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ENSURING THE OPERATIONAL-TECHNOLOGICAL CHARACTERISTICS OF THE NEW DESIGN SOLUTION OF THE SUCKER-ROD PUMPING UNIT

In Azerbaijan oil production is carried out both in the offshore and onshore. Offshore production is carried out on special platforms, while the onshore exploitation carried out directly by a mechanized method. Thus, the object of study is downhole pumps, which consist of a surface mechanical transmission and downhole equipment. For direct mechanization of ground equipment, a device called rocking machine is used, consisting of transmission and converting mechanisms. The main task of the rocking machine is to ensure the conversion of the rotational motion of the engine into the up and down stroke of the plunger of the pump. The downhole equipment includes rods column that lift liquid from the well, a cylinder and a plunger. However, the existing classic rocking machines have some advantages as well as some disadvantages. In order to overcome them, developed new design solution of the sucker-rod pumping unit, which consisting of a crank-rope-movable counterweight system has been designed. As a result of the research carried out in the article, a progressive expression was proposed for determining the strength condition of the rods column, which is one of the main working elements of the rocking machine. Then, in order to specify the wells in which the rocking machine can be applied, the statement regarding the determination of the value of the linear density of liquid column based on the strength condition of the rod column was put forward. These, in turn, can be determined in which oil wells with specific physical characteristics of the rocking machine with the given technical characteristics can be applied. All this can contribute to the prevention of accidents that may occur due to the breakage of the rods column of rocking machine. The formula proposed in this paper can be applied not only to the existing classic rocking machines, but also to other new design of rocking machines.

Keywords: *rocking machine, oil production, rods column, strength condition, linear density.*

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1. Introduction

Oil production plays a critical role in the development of all sectors of the economies of countries such as Azerbaijan, Kazakhstan, and several Arab nations, which is why they give special attention to the oil industry. Currently, most of the world's wells are located on land, and the mechanical drive of sucker rod pumps, also known as rocking machines, is used to operate them. These pumps are individually driven and lowered into the well, and are connected to the drive by a flexible mechanical connection called a rod column.

Pumping units have played a leading role in oil operations since the beginning of the 20th century, and according to experts, no other equipment is as reliable and easy to maintain as these drives. The classic beam pumping units consist of a four-link mechanism that converts the rotational movement of the engine into the up and down strokes of the rods column and comprises several independent subassemblies. With most onshore oil fields entering the late stages of development, characterized by a decrease in production well flow rate and a tendency towards lower crude oil prices in the global market, improving the efficiency of mechanized oil production methods is particularly crucial today. As a result, the volume of oil produced heavily depends on enhancing the efficiency and reliability of these units while minimizing energy costs.

Most of the pumping units currently in use are classic beam pumping units, which have undergone a long evolution and possess numerous advantages, such as high unification and a simple design. Nevertheless, there are also several disadvantages characteristic of beam pumping units [1–3]. One of the significant drawbacks of beam sucker-rod pumping units is the presence of significant unbalanced masses, which require building expensive foundations due to the unit's substantial weight. Additionally, the gearbox has a low service life, and high-energy consumption results from the high value of torque on the output shaft.

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Additionally, the gearbox has a low service life, and the high value of torque on the output shaft results in high energy consumption [4, 5].

Another topical issue is the prevention of accidents on rocking machines. The analysis of existing researches in this field shows that one of the main reasons for the accidents occurring in rocking machines is related to the breaking of their rods column. In order to prevent such a situation, it is necessary to take into account not only the characteristics of the rocking machine, but also the strength condition of the rods column to be used in it, and specify which oil wells with certain linear density of the rocking machines with certain technical instructions can be applied. These mentioned issues are of actual practical importance and require their solution [6–10].

Thus, *the aim of this research* is to draw up a formula for determination of the linear density of liquid column based on the strength condition of the rod column was put forward using new design of the pumping unit, which in a large way eliminate the main disadvantages of the existing pumping units.

