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ИЗВЕСТИЯ

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NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

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.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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PERFORMANCE OF GROUND CHAIN DRIVES OF ROD PUMP UNITS FOR HIGH-VISCOSITY OIL EXTRACTION

Abstract: in the development of deposits at a late stage of design, especially during high-viscosity oil extraction in difficult operating conditions, the question of revising and selection of promising equipment and technologies occurs. Technologies improve production efficiency of hydrocarbon raw materials at minimal cost. High viscosity oil occurs not only at a late stage of development, but also during the development of new fields. Proof is from the analysis of the activities of oil producing enterprises in Kazakhstan and Russia, as well as some companies from far abroad.

Work experience of scientific and design organizations and production associations of Tatarstan, one of the main oil regions of Russia has shown the promise of application in fields of OJSC "Tatneft" of chain drives (CD) as part of plunger rod borehole pumping units (RBPU) instead of the usual balancing pumping units (PU).

In Kazakhstan, such technologies were first applied at the Zhanazhol high-viscosity oil fields (Mangistau region) based on Chinese-made RBPU chain drives. It should be noted that there are also other fields in Kazakhstan, which, in terms of oil properties and geological and technical conditions, are identical with the above. The use of the RBPU CD in these fields would give significant results in improving the efficiency of wells operation.

An analysis of previous studies has shown that, in addition to advantages, CDs have several disadvantages, which, first, are the presence of nodes of increased wear, especially at the junction of the converting mechanism and its individual load-bearing elements, which are caused by dynamic loads. These shortcomings require the development of scientifically grounded methods for assessing the bearing structural elements of the chain transmission for strength, considering the peculiarities of the operation of the RBPU.

In this work, the authors substantiated the basic principles of ensuring the operability of the CD RBPU when acting on the bearing elements of dynamic loads.

Key words: chain drive, roller chain, ground chain drives, rod borehole pumping unit, high-viscosity oil, dynamic loads, stress-strain state, bearing elements.

Introduction. Fundamental and applied research of a number of authors is devoted to the study of the peculiarities of high-viscosity oil production in Kazakhstan, who proposed promising technologies and technical means for increasing oil recovery [1-5]. In work [6], the authors investigated unconventional methods of processing high-viscosity oils and their heavy residues produced in wells. The mechanism of chemical transformations of high-molecular components of various types of petroleum raw materials under the conditions of mechanical-wave and other methods of exposure has been studied. The possibilities of using the method of mechanical activation of oil as an effective direction of acceleration of mechanical and chemical processes occurring in a hydrocarbon substance due to intense mechanical loads are considered.

Despite the large number of studies carried out in this area, only thanks to research devoted to the use of chain drives as ground drives of plunger RBPU it became possible to improve their operational and technological qualities in the production of high-viscosity oil, which are as follows [1, 4]:

- the efficiency of operation of marginal wells with high-viscosity oil due to the uniform

movement of the rods in a low-speed pumping mode, contributing to their continuous operation;

- reduction in specific energy consumption (10 - 20%) for lifting production during the operation of high-rate wells with long-stroke RBPU in comparison with installations of centrifugal electric pumps (ICEP), due to sufficiently large strokes of the rod traction drive (RTD);

- a significant decrease (by 1.7 times) of the hydrodynamic resistance forces in the underground part of the sucker rod pumping unit.

The CD, in comparison with the balancing drives of pumping units (PU), differ in the following design and technical features [1]:

- constant speed of movement of the point of suspension of the rods (PSR) on the predominant part of the stroke, which is approximately 1.6 - 1.7 times less than the maximum speed of the rods per cycle for the PU (Figure 1);

- the presence of reducing properties in the converting mechanism, because of this, to ensure the same technological characteristics of the CPU, a gearbox with a lower gear ratio and torque is required (by a factor of 5 - 8). This, in turn, significantly reduces the dimensions, and, consequently, the metal amount and weight of the gearbox and the sucker rod pumping unit drive as a whole;

- less dependence of mass and dimensions on the stroke length of the PSR compared to the PU crank mechanism;

- the possibility of providing a mode of operation with a small number of oscillations due to the use of the reducing property of the converting mechanism for this, without additional devices, i.e., without complicating the design and reducing the efficiency of the mechanism.

