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«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылыметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылымды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

Индексирование в Scopus и Web of Science обеспечивает высокую международную востребованность публикаций, способствует росту цитируемости и подтверждает стремление редакционной коллегии публиковать актуальные, оригинальные и научно значимые исследования в области геологии и технических наук.

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METHODS FOR IMPROVING OIL PRODUCTION EFFICIENCY USING PUMPING UNITS

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Abstract. The article examines methods for improving the efficiency of pumped oil production using low-power equipment–pendulum-type sucker-rod pumping units used in the mechanized operation of mature and low-rate oil fields. These units are characterized by high reliability, simplicity of operation and repair, and effective performance in high-viscosity oil production and increased water cut. Changes in the hydrodynamic and technological characteristics of wells at different stages of operation require adaptive control of the pumping equipment. The aim of the study is to develop and investigate an automatic control system that coordinates reservoir inflow with pumping unit capacity and ensures an energy-optimal well operating regime. The controlled object is a single well equipped with a pendulum-type sucker-rod pumping unit. The paper proposes a mathematical description of downhole fluid-level dynamics, taking into account the relationship between the dynamic fluid level, the position of the oil–water interface, and pump capacity. Two

variants of the control-system structure are considered, corresponding to early and late stages of well operation that differ in the degree of produced water cut. For wells at the early stage, a single-loop stabilizing control system with a proportional (gain) controller is synthesized; static accuracy is provided by the integrating properties of the well as the control object. For wells at the late stage, a two-loop control structure is developed, based on regulating the dynamic level and maintaining a minimum allowable "safety oil layer" that prevents water from entering the pump, thus limiting premature water breakthrough into the intake. The effectiveness of the proposed algorithms is confirmed by Simulink simulations. It is shown that the developed automatic control system provides stable operation of the pumping equipment under varying inflow conditions, reduces energy consumption, and increases the efficiency of operating low-rate and high-water-cut wells, confirming its practical applicability in oilfield production.

Keywords: oil production, sucker rod pumping units, well water cut, pump performance, wellbore fluid, oilfield

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СОРАП ҚОНДЫРҒЫЛАРЫН ҚОЛДАНУ АРҚЫЛЫ МҰНАЙ ӨНДІРУ ТИІМДІЛІГІН АРТТЫРУ ӘДІСТЕРІ

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Аннотация. Мақалада мұнайды сораптық әдіспен өндіру тиімділігін арттырудың тәсілдері аз қуатты жабдықты - жетілген және аз дебитті мұнай кен орындарын механикаландырылған пайдалану кезінде кеңінен қолданылатын маятникті типті штангалы ұңғымалық сорап қондырғыларын пайдалану арқылы қарастырылады. Бұл қондырғылар жоғары сенімділігімен, пайдаланудың, жөндеудің қарапайымдылығымен, тұтқырлығы жоғары мұнайды өндіру және өнімнің сулануы артқан жағдайларда тиімді жұмыс істеу мүмкіндігімен сипатталады. Сонымен қатар, ұңғымалардың әртүрлі пайдалану кезеңдеріндегі гидродинамикалық және технологиялық сипаттамаларының өзгеруі сорап жабдығының жұмыс режимдерін басқарудың бейімделгіш әдістерін қолдануды талап етеді. Жұмыстың мақсаты — қабаттан келетін сұйық ағынын сорап қондырғысының өнімділігімен үйлестіруді және ұңғыманы энергия тұрғысынан оңтайлы пайдалану режиміне қол жеткізуді қамтамасыз ететін мұнай өндіру процесін автоматты басқару жүйесін әзірлеу және зерттеу. Басқару объектісі ретінде маятникті типті штангалы сорап қондырғысымен жабдықталған жеке ұңғыма қарастырылады. Жұмыста динамикалық деңгей, мұнай-су шекарасының орналасуы және сорап өнімділігі арасындағы өзара байланыс ескерілетін, ұңғымадағы сұйық деңгейлерінің динамикасына математикалық сипаттама ұсынылған. Өндірілетін өнімнің сулану дәрежесі бойынша ерекшеленетін ұңғымаларды пайдаланудың ерте және кеш кезеңдеріне сәйкес автоматты басқару жүйесінің құрылымының екі нұсқасы қарастырылды. Ерте кезеңдегі ұңғымалар үшін күшейткіш реттегіші бар бір арналы тұрақтандырушы басқару жүйесі синтезделді, мұнда статикалық дәлдік басқару объектісі ретінде ұңғыманың интегралдаушы қасиеттерімен қамтамасыз етіледі. Кеш кезеңдегі ұңғымалар үшін динамикалық деңгейді реттеуге және суының сорапқа түсуін болдырмайтын мұнайдың ең төменгі рұқсат етілген «сақтандыру қабатын» ұстап тұруға негізделген екі арналы басқару құрылымы әзірленді. Ұсынылған басқару алгоритмдерінің тиімділігі Simulink ортасында жүргізілген имитациялық модельдеу нәтижелерімен расталды. Әзірленген автоматты басқару жүйесі сорап жабдығының тұрақты жұмысын қамтамасыз ететіні, энергетикалық шығындарды азайтатыны және аз дебитті әрі жоғары суланған ұңғымаларды пайдаланудың тиімділігін арттыратыны көрсетілді, бұл оның мұнай өндіру тәжірибесінде қолданылуының перспективалылығын дәлелдейді.