2. Materials and Methods

One of the primary solutions for addressing these issues involves the utilization of beamless sucker-rod pumping units. By eliminating the balancer and balancer head, which comprise the majority of the pumping units' metal capacity, these units can offer several benefits. Notably, when compared to beam pumping units, the movement patterns of the rod suspension point and the dynamic forces that impact the structure of beamless pumping units differ significantly in a positive manner [11]. The department of «Mechatronics and machine design» at Azerbaijan Technical University has developed new Design Solution of the Sucker-rod Pumping Unit that boasts several advantages. This unit has a smaller metal capacity, more compact overall dimensions, and a suspension point movement pattern that more closely adheres to the harmonic law. Additionally, this original design has been approved by the Eurasian Patent Organization under No. 039650 in 2022 [12] and the Intellectual Property Agency of the Republic of Azerbaijan under No. a2019-0162 in 2021 [13]. The new pumping unit comprises with a rope-block and crank-slide converter mechanism.

Fig. 1 shows an overview of a new constructive solution for the sucker-rod pumping unit. The unit consists of a frame *1*, a three-phase short-circuited asynchronous motor *2*, a V-belt drive *3*, a two-flow three-stage reducer *4* rigidly connected to the drive shaft, a double-shaped brake *5* mounted on one side of the drive shaft, and a V-belt pulley *6* mounted on the other side. Two cranks *7* are installed on the driven shaft. The unit also includes guide blocks *8, 9* and ropes *10* connected to the rod suspension point *11*.

The conversion mechanism in the design comprises of two slider-crank linkages *12*, which convert the rotary motion of the crank into the vertical upstroke and downstroke movement of the rod suspension point. The mechanical transmission has counterweights *14,* whose weight can be adjusted, and they are placed on a movable cross beam *13* that is connected to the connecting-rod through a hinge joint.

The guide blocks are encircled by a flexible rope that is connected at one end to the movable beam and at the other end to the suspension point of the rods. Additionally, the mechanical drive includes a guide system that comprises two cylindrical tubes *15* positioned vertically and the movable beam. The mechanical transmission features hinged front *18* and rear *19* arms, which can be adjusted using screw tensioners *16, 17*. A fixed cross beam *20* is rigidly connected to the guide tubes. The screw tensioner *21* is linked to the construction frame and the joints with the front and rear arms.