The most promising direction for improving the design of chain drives of RBPU is drives based on the use of carriages as a connecting intermediate link between the traction chain working body (chain transmission) and the rod of the rod string.

The actuators developed by the Highland Pump Company (USA), due to their simplicity and reliability, have now become in demand. The basis of these designs is the so-called reducing converting mechanism (RCM), the kinematic diagram of which is shown in Figure 2. The drives created based on this mechanism were later called ROTAFLEX drives, which, in more advanced versions, found application in the central CD of the RBPU produced by the Bugulma Mechanical Plant of Tatarstan and OJSC "Izhneftemash", which began to be used also in Kazakhstani fields. The main difference of the ROTAFLEX drive is the presence in the RPM of only one loop with a closed flexible link - a chain, while in the previous schemes there were two parallel circuits with closed flexible links.

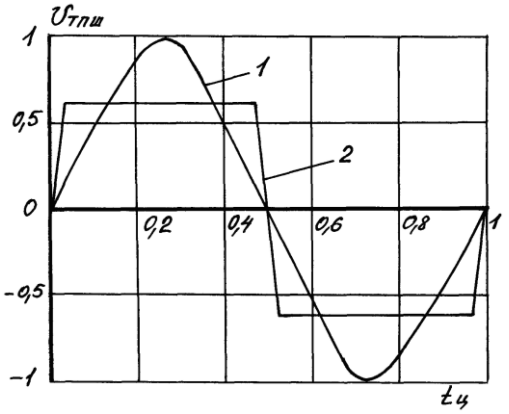

Figure 1 - Comparative characteristics of the change in the relative speed υ_{PSR} of the rod PU and the CD for one cycle of time t_c of the PSR stroke at the same pumping speed:
1 - PU; 2 – CD

The emergence of this kind of a new design of the drive made it possible to create a more compact and easy-to-operate device that provides high maneuverability of installation and tangible cost-effectiveness in relation to energy and metal consumption. Moreover, in these drives it is possible to widely use conventional sleeve-roller chains, which, after simple structural transformations due to the cantilever attachment of a special pin to them, can carry the counterweight of the sucker rod-pumping unit, as shown in Figure 2. The latter, at the same time, plays the role of a balancing weight, which, if necessary, can be equipped with additional removable weights - metal or reinforced concrete plates.

Aims and Objectives. Nevertheless, the operating experience of the CD of the RBPU shows [7-11] that the main reasons for the failure of the load-bearing elements can be their damage, the main types of which are given in table 1.

Results of theoretical research. In the CD of the RBPU, drive roller chains of the DR or DRM type (multi-row) are used as traction elements of the RCM [12-13].

Figure 3 shows a generalized design diagram of the chain transmission 6 of the RCM RBPU, the driving sprocket of which is driven by an electric drive consisting of a series-connected electric motor 3, a V-belt transmission 4 and a gearbox 5.

The dashed lines show the sags in the leading and driven branches of the chain drive, which are characteristic when they are used as traction bodies in the CD of the RBPU. Figure 4 shows the chain drive separately with a detailed indication of all geometric parameters of the sag.