Түйін сөздер: мұнай өндіру, штангалы сорап қондырғылары, ұңғымадағы су мөлшері, сорап өнімділігі, ұңғы түбіндегі сұйықтық, мұнай кен орны

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МЕТОДЫ ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ НЕФТЕДОБЫЧИ С ПРИМЕНЕНИЕМ НАСОСНЫХ УСТАНОВОК

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Аннотация. В статье рассматриваются методы повышения эффективности насосной добычи нефти с использованием маломощного оборудования — штанговых скважинных насосных установок маятникового типа, широко применяемых при механизированной эксплуатации зрелых и малодебитных нефтяных месторождений. Данный тип установок характеризуется высокой надёжностью, простотой эксплуатации и ремонта, а также возможностью эффективной работы в условиях добычи высоковязкой нефти и повышенной обводнённости продукции. Вместе с тем изменение гидродинамических и технологических характеристик скважин на различных этапах эксплуатации требует применения адаптивных методов управления режимами работы насосного оборудования. Целью работы является разработка и исследование системы автоматического управления процессом добычи нефти, обеспечивающей согласование притока жидкости из пласта с производительностью насосной установки и достижение энергетически оптимального режима эксплуатации скважины. В качестве объекта управления рассматривается одиночная скважина, оборудованная штанговой насосной установкой маятникового типа. В работе предложено математическое описание динамики уровней скважинной жидкости с учётом

взаимосвязи между динамическим уровнем, положением границы раздела нефти и воды и производительностью насоса. Рассмотрены два варианта структуры системы автоматического управления, соответствующие ранней и поздней стадиям эксплуатации скважин, различающимся степенью обводнённости добываемой продукции. Для скважин на ранней стадии эксплуатации синтезирована одноканальная стабилизирующая система управления с усилительным регулятором, при которой статическая точность обеспечивается интегрирующими свойствами скважины как объекта управления. Для скважин на поздней стадии эксплуатации разработана двухканальная структура системы управления, основанная на регулировании динамического уровня и поддержании минимально допустимого «страхового слоя» нефти, предотвращающего поступление воды в насос. Эффективность предложенных алгоритмов управления подтверждена результатами имитационного моделирования в среде Simulink. Показано, что разработанная система автоматического управления обеспечивает устойчивую работу насосного оборудования, снижение энергетических затрат и повышение эффективности эксплуатации малодебитных и высокообводнённых скважин, что подтверждает перспективность её применения в практике нефтедобычи.

Ключевые слова. Добыча нефти, штанговые скважинные насосные установки, обводненность скважины, производительности насоса, скважинная жидкость, месторождение

Introduction. One of the key challenges facing the oil industry is improving production efficiency at fields where primary hydrocarbon reserves have been depleted. In Kazakhstan, as elsewhere globally, discovered reserves of light crude are being exhausted, while production increasingly relies on oil with high paraffin, resin, and asphaltene content. From the standpoint of rational natural resource management, the development of new combined, environmentally safe, and efficient technologies to enhance reservoir oil recovery can deliver significant material savings, reduce environmental risks, and improve overall production efficiency. At many producing hydrocarbon fields worldwide, extraction is approaching its final stages. Conventional recovery methods that rely on natural reservoir energy typically allow only about 5–20% of the original oil in place to be produced (Mullakaev et al., 2017: 1-7; Ghamartale et al., 2019:305-314), leaving a substantial portion of the resource unrecovered in the reservoir. Therefore, it is essential to develop technologies that increase oil recovery and enable the secondary use of existing oil wells (Jeong et al., 2021). Enhancing the performance of innovative oil production methods is thus one of the most critical tasks in the oil and gas industry.

