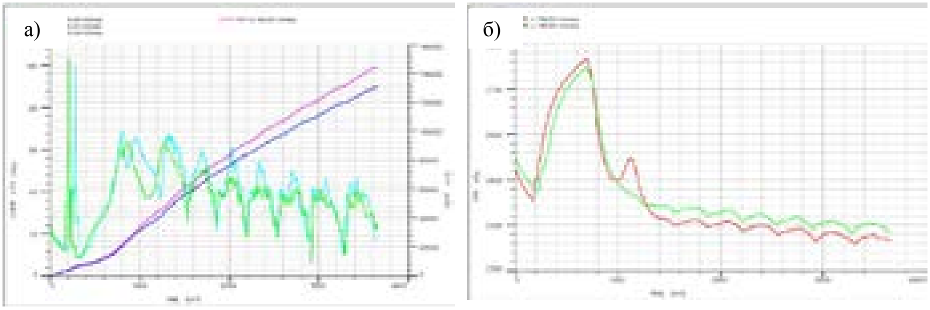


Fig.4 - Expected growth of ORF (a) and total oil production (b) according to Butler theory



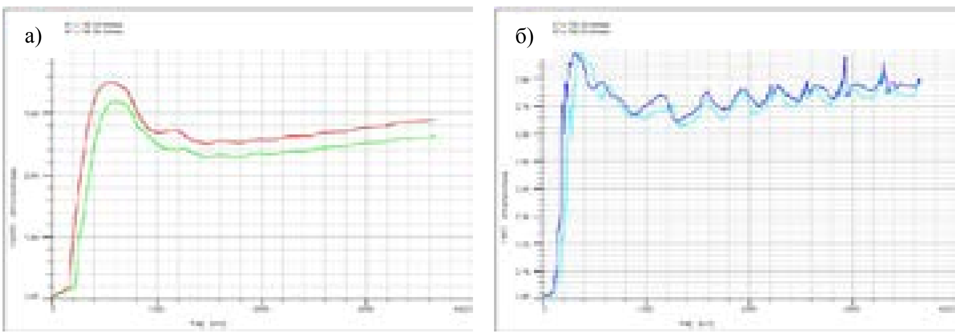
Total oil production at h=25 m
Total oil production at h=30 m
Oil production rate at h=25 m
Oil production rate at h=30 m

Pressure event at h = 25 m
Pressure event at h = 30 m

Fig. 5 - Oil production rate and total water production (a) and pressure event (b) at h = 25 and h = 30 m

Numerical results from Graph 5a predict the typical three stages of SAGD, i.e., the steam chamber while Butler theory captures only steam chamber growth and oil production decline after reaching a peak, when the steam chamber extends vertically to the top of the pay zone (Zhao et al., 2013). It has been observed that oil production rate curves show significant fluctuations, especially in the early stages of steam injection. This is probably due to frequent phase changes in the unit grid near the well area (Shin et al., 2007).

The Graph 5b shows the dependence of total oil production on the time of field development. Upon completion of all phases of field development, we determine the total production based on this graph. It is known that with increasing the period of field operation there is a decrease in reservoir pressure and the transition from the free-flow production method of the field to the pumping method, this process is well reflected in Graph 5b.



Cumulative steam-oil factor at h=25 m
Cumulative steam-oil factor at h=30 m

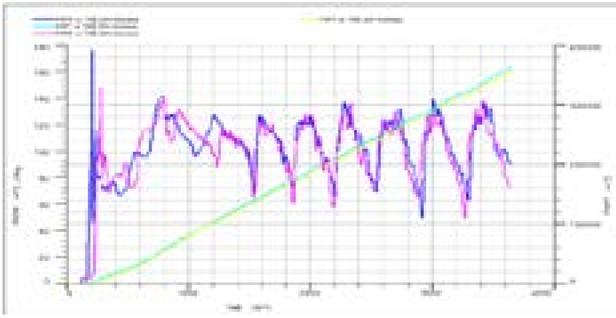
Watercut at h = 25 m
Watercut at h = 30 m

Fig. 6 - Cumulative steam-oil factor (a) and watercut (b) at h =25 and 30 m

Fig. 6 - Cumulative steam-oil factor (a) and watercut (b) at h =25 and 30 m

The increase in the steam-oil factor does not begin immediately with the injection of steam, but there is a gradual increase in its effect on the increase in oil production, as shown in the graph in Figure 6a.

As follows from the analysis of data shown in Figure 6b, when carrying out technological SAGD operations, the water cut of wells increases slightly from 0.55 to 0.75, which is due to a high degree of oil steam energy transfer and steam condensation at the boundary of the steam chamber.



Water flow rate at h=25 m — Total water production at h = 25 m
Water flow rate at h=30 m — Total water production at h = 30 m

Fig. 7 - Water flow rate and total water production at h = 25 and 30 m

Water flow rate during technological SAGD operations fluctuates in a significant amplitude in the initial period of time, and then the value of the water flow rate, significantly reduced and stabilized over time. Since the main source of steam in SAGD is water, the growth of its extraction over time is quite logical. The graph in Figure 7 shows that the growth of the volume of extracted water grows linearly over time.

Conclusion

The Steam-Assisted Gravity Drainage (SAGD) method is one of the thermal methods for increasing oil and gas production from low-permeability reservoirs with viscous oil. The method is based on the use of high-temperature steams to reduce oil viscosity and increase its mobility, which contributes to increased production.

The developed method of simulation in the ECLIPCE program allows to:

- preliminary evaluate the effectiveness of the SAGD method for the development of low-capacity productive reservoirs with high-viscosity oil;
- trace the process of high-viscosity oil heating in the reservoir and display the distribution of highly heated steam over time;
- determine the initial heat loss and initial oil reserves in the reservoir;
- calculate the expected ORF for a specified period of time;
- predict the rate of oil and water production, as well as pressure events in the reservoir;
- set the expected steam-oil factor and watercut of productive wells over time;
- obtain the expected water flow rate and total water production over time.

When simulating SAGD for different thicknesses of productive reservoirs, it is necessary to keep in mind that the SAGD process may be more effective for thin reservoirs than for thick ones. Thick formations may require the use of more wells and more steam generators to achieve the desired efficiency.

Thus, the hydrodynamic simulation of the Steam-Assisted Gravity Drainage method for different thicknesses of productive reservoirs using Eclipse is a complex and multi-parameter process, which requires the preparation of a geological model, determining the physical parameters of the reservoir.

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