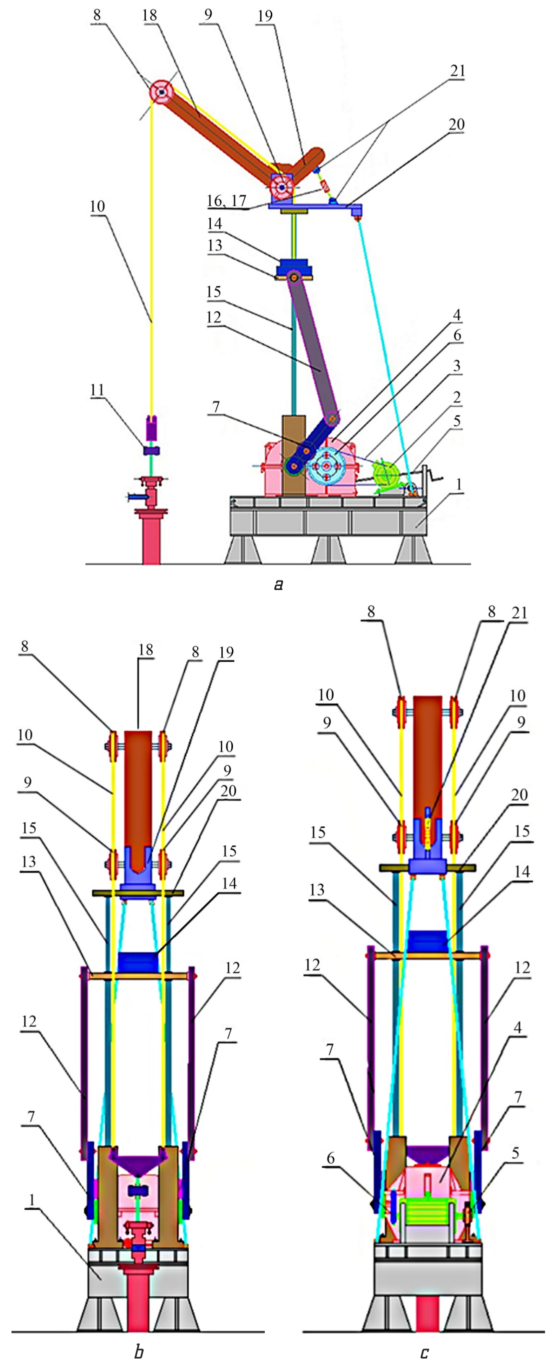

Fig. 1. New constructive solution of beamless pumping unit: *a* – side view; *b* – front view; *c* – rear view

The converting mechanism is utilized in the pumping unit to facilitate the upstroke and downstroke movement of the rod column. The four-link hinged slider-crank linkage mechanism is presently employed in the converting mechanisms of the pumps. It is widely acknowledged that the goal of kinematic analysis of each hinged mechanism is to ascertain the displacement, velocity, and acceleration of its corresponding points [14].

When determining the application areas of the pumping unit with a new constructive solution, i. e. which types of wells it would be more efficient to apply in terms of technical characteristics, it should be divided into 3 groups as exploitation-technological, technical and economic factors. These factors create the basis for the more efficient application of the proposed new constructive solution of the pumping unit to achieve higher efficiency.

The application areas of the sucker-rod pumping units can be divided into three groups based on exploitation-technological, technical, and economic factors. It is essential to consider these factors to determine where the application of the new constructively designed pumping unit will be more efficient. The exploitation-technological factors include the hanging depth L of the rod column, flow rate Q of the column, plunger stroke S, number of exact movements of the hanging point of the rod column n, and the characteristics of the sucker used in the pumping unit. The technical factors include the mechanical transfer characteristic axis dimensions of the pumping unit, such as the effective area of the sucker's cross-section and the plunger stroke, the working pressure of the pumping unit, and its transmission. The economic factors include the increase in the power of transfer that can be achieved by using the balanced pumping unit compared to the unbalanced analogous mechanism, the capital costs, exploitation expenses, and other related factors [15–17].

According to the analysis of the current experience and modern literature related to this field, it is evident that the parameters of the rod pump's stuffing boxes, namely the applied releasable tension $[\sigma]$ and the increase in the power ratio of the drive mechanism, have the most significant impact on the application area of the newly designed pumping unit. These parameters reflect all the factors included in the three groups mentioned above and have a direct effect on the efficiency of the pumping unit [1, 2, 11].

3. Results and Discussion

According to the analysis of the current experience and modern literature related to this field, it is evident that the parameters of the rod pump's stuffing boxes, namely the applied releasable tension $[\sigma]$ and the increase in the power ratio of the drive mechanism, have the most significant impact on the application area of the newly designed pumping unit. These parameters reflect all the factors included in the three groups mentioned above and have a direct effect on the efficiency of the pumping unit [18–20].

The main factor limiting the application of plunger pumps is related to the strength characteristics of the column of plungers applied there. The main function of the column of plungers is to transmit the reciprocating motion from the plunger of the reciprocating mechanical pump to the plunger inside the cylinder. As it is known, the dimensions of the cross-section of the plungers are selected depending on the value of the applied stresses:

$$\sigma_{st} = \sqrt{\sigma_a \cdot \sigma_m}, \tag{1}$$

where $\sigma_a = (P_{\max} - P_{\min})/2f$ and $\sigma_m = P_{\max}/f$ – the amplitude and maximum values of the tension are the parameters that affect the shafts accordingly.