To improve well productivity and reduce production costs, various methods are employed, including traditional, technological, and modern innovative approaches: artificial lift methods (mechanical recovery) (Leontyev et al., 1990), ultrasonic technologies (Liang et al., 2021: 1066-1076; Chaiworapuek et al., 2021; Ostermeier et al., 2021; Avvaru et al., 2018:493-507), the application of artificial intelligence

and digital technologies (Artun,2016; Bakshi et al., 2017; Vershinin et al., 2020 a; Vershinin et al., 2021 b), enhanced oil recovery (EOR) techniques (Larry, 1989), and others. These methods help improve efficiency and resilience in the presence of uncertainties and process variations. One of the approaches for modeling technological processes under uncertainty is the robust approach (Satybaldina et al., 2022 a: 4883-4891; Satybaldina et al., 2022 b:3572-3582; Satybaldina et al., 2023 c:6249-6258). In the control of oil production processes, uncertainties arise because real-world operating conditions often deviate significantly from ideal assumptions: variations in reservoir parameters (permeability, fluid saturation, pressure, etc.), fluctuations in fluid properties (oil, water, gas), instability of equipment (pumps, wells, compressors), and external disturbances (changes in bottomhole pressure, water breakthroughs, increasing water cut), among others. The robust approach in oil production process control enables the design of control systems that deliver the required performance and safety levels despite large uncertainties in the properties of the medium, processes, and equipment.

It is expected that declining oil production at large fields will primarily result from falling reservoir pressure and sharp increases in water cut. Increasingly, oil production will shift away from aging giant reservoirs toward large, medium, and small fields (Kalyuzhnyy, 2019). In Kazakhstan, most of the growth in oil reserves comes from hard-to-recover, high-cost reservoirs. At mature fields, an increasing number of wells will transition into the low-production category (producing small amounts of fluid), thereby increasing the importance of low-power pumping equipment — specifically, sucker rod pumping units (SRPUs). Among SRPU surface drives, the most energy-efficient in terms of power consumption are beam-type (oscillator) drives (Shangin et al., 2000). Based on these systems, it is possible to design automatic control systems (ACS) both for individual well production and for groups of wells. This offers the prospect of virtually eliminating human involvement in the oil extraction process, optimizing production based on key criteria and parameters, significantly improving oil production efficiency, reducing declared power demand and equipment wear, and minimizing downtime. As a result, the cost per ton of produced oil can be substantially reduced. In this article, to improve the efficiency and productivity of oil production, we propose the implementation of artificial lift methods employing beam-type SRPU drives.

Two variants of the ACS structure for a single well are considered: for a well at the early production stage with low water cut, and for a well at the late production stage characterized by high water cut. For the second variant, a new oil recovery model is proposed that allows for more complete utilization of oil reserves while eliminating water recycling, reducing the metal intensity of the SRPU by shortening the pump suspension depth, and lowering energy consumption by reducing rod loads and applying the pendulum operating principle of the surface drive.

The article is organized as follows. Section 2 presents the mathematical description of the control object for designing the oil production ACS, including an overview of the technological process and the two proposed ACS structures for

a single well in early and late production stages. Section 3 discusses the control algorithms and the selection of regulator structures that meet the necessary ACS performance requirements for both variants. The effectiveness of the proposed approach is validated through simulation results of the studied system in Simulink. Section 4 presents the main conclusions of this article and ideas for future research.

Research materials and methods. Let us consider a local automatic control system (ACS) for the beam-type sucker rod pumping unit (SRPU) drive (Fig. 1). This control system functions as a stabilization system — when the dynamic fluid level in the well changes, the pump output is adjusted to match the current fluid inflow into the wellbore. To achieve an energy-optimal operating mode for the production unit, it is necessary to maintain an operating regime that aligns the reservoir fluid inflow (at a given pressure differential) with the pump's capacity (Shangin et al., 2000; Ganeev, 2004).

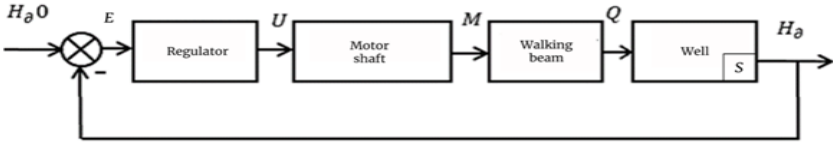

Figure 1 - Structural diagram of the automatic control system (ACS) for regulating the technological mode of a beam-type sucker rod pumping unit (SRPU).