Table 1 - The main reasons for the failure of chain drives used in RBPU as ground drives and types of damage

Type of damage	Performance criterion
Chain pivot wear	Wear resistance of hinges
Fatigue failure of plates	Fatigue resistance of plates
Loose connections of rollers and bushings with plates	Connections strength
Chipping and splitting of rollers	Impact-cyclic strength of rollers
Seized joint friction pair	Contact strength of rollers

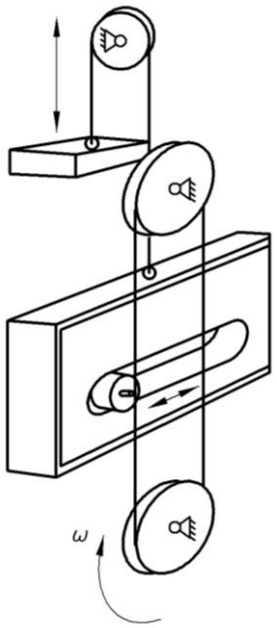

Figure 2 – Kinematic scheme RCM of ROTAFLEX drive

In most cases, setting up chain drives comes down to choosing an initial sag arrow $f_{2н}$ (figure 4) (without regard to transmission durability). In the technical and reference literature [14, 15], it is recommended to set the branch sag arrow within

$$f_н = (0.01 \div 0.02) a_t , \quad (1)$$

where a_t – chain drive interaxial distance (see figures 3 и 4).

Some sources [15] propose to assign

$$f_н = 0.025 l , \quad (2)$$

in this case, the tension in the driven branch of the operating gear should be $S_2 < 0.1P$, where l and P – respectively, the span of the driven branch and the net force transmitted by the chain.

The main criterion for the performance of chain drives operated at low speeds and high variable loads is the fatigue resistance of the working elements of the chain. In the first place, intermediate plates are adhered to such loads. This is since these plates are set on rollers with a gap, in contrast to the outer and inner plates, which are pressed with an interference fit, which increases their fatigue resistance.

Fracture of plates under the action of alternating stresses is caused by the formation of fatigue cracks in the most stressed zones of the plate, as a rule, in places of the highest stress concentration. In the chain plates, such a place is the lugs, where the stresses during operation are always much higher than the average (nominal) stresses σ_{nom} [16].

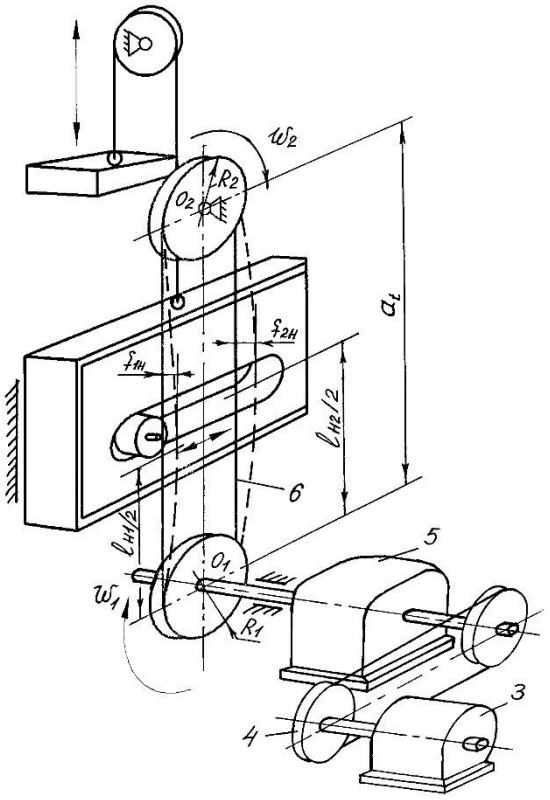

Figure 3 - Design scheme for the study of the traction and bearing capacity of the chain RCM CD RBPU

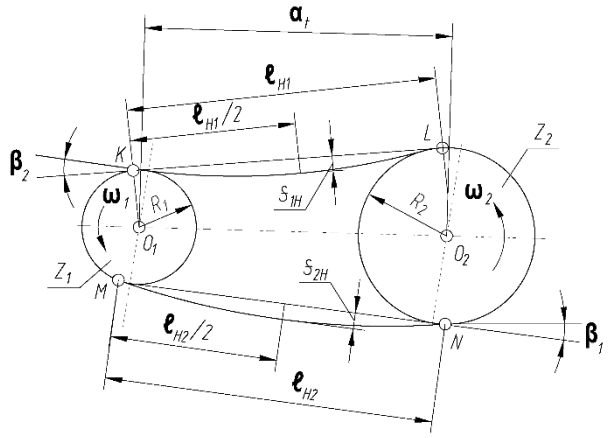

Figure 4 - To the study of the geometric parameters of the sag of the CD of the RBPU