If to neglect the frictional forces in the column and plunger, the maximum and minimum forces acting on the plungers in the column under the influence of inertia forces during the upward and downward movement of the plunger through the pump will be as follows:

$$P_{\max} = P_{rod} + P_{liquid} + P_{in}^{up}; \tag{2}$$

$$P_{\min} = P_{rod} - P_{in}^{dw}. \tag{3}$$

By performing substitutions in equations (2) and (3), the maximum and minimum forces acting on the plungers during their up and down motion can be obtained as follows:

$$P_{\max} = P_{rod} + P_{liquid} + \left(P_{rod} + P_{liquid}\right) \cdot \frac{S \cdot n^2}{1440} =$$
$$= \left(P_{rod} + P_{liquid}\right)\left(1 + \frac{S \cdot n^2}{1440}\right) = \left(P_{rod} + P_{liquid}\right) K_{up};$$

$$P_{\min} = P_{rod} - P_{rod} \cdot \frac{S \cdot n^2}{1440} = P_{rod}\left(1 - \frac{S \cdot n^2}{1440}\right) = P_{rod} K_{dw},$$

where K_{up} and K_{dw} – the corresponding values for the dynamic coefficients are obtained during the upward and downward movement of the plungers in the rods columns. If to consider $P_{rod} = q_{rod} \cdot L \cdot g$ and $P_{liquid} = q_m \cdot H \cdot g$, and the left-hand side of the equation is moved to the right and set to zero:

$$q_m^2 + q_{rod} q_m \frac{L}{H} \frac{\left(2K_{up} - K_{dw}\right)}{K_{up}} +$$
$$+ q_{rod}^2 \left(\frac{L}{H}\right)^2 \frac{K_{up} - K_{dw}}{K_{up}} - 2\left(\frac{f^2 [\sigma_{st}]^2}{HgK_{up}}\right) = 0. \tag{4}$$

Thus, the strength of the rods column will be ensured if the following condition is met, where the thickness of the liquid column above the plunger is taken into account:

$$q_m < -\frac{q_{rod} L\left(2K_{up} - K_{dw}\right)}{2HK_{up}} +$$
$$+ \left\{ \begin{aligned} &\left(\frac{q_{rod} L\left(2K_{up} - K_{dw}\right)}{2HK_{up}}\right)^2 - \\ &- q_{rod}^2 \left(\frac{L}{H}\right)^2 \frac{K_{up} - K_{dw}}{K_{up}} - 2\left(\frac{f^2 [\sigma_{st}]^2}{HgK_{up}}\right) \end{aligned} \right\}.$$

As a result of the carried-out research, a progressive expression was proposed to determine the strength condition of the rod column, which is one of the primary working elements of the rocking machine. Subsequently, a statement was put forward to determine the value of the linear density of the liquid column based on the strength condition of the rod column. This information helps specify the oil wells suitable for the application of the rocking machine, considering their specific physical characteristics and the given technical specifications of the rocking machine. Implementing these findings can effectively prevent accidents that may arise from rod column failures in rocking machines. Furthermore, this formula is not limited to conventional rocking machines but can also be applied to new designs of rocking machines.

However, at this time, it must be taken into account that the proposed considerations and mathematical formulas are based on theoretical studies carried out as close to reality as possible. Naturally, during the installation and operation of a pumping unit on a well, certain discrepancies will arise between theoretical and practical results as a result of the influence of a larger number of working factors on the construction. Comparison of the results obtained from the proposed new mathematical expressions with the results obtained from the real workflow remains open and may be the main topic of further research.

4. Conclusions

The article discusses the new mechanical solution for the construction of plunger pumps used in the oil industry. In this paper, a new design of the pumping unit was considered, taking advantage of its innovative design which consists of with a rope-block and crank-slide converter mechanism in which the heavy walking beam and the horse had been removed from the construction, and replaced by movable counterweights that allow much more perfect balancing of the pumping unit, which largely eliminates the main disadvantages of existing pumping units. As a result of the conducted research, a mathematical expression has been proposed for determining the line thickness of the liquid column that will meet the strength condition of the column of plungers for ensuring the accurate identification and safe operation of the new executive plunger mechanism's application areas.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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