Here, $H_{\partial 0}$ - is the setpoint (calculated) dynamic fluid level in the well, ε - is the control error, U - is the control signal from the regulator (controller), M - is the torque on the motor shaft, Q - is the pump flow rate (capacity), H_{∂} - is the current dynamic fluid level in the well, S - is the well flow rate sensor.

Approximately, the electric drive and pump can be modeled as a first-order aperiodic (inertial) element. The well itself can be represented as an integrator with a gain factor ζ, which depends on the near-wellbore zone properties, since $\frac{dx}{dt} = \zeta Q$. Thus, the rate of change of the dynamic fluid level $\frac{dh}{dt}$ depends on the pump capacity Q and the specific well parameters (Ganeev, 2004).

The ability to automatically control the SRPU's operating mode based on the current flow rate of a producing well enables a fundamentally new approach to organizing the oil extraction process. At the low-oil, high-water-cut stage of exploitation, the characteristics of the in-well medium change significantly — instead of a wellbore filled predominantly with oil (characteristic of the high-production stage), the lower section of the well is largely occupied by water, while oil accumulates in the upper section. This altered in-well environment requires the application of alternative oil recovery techniques. The scheme for organizing oil lifting is shown in Figure 2. To exclude water from the produced well fluid, the pump intake must be positioned within the oil layer in the upper section of the well, with the pump intake level coinciding with the static water level in the well in the absence of oil (Ganeev, 2004).

Let us assume that, at the moment under consideration, the well is filled with water and the reservoir pressure remains constant, $P_m = const$. Then, the static water level, which depends on the reservoir pressure, is determined by the following expression:

$$h_{st.w} = P_r/\rho_w * g = const, \quad (1)$$

where, ρ_w - is the density of water $(1{,}016\ g/cm^3)$; g – is the acceleration due to gravity $(9{,}8062\ m/s^2)$.

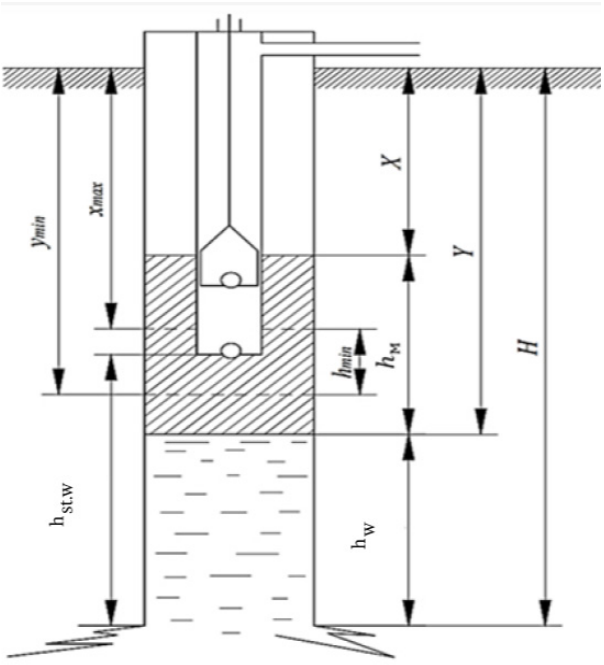

Figure 2 - Schematic of subsurface pump placement during the late stage of well operation.

As an oil layer accumulates in the upper part of the well, with height $h_н$, it becomes necessary to determine the position of the lower boundary of the oil layer — that is, the oil-water interface:

$$h_в = h_{st.w} - \frac{\rho_н}{\rho_w} * h_н, \quad (2)$$

where $\rho_н$ - is the density of oil.

Let us denote the dynamic fluid level in the well (the upper boundary of the oil layer) by x and the lower boundary of the oil layer (the oil-water interface) by y.

Then, we have: $h_н = y - x$, $h_w = H - y$, a $\frac{\rho_н}{\rho_w} = k$ where H – is the total well depth (Figure 2). The total well depth is determined by the expression:

$$H = h_{st.w} - ky + kx + y \quad (3)$$

From this, we derive the functional relationship of the oil-water interface position y as a function of the dynamic level x, $y = f(x)$:

$$y = \frac{H - h_{st.w} - kx}{1 - k}. \quad (4)$$

Knowing this relationship (see Figure 2), for pump control purposes, it is sufficient to measure only the dynamic level.

