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Influence of technological and operational parameters on the energy efficiency of downhole pumping units

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ABSTRACT: The article presents the results of experimental studies to determine the mode of operation of downhole pumping units. A mathematical model of the mode of operation of downhole pumping units, taking into account the parameters of the well and technological mode. The possibility of evaluating the energy efficiency of the mode of operation of downhole pumping units is shown.

KEYWORDS: well pump, operating mode, instrumental measurements, mathematical model, well flow rate, energy efficiency assessment.

I. INTRODUCTION

Experimental studies of the process of pumping out water using borehole pumps have shown that the efficiency of the operation of borehole pumps, as well as the process of extracting and transporting water, depends on increasing the flow rate of a well. well pump operation depends on water consumption. The seasonality factor (time of year) does not significantly affect the mode of operation of the well pump. Download active power downhole pumping unit is from 0.3 to 0.8 [Ref 1].

In paper [Ref 2] various schemes for installing water-lifting equipment in water wells are considered. The features of the hydraulic calculation of the joint operation of the pump and well are considered. Provides information about the design solutions for downhole water intake of groundwater, providing savings in electricity costs directly on water rise.

This paper [Ref 3] discusses the impact of process parameters on the likelihood of trouble-free operation of a well pump. The possibility of improving the reliability of the pumping downhole installation based on the redundancy of individual elements of the pumping unit. In paper [Ref 4] presents the results of determining the optimal parameters of the in-hole reactive power compensator, which minimizes the consumption of active power. The influence of the reactive power compensator on the operation mode of the downhole pumping unit is shown. The authors [Ref 5] conducted research on the impact on energy consumption of various technological and operational parameters. It has been determined that the power loss in an electrical cable depends on its temperature. However, determining the average cable temperature is quite a challenge, since the temperature of the well varies in depth, the cable is self-heating from the flowing current, heat exchange through the shell with the well fluid, and the liquid is heated by the heat generated by the working pump unit. In addition, the dependence of energy consumption on the viscosity of the well fluid was investigated. It is shown that the viscosity of the pump changes such characteristics as pressure, flow and efficiency.

The mode of operation of downhole pumping units depends on changes in water consumption patterns, parameters and well flow rate and other technological features when pumping out fluid. The mode of operation of borehole pumps is usually characterized by daily, monthly and annual schedules of fluid consumption. In accordance with this, experimental studies were conducted on the mode of fluid consumption and energy consumption of downhole pumping units, which is presented in Figure 1.

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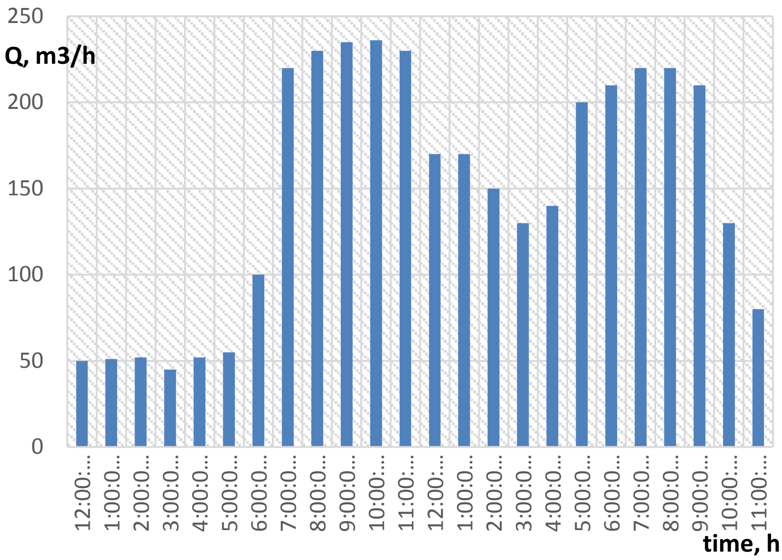

Fig. 1. Daily schedule of fluid intake

II. MATHEMATICAL MODEL OF THE DOWNHOLE PUMPING UNIT

According to our research, the operational and operational parameters of the well affect the efficiency of the downhole pumping unit.

The mode of operation of the well reflects the process of filling and emptying due to the interaction of the well with the reservoir and the pump, which is determined according to the expressions

$$V = D - Q + V_0, \quad (1)$$

$$h = \frac{V}{S}, \quad (2)$$

$$P_п = h \cdot \rho, \quad (3)$$

$$H_{дин} = H_c - h, \quad (4)$$

$$P_{заб} = (H_{заб} - H_c) \cdot \rho + P_п, \quad (5)$$

$$S = \pi\left(r_с^2 - r_{тр}^2\right), \quad (6)$$

where $V and V_0$- the initial and current volume of water (solution) in the working area of the well; h- the height of the liquid column in the working area of the well; S – borehole annulus cross-sectional area $\left(r_с\ и r_{тр}\right.$ – radius of the well and pipe, respectively;$Hзаб$ – bottomhole depth; Hc- pump running depth; $Hдин$- dynamic water level (solution) in the well; $P_{заб}$ – bottomhole pressure; ρ – density of water (solution).