When determining the bearing capacity of chains, designing plates, and calculating them for endurance, it is important to know the actual nature of the distribution of stresses in the eyelet and be able to quantify their concentration at the most dangerous points. The work of many local and foreign scientists is devoted to the calculation of lugs [16 - 20]. However, the calculation method considering the elastic deformation of elements is not fully understood. Moreover, a comparative methodology that summarizes the properties of various types of roller chains has not yet been developed. Therefore, it is necessary to investigate the stress-strain state of the intermediate plate of the most common chains of the DR and DRM type to determine their rational shapes and sizes.

The design schemes presented in Figure 5 simulate the typical cases of loading the plates of roller chains of the DR and DRM types, used as traction working bodies of RCM CD RBPU (Fig. 5,*a* и 5,*b*). On these schemes: 1 – roller, 2 – axle.

The calculation of contact stresses when placing a plate on a roller with a small gap was performed on the basis of the results of [21], in which, by analogy with the Hertz distribution, the dependence for contact stresses was adopted in the form of an elliptic law

$$\sigma_r = \sigma_{r\max}\sqrt{1-\frac{\varphi^2}{\varphi_0^2}}, \qquad (3)$$

where φ - angular coordinate; φ_0 - half of a contact angle; $\sigma_{r\max}$ - maximum value of contact stresses,

$$\sigma_{r\max} = \frac{2F}{\pi \cdot d \cdot h \cdot J_1(\varphi_0)}, \qquad (4)$$

where F - force, applied to plate; d - hole diameter; h - plate thickness; $J_1(\varphi_0)$ - Bessel function of the first kind [22].

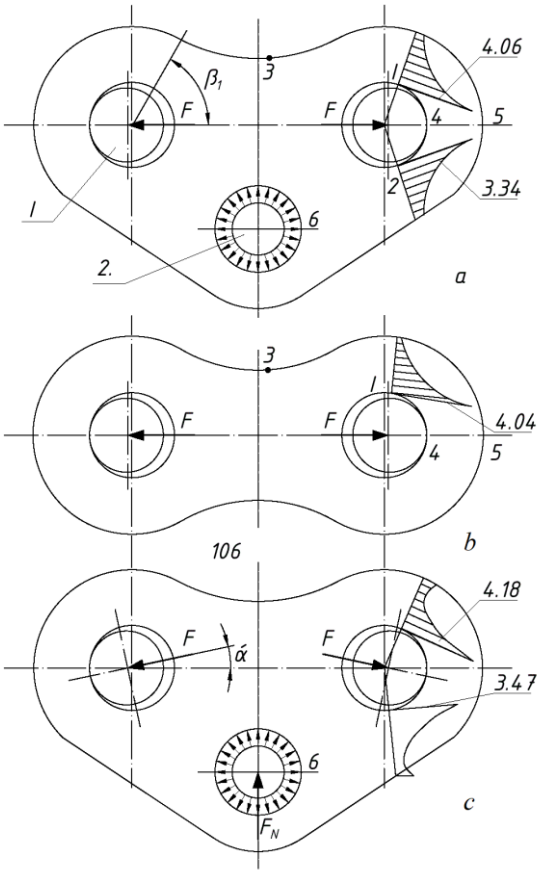

Figure 5 - Design schemes for loading the intermediate plate.