At the start of the oil extraction process, when the oil layer is sufficiently thick, the pump operates in an intensive pumping mode. As the oil layer thins, the upper and lower boundaries of the oil layer approach the pump intake from both sides. To ensure efficient pump operation, it is necessary to limit the reduction of the oil layer to a "safety layer" level: $h_{min} = y_{min} - x_{min}$ (figure 2). (Ganeev, 2004; Sergeev, 2016: 98-101)

If the oil layer reduces to zero, the water level will rise to the level of the pump intake. The graph of fluid level changes in the well is shown in Figure 3. The proposed oil extraction scheme is implemented by the control system illustrated in Figure 4.

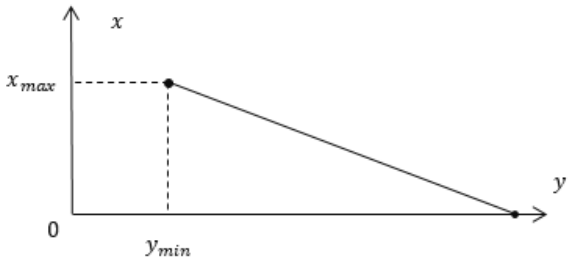

Figure 3 - Functional dependence $y = f(x)$ of the oil-water interface level on the dynamic fluid level in the well.

Here: CD1- control device 1, CD2 - control device 2, E/Drive - electric drive of the beam-pumping unit, Pump - beam-pumping unit with pump equipment, ω^0 - initial stroke frequency, $x^0_{ср}$- desired (setpoint) dynamic fluid level.

When the dynamic level changes, and consequently the lower boundary of the oil layer (the oil-water interface) changes according to the functional dependence, the automatic control system (ACS) adjusts the pump delivery rate Q:

$$\frac{dx}{dt} = +\xi_1 Q; \qquad (5)$$
$$\frac{dy}{dt} = -\xi_2 \frac{dx}{dt} + \zeta_3 P_r;$$

where ξ_1, ξ_2, ξ_3 - are coefficients accounting for the influence of pump delivery, the interaction between x and y, and the reservoir pressure, respectively, on the oil layer level.

The equation for the fluid level in the well is:

$$x = x_0 + \frac{Q * t}{S}, \qquad (6)$$

where Q - is the total fluid flow rate, $Q = Q_{pump} + Q_{well}$ (7)

and the inflow of fluid into the well is given by: $Q_{well} = K\Delta P$ (8)

where K - is the productivity index (coefficient) [Sergeev, 2016: 98-101].

Results

To develop an ACS for oil production, it is necessary not only to have a mathematical description of the controlled object but also to design control algorithms and select regulator structures that meet the required system performance criteria. We considered two structural variants of the ACS for oil production from an individual well.

Regarding the ACS structure for a well at an early stage of operation, which does not exhibit high water cut, it is sufficient to use a simple amplifier as the controller, since the static accuracy is ensured by the integrating properties of the well as the control object. The setpoint input is the required dynamic fluid level in the well. The corresponding Simulink model is shown in Figure 5.

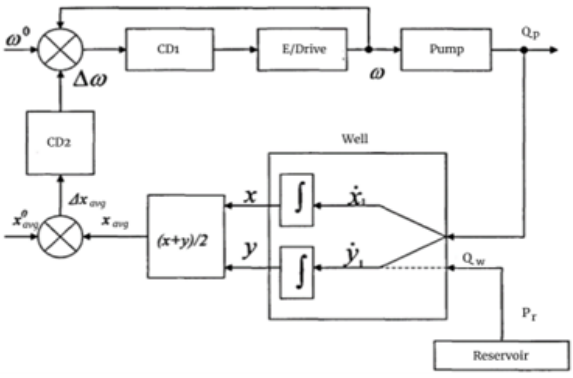

Figure 4 - Dual-channel automatic control system (ACS) for regulating the technological mode of the SRPU based on the current production rate.

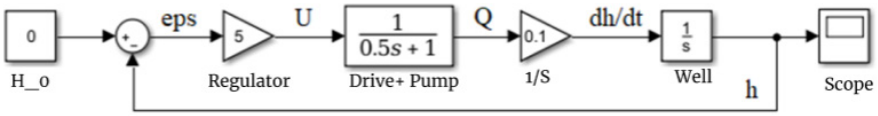

Figure 5 - Single-channel ACS model for downhole pumping (DHP) for an individual well.

The transient (response) process is shown in Figure 6. Here: H_0 - required (setpoint) dynamic level, ε - control error, U - voltage applied to the electric drive, Q - pump flow rate (delivery), $\frac{dh}{dt}$ - rate of change of the dynamic level, h - current level value.

As the actuator, for example, an electric submersible pump (ESP) or a variable-speed beam-pumping unit (BPU) drive can be used.

This ACS functions as a disturbance-rejection (stabilizing) control system - it compensates for changes in the fluid inflow into the well under a given reservoir drawdown.

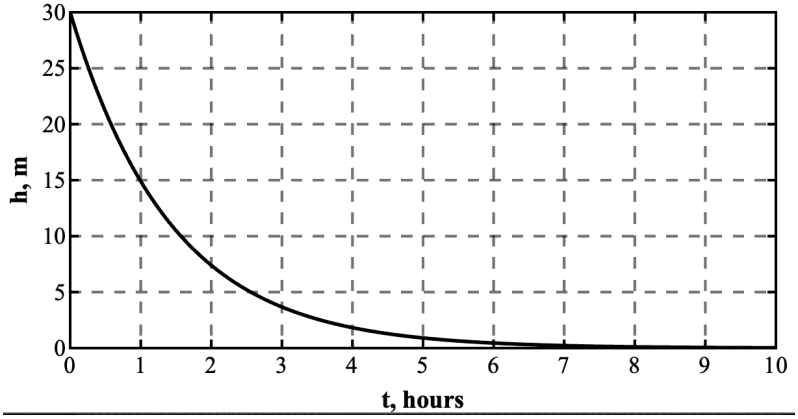

Figure 6 - Dynamic level as a function of time.

For the ACS structure variant designed for a well at a late stage of operation, a mathematical model of a controlled beam-pumping unit (BPU) was used in the simulations (Ganeev, 2004; Sergeev, 2016: 98-101). The modeling accounted for pump limitations, changes in pump delivery due to fluid oscillations, and selected parameter values corresponding to widely used BPU equipment in the oil production industry. To illustrate the performance of this system, the ACS was simulated in Simulink (Figure 7).

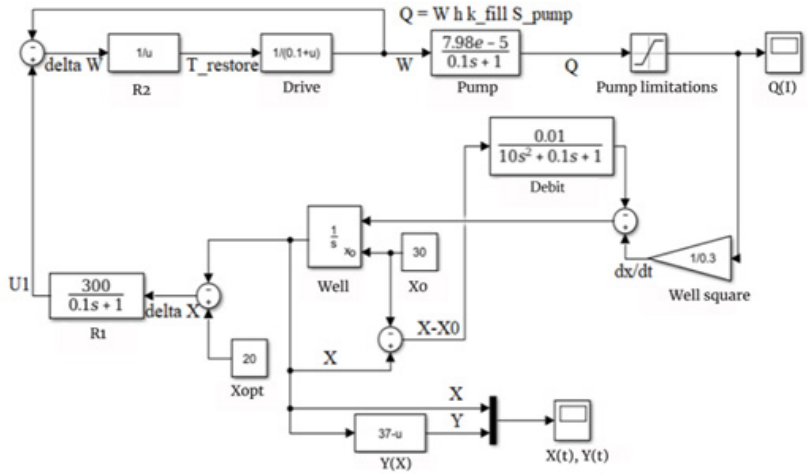

Figure 7 - Model of a two-channel ACS for oil production in a well at a late stage of operation.

To implement the specified dependencies in Simulink, an integrator with an input x_0, which sets the initial conditions (block Well), was used. By dividing the pump's flow rate by the cross-sectional area of the bottomhole zone, we obtain the rate of change of the fluid level x. Blocks R_1 and R_2 function as controllers (regulators). The Debit block implements the well's inflow rate (it is proportional to the difference between the initial and current fluid levels, $x - x_0$). The x_{opt} block sets the required fluid level in the well.

As a result of the simulation, time-dependent relationships for the fluid level in the well $X(t)$ and the oil-water interface level $Y(t)$ were obtained (Figure 8).

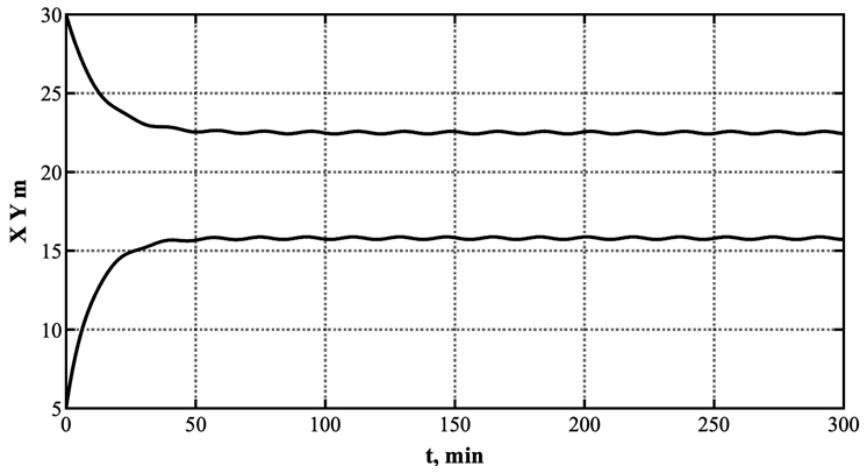

Figure 8 - Graphs of the dependencies $X(t)$ and $Y(t)$.