When determining the contact angle $2\varphi_0$ the empirical formula was used [21]:

$$2\varphi_0 = \pi \cdot th0{,}68\frac{m}{m-1}\sqrt{\frac{F}{E\varepsilon h}}, \qquad (5)$$

where m - eyelet parameter ($m = 2R/d$); E - modulus of elasticity; ε - radial clearance.

Relative clearance ($\xi_S = 2\varepsilon/d$) in this study, it is assumed to be constant and is equal to 0,00585.

The design loads on the plate from the axis according to the loading option shown in Figure 5c were determined based on a study [23], which makes it possible to conclude that an independent solution of the problems of stresses during pressing-in and under loading with zero clearance gives sufficiently accurate information about the actual stresses from the total effect.

The contact stresses from pressing the axle into the plate were calculated using the Lamé formulas at a constant relative tension equal to

$\xi_N = 0{,}00592$, but from the action of force F_N - by the well-known expression [15]:

$$\sigma_r = \frac{4F_N}{\pi \cdot d_o \cdot h} \cdot \cos\theta, \qquad (6)$$

where $F_N = 2F \sin\alpha$; θ - angular coordinate.

When solving problems for areas with complex geometry and loading, such as plates, where the use of traditional analytical methods of the theory of elasticity becomes either ineffective or simply does not allow bringing the solution to the result. The most effective is the finite element method (FEM) [24].

Comparative analysis of the stress-strain state of intermediate plates of DR and DRM type chains at a pitch of 25.4 mm, load = 5.88 kN and angle = 60º was performed by the FEM in the form of the displacement method proposed in [25] using standard computer programs. In this case, it is assumed that the stress state of the plate is flat, and the stress level does not exceed the proportionality limit. Considering the geometric shape of the plates, half of the DRM chain plate (Figure 6) and a quarter of the DR chain plate (Figure 7) are considered.

To determine the rational shape of the chain plate (displacement coefficient y = 0.4), its stress-strain state was analyzed by varying the angles of the plate shape β_1 (see Figure 6). The total number of triangular plate and nodal elements, as well as support nodes for various values of β_1 is given in Table 2, with smaller elements located in the assumed stress concentration zones and larger ones in the remaining areas of the plate.

Table 2 - Quantitative characteristics of grids on the surface of roller plates chains of type DR and DRM

	Type of chain plate	Number of elements and nodes at angle β_1 plate shape			
		30^0	45^0	60^0	90^0
number of nodal elements	DRM	394	397	401	412
	DR	155	163	172	187
number of lamellar elements	DRM	677	684	692	714
	DR	251	266	280	310
number of supporting nodes	DRM	13	14	15	17
	DR	18	20	22	25

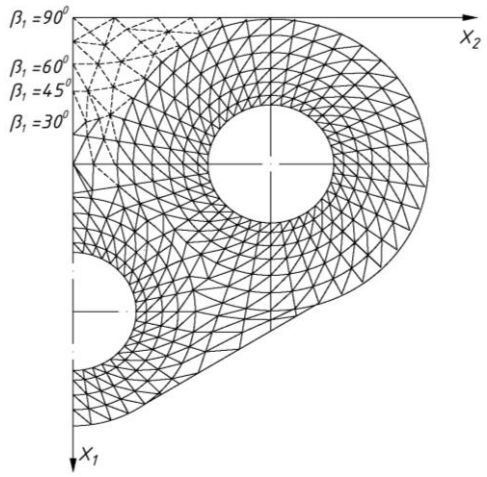

Figure 6 - Division of a chain plate of the DRM type into finite elements

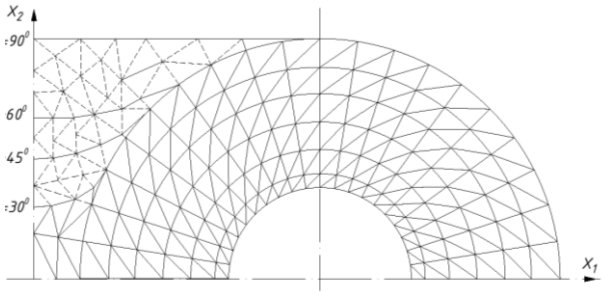

Figure 7 - Division of a chain plate of the DR type into finite elements

Conclusion. By studying the stress-strain state of intermediate plates of chains of the DRM and DR types, it was established that:

- comparison of the calculation results obtained by the FEM give a more realistic picture and accuracy (7 ... 8)% of the dynamics of the force interaction of the elements of the chain transmission in comparison with the reference data;

- the greatest concentration of stresses in the lug of the plate occurs on the contour of the hole in which the roller is installed with a small gap;

- in terms of mass, stiffness, and stress concentration, and, consequently, in terms of traction and bearing capacity, the intermediate plates of the DR and DRM chains are at the same level, therefore, their application in practice as traction elements in the CD of sucker rod pumping units gives the same results.

Developed based on the research, new technical solutions for improving the CD of the sucker rod pumping unit [26], when introduced into practice, make it possible to realize the following advantages:

- significantly reduce the costs associated with material and metal consumption;

- to improve the quality of control of the kinematic and dynamic parameters of the liquid lifting process over a wide range;

- increase the lead angle at a minimum load of the drive electric motor (10÷15%);

- reduce dynamic loads, increase the service life of downhole equipment;

- to reduce the costs of transportation, installation, and maintenance, and of course, as it was said at the beginning of this work, the efficiency of operation in the production of high-viscosity oil from deep wells increases with the maximum permissible amounts of solid mechanical inclusions in the well product.

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ТҰТҚЫРЛЫҒЫ ЖОҒАРЫ МҰНАЙДЫ ӨНДІРУГЕ АРНАЛҒАН ШТАНГАЛЫ СОРҒЫ ҚОНДЫРҒЫЛАРЫНЫҢ ЖЕРҮСТІ ТІЗБЕКТІ ЖЕТЕКТЕРІНІҢ ЖҰМЫС ҚАБІЛЕТТІЛІГІ

Аннотация: кен орындарын игерудегі әзірлеудің кеш сатысында, әсіресе, тұтқырлығы жоғары мұнай өндіру кезінде пайдаланудың күрделі жағдайларында, қаражаттың ең аз шығынымен көмірсутек шикізатын өндіру тиімділігін арттыруды болашақта қамтамасыз ететін техника мен технологияларды қайта қарастыру және таңдау туралы мәселелер туындайды. Тұтқырлығы жоғары мұнай тек игерудің соңғы сатысында ғана емес, сондай-ақ жаңа кен орындарын игеру кезінде де кездеседі, бұған Қазақстан мен Ресейдің мұнай өндіруші кәсіпорындарының, сондай-ақ, алыс шетелдердің кейбір компанияларының қызметін талдау дәлел бола алады.

Ресейдің негізгі мұнай аймақтарының бірі болып табылатын Татарстанның ғылыми-жобалау ұйымдары мен өндірістік бірлестіктерінің жұмыс тәжірибесі "Татнефть" ААҚ кен орындарында плунжерлік штангалық ұңғымалық сорғы қондырғыларының (ШҰСҚ) құрылымында әдеттегі тербелме станоктарының (ТС) орнына тізбекті жетектерді (ТЖ) қолданудың болашақта тиімділігін көрсетті.

Қазақстанда мұндай технологиялар алғаш рет тұтқырлығы жоғары "Жаңажол" (Маңғыстау облысы) мұнай кен орындарында қытайлық ШҰСҚ-ның тізбекті жетектері базасында қолданыла бастады. Айта кететін нәрсе, өндіру технологиясы, мұнайларының қасиеттері мен геологиялық-техникалық жағдайлары бойынша жоғарыда аталғанға ұқсас Қазақстанда басқа да кен орындарының бар екендігі. Осы кен орындарында ШҰСҚ ТЖ қолдану ұңғымаларды пайдалану тиімділігін арттыру бойынша елеулі нәтижелер берері сөзсіз.