A drawback of this organization of the oil production ACS is that dynamic level sensors (for example, sonic measurement devices) are not installed on every well. Moreover, level measurements are often performed by the operator and may occur irregularly - consequently, the information support for the control system is insufficient. With a sufficient degree of controllability, using these algorithms, it is possible to achieve the desired values of the internal parameters of the object, but this will come at the cost of significant energy expenditures for regulation. Such systems may achieve low parametric sensitivity (operability over wide ranges of object characteristic variations). However, what is needed is optimal control that maximally leverages the natural (inherent) movements of the object. Applying a robust approach in control system design and process optimization will ensure that the system remains efficient and stable even under conditions of uncertainty and variation.

Conclusion. In this work, an automatic control system for the operating regimes of pendulum-type sucker-rod pumping units was developed and investigated, with the aim of improving the energy and technological efficiency of oil production at different stages of well operation. A mathematical description of wellbore fluid-level dynamics was proposed, enabling the relationship between the dynamic fluid level, the position of the oil–water interface, and the pumping equipment capacity to be taken into account. It was shown that, for wells at an early stage of operation with a low water cut, a single-loop stabilizing control system with a proportional (gain) controller is sufficient, where static accuracy is ensured by the integrating properties of the well as the controlled object. Simulation results confirm system stability and effective disturbance rejection associated with variations in reservoir inflow at a specified drawdown on the formation.

For wells at a late stage of operation with a high-water cut, a two-loop automatic control structure was developed, ensuring coordination between pump capacity and the current downhole conditions, while maintaining a minimum allowable “safety oil layer.” Simulink simulations demonstrated that the proposed control algorithm provides stable regulation of the dynamic fluid level and prevents water from entering the pump, thereby reducing energy consumption and improving the operating efficiency of low-rate wells. The obtained results confirm the feasibility of using adaptive and stabilizing automatic control systems in pumped oil production and demonstrate the potential for improving energy efficiency by coordinating the natural dynamic properties of the well with the operating modes of the pumping equipment.

Future research is associated with the development of optimal and robust control algorithms that account for uncertainties in reservoir and equipment parameters, limited availability of dynamic-level measurements, and the integration of state estimation methods and energy-criterion-based optimization of pumping regimes under real operating conditions.

References

Abramova A.V., Abramov V.O., and Mullakaev M.S. (2017). Ultrasonic automated oil well complex and technology for enhancing marginal well productivity and heavy oil recovery. Journal of Petroleum Science and Engineering, 159, 1–7. https://doi.org/10.1016/j.petrol.2017.09.019 (In Eng.)

Artun E. (2016). Characterizing reservoir connectivity and forecasting waterflood performance using data-driven and reduced-physics models. In SPE Western Regional Meeting. Society of Petroleum Engineers. https://doi.org/10.2118/180488-MS (In Eng.)

Avvaru B., Venkateswaran N., Uppara P., Iyengar S.B., and Katti S.S. (2018). Current knowledge and potential applications of cavitation technologies for the petroleum industry. Ultrasonics Sonochemistry, 42. – P. 493–507. https://doi.org/10.1016/j.ultsonch.2017.12.010 (In Eng.)

Bakshi A., Uniacke E., Korjani M., and Ershaghi I. (2017). A novel adaptive non-linear regression method to predict shale oil well performance based on well completions and fracturing data. In SPE Western Regional Meeting. Society of Petroleum Engineers. https://doi.org/10.2118/185695-MS (In Eng.)

Chaiworapuek W., Chungprempree J., Pukrushpan J., and Khaothong K. (2021). Numerical study of performance augmentation of a vertical coil and shell heat exchanger using high frequency ultrasonic waves. IOP Conference Series: Materials Science and Engineering, 1137, 012069. https://doi.org/10.1088/1757-899X/1137/1/012069 (In Eng.)

Ganeev A. R. (2004). Upravlenie protsessom dobychi nefti na osnove matematicheskogo modelirovaniya [Control of oil production process based on mathematical modeling]. Ufa State Aviation Technical University, Ufa, 151 p. (in Russian)

Ghamartale A., Escrochi M., Riazi M. and Faghih A. (2019). Experimental investigation of ultrasonic treatment effectiveness on pore structure. Ultrasonics Sonochemistry, 51. – P. 305–314. https://doi.org/10.1016/j.ultsonch.2018.10.002 (In Eng.)

Jeong D., Yoshioka K., Jeong H. and Min B. (2021). Sequential short-term optimization of gas lift using linear programming: A case study of a mature oil field in Russia. Journal of Petroleum Science and Engineering, 205, 108767. https://doi.org/10.1016/j.petrol.2021.108767 (In Eng.)

Kalyuzhnyy S.V. (2019). Avtomatizatsiya upravleniya tekhnologicheskim protsessom dobychi nefti iz malodebitnykh skvazhin na osnove dinamicheskikh modeley [Automation of control of the technological process of oil production from low-rate wells based on dynamic models]. Peter the Great St. Petersburg Polytechnic University, St. Petersburg, 14 p. (in Russian)

Lake L.W. (1989). Enhanced oil recovery. Prentice Hall. (In Eng.)

Leontyev L.V. and Trofimchuk S.M. (1990). Tekhnologiya i tekhnika dobychi nefti [Technology and techniques of oil production]. – Nedra. – 480 p. (in Russian)

Liang T., Isayev A.I., Zhang S. and Cheng S.Z. (2021). Effect of ultrasonic extrusion on properties of colloids and bio-based nanocomposites containing epoxidized soybean oil and nanoclay. Polymer Engineering and Science, 61(4). – P. 1066–1076. https://doi.org/10.1002/pen.256334 (In Eng.)

Ostermeier R., Hill K., Dingis A., Töpfl S. and Jäger H. (2021). Influence of pulsed electric field (PEF) and ultrasound treatment on the frying behavior and quality of potato chips. Innovative Food Science and Emerging Technologies, 67, 102553. https://doi.org/10.1016/j.ifset.2020.102553 (In Eng.)

Sergeev S.V., Kozhevnikov A.P. and Zaytsev S.A. (2016). Metody modelirovaniya i optimizatsii periodicheskikh rezhimov ekspluatatsii skvazhin [Methods for modeling and optimization of periodic well operating modes]. Neftyanoye khozyaystvo (Oil Industry), (10). – P. 98–101. https://doi.org/10.24887/0028-2448-2016-10-98-101 (in Russian)

Shangin E.S. and Dyachuk I.A. (2000). Dobycha vysokovyazkoy nefti s ispol'zovaniem nazemnogo privoda shtangovykh glubinnykh nasosov mayatnikovogo tipa [Heavy oil production using a surface drive for pendulum-type sucker-rod pumps]. In Problemy neftedobychi: tematicheskiy sbornik nauchnykh trudov [Problems of oil production: Thematic collection of scientific papers]. Moscow: YUKOS. (in Russian)

Satybaldina D., Amirzhanova Z. and Mashtayeva A. (2022). Robust control of aircraft flight in

conditions of disturbances. International Journal of Electrical and Computer Engineering, 12(4). – P. 3572–3582. https://doi.org/10.11591/ijece.v12i4.pp3572-3582 (In Eng.)

Satybaldina D., Dabayeva A., Kissikova N., Uskenbayeva G. and Shukirova A. (2023). Mixed H2/H∞ robust controllers in aircraft control problem. International Journal of Electrical and Computer Engineering, 13(6). – P. 6249–6258. https://doi.org/10.11591/ijece.v13i6.pp6249-6258 (In Eng.)

Satybaldina D. and Kalmaganbetova Z. (2022). Robust control for a tracking electromechanical system. International Journal of Electrical and Computer Engineering, 12(5). – P. 4883–4891. https://doi.org/10.11591/ijece.v12i5.pp4883-4891 (In Eng.)

Vershinin V.E. and Ponomarev R.Y. (2021). Long-term forecasting and optimization of non-stationary well operation modes through neural networks simulation. In SPE Russian Petroleum Technology Conference. Society of Petroleum Engineers. https://doi.org/10.2118/206529-MS (In Eng.)

Vershinin V.E., Ponomarev R.Y. and Strekalov A.V. (2020). Neural network as a tool for predicting and controlling the technological regime of production wells. In SPE Russian Petroleum Technology Conference. Society of Petroleum Engineers. https://doi.org/10.2118/201937-MS (In Eng.)

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