Бұрын соңды жүргізілген зерттеулерді талдау, ТЖ өзінің артықшылықтарынан басқа, бірқатар кемшіліктерінің де бар екендігін көрсетті, атап айтқанда, ең алдымен, олардың қатарына, динамикалық жүктемелердің түсуінен туындайтын, әсіресе түрлендіру механизмі мүшелерін біріктіру жерлерінде

және оның бөлек жүк көтергіш элементтерінде жоғары тозу тораптарының болуын жатқызуға болады. Бұл кемшіліктер ШҰСҚ-ның пайдалану ерекшеліктерін ескере отырып, тізбекті беріліс құрылымының тірек элементтерін беріктікке бағалаудың ғылыми негізделген әдістерін әзірлеуді қажет етеді.

Бұл жұмыста, ШҰСҚ ТЖ-нің жүк көтергіш элементтеріне динамикалық күштер әсер еткен кездегі олардың жұмыс қабілеттігін қамтамасыз етудің негізгі принциптері авторлармен негізделген.

Түйін сөздер: тізбекті беріліс, роликті тізбек, жерүсті тізбекті жетектер, штангалы ұңғымалық сорғы қондырғысы, жоғары тұтқыр мұнай, динамикалық күштер, кернеулі деформацияланған күй, жүк көтергіш элементтер.

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РАБОТОСПОСОБНОСТЬ НАЗЕМНЫХ ЦЕПНЫХ ПРИВОДОВ ШТАНГОВЫХ НАСОСНЫХ УСТАНОВОК ДЛЯ ДОБЫЧИ ВЫСОКОВЯЗКОЙ НЕФТИ

Аннотация: в освоении месторождений на поздней стадии разработки, особенно при добыче высоковязкой нефти в осложненных условиях эксплуатации, остро встает вопрос о пересмотре и выборе перспективных техники и технологии, обеспечивающих повышение эффективности производства углеводородного сырья при минимальных затратах средств. Высоковязкая нефть встречается не только на поздней стадии разработки, но и при освоении новых месторождений, о чем свидетельствуют анализ деятельности нефтедобывающих предприятий Казахстана и России, а также некоторых компаний дальнего зарубежья.

Опыт работы научно-проектных организаций и производственных объединений Татарстана, одного из основных нефтяных регионов России, показал перспективность применения в месторождениях ОАО «Татнефть» цепных приводов (ЦП) в составе плунжерных штанговых скважинных насосных установок (ШСНУ) вместо привычных балансирных станков-качалок (СК).

В Казахстане такие технологии впервые начали применяться на месторождениях высоковязкой нефти «Жана жол» (Мангистауская область) на базе цепных приводов ШСНУ китайского производства. Следует отметить, что в Казахстане имеются также и другие месторождения, которые по технологии добычи, свойствам нефти и геолого-техническим условиям идентичны с вышеназванным. Применение ЦП ШСНУ на этих месторождениях дали бы значительные результаты по повышению эффективности эксплуатации скважин.

Анализ проведенных ранее исследований показали, что, помимо достоинств, ЦП имеют ряд недостатков, которые, прежде всего, заключаются в наличии узлов повышенного износа, особенно в местах сочленения преобразующего механизма и отдельных его несущих элементов, которые обусловлены динамическими нагрузками. Эти недостатки требуют разработки научно-обоснованных методик оценки несущих элементов конструкции цепной передачи на прочность с учетом особенности эксплуатации ШСНУ.

В данной работе авторами обоснованы основные принципы обеспечения работоспособности ЦП ШСНУ при действии на несущие элементы динамических нагрузок.

Ключевые слова: цепная передача, роликовая цепь, наземные цепные приводы, штанговая скважинная насосная установка, высоковязкая нефть, динамические нагрузки, напряженное деформированное состояние, несущие элементы.

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