The performance and pressure of the well pump depends, respectively, on the resistances $R_{\infty Q}$ and $R_{\infty H}$, the numerical value of which, taking into account the equivalent circuit (Fig. 2) [Ref 6-7], is determined

$$R_{*\infty H} = \left(\frac{H_{*0}}{Q'_{*\infty}} - V_0 R_{*t}\right)(1 - \infty_H), \quad (7)$$

$$R_{*\infty Q} = \left(\frac{H_{*0}}{Q'_{*\infty}} - V_0 R_{*t} - R_{\infty H}\right)\frac{1}{1-\infty_H}. \quad (8)$$

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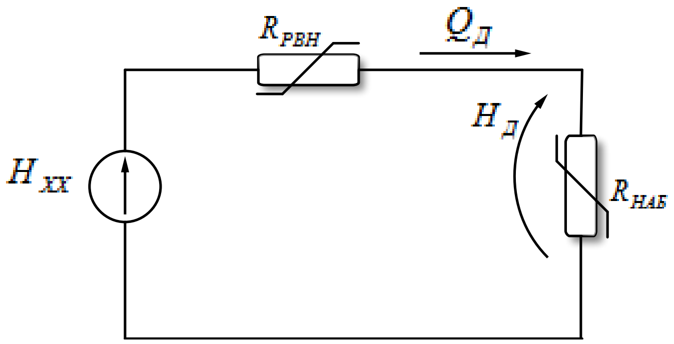

Fig. 2. Equivalent circuit replaced by well pumps

The value of the volume resistance $R_{\Delta O}$ is determined by the ratio of the volumetric efficiency of the pump η_O to the full value of the efficiency of the pump $\eta_п$, taking into account the dynamic level and pump performance

$$R_{\Delta O} = \frac{\eta_o}{1-\eta_O}\sqrt{H_{дин} Q} \ . \tag{9}$$

The hydraulic losses in the borehole pumps, which are conventionally composed of the sum of the eddy losses (impact and diffuser) and the losses along the length, after the equivalent, displays the hydraulic resistance $R_{*\Delta H}$ [Ref 8]

$$R_{*\Delta H} = \frac{C_2}{Q'_{*T}}(Q'_{*T} H_c - C_1 Q'^{ном}_{*T})^2 + С_0 Q'_{*T} \ . \tag{10}$$

Constant coefficients C_0 - C_2 are determined from the analysis of hydraulic losses in idle, nominal and “open” pressure networks [Ref8].

Mechanical losses, which consist of disc friction losses, friction in glands and bearings, and hydraulic braking losses, are simulated by hydraulic resistance $R_{мех}$, the approximate value of which is calculated through the full efficiency $\eta_п$ and internal mechanical efficiency (which takes into account disk friction losses) $\eta_м$.

$$R_{мех} \approx \frac{H_{дин}\eta_п}{1-\eta_м} \tag{11}$$

The general solution of equations (1) - (11) makes it possible to determine the energy balance of borehole pumps based on the calculation of interconnected hydraulic, volumetric and mechanical losses in the full range of the machine and the theoretical construction of the characteristics of the downhole pump from its catalog data.

III. EVALUATION OF THE ENERGY EFFICIENCY MODE OF THE DOWNHOLE PUMP

The existing variety of energy-saving solutions in water (solution) pumping systems is determined by a large opportunity to increase the efficiency of these systems. To assess the effectiveness of the use of any energy-saving solution, the following methods are used: conducting field experiments and tests; mathematical modeling of the engine - well pump system and determination of pump performance over certain periods of time; analysis of the results of the use of similar energy-saving solutions in existing systems "engine - well pump"; the use of data on the efficiency of energy-saving solutions established by firms producing energy-efficient equipment [Ref 9,10].

Based on the analysis of instrumental measurements, we propose a multi-purpose method for assessing the contribution of a wide range of energy-saving solutions to reducing electrical energy consumption by well pumping units using the method of evaluating the effectiveness of energy-saving equipment, technologies and measures [Ref 9-11].

The main objective of this method is to identify each contribution of the identified measures for energy saving and increase the efficiency of electric energy use.

Participation in energy saving and increasing the efficiency of use of electric energy in reducing the consumption of electric energy can be interpreted by introducing into the equation the efficiency coefficients of energy-saving measures and recommendations.

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In accordance with this, the efficiency ratio of energy saving measures and recommendations can be determined on the basis of the following formula:

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$$\sigma = \frac{H_{\Phi}}{H_{T-1}} (12)$$

where $H_{(T-1)}$ is the rate of electrical energy consumption for the technological process of pumping water (solution) per unit of pumped water (solution) in the annual cycle before applying energy-saving solutions, (kW · h / m3); where H_{Φ} is the rate of electric energy consumption for the technological process of pumping water (solution) per unit of pumped water (solution) in the annual cycle before applying energy-saving solutions (kW · h / m3).

The efficiency factor of energy-saving measures and recommendations describes the respective and comparative magnitude of the reduction in electrical energy consumption due to the application of a specific energy-saving measure.

IV. CONCLUSION AND FUTURE WORK

Because mechanical losses are external to the hydraulic circuit of the borehole pumps and do not affect the pressure characteristics of the machine, an equivalent circuit can be obtained for borehole pumps with a non-linear resulting resistance of the pump R_PBH. In relation to the load branch, it can be replaced by an equivalent hydrogenerator, whose analogue of electromotive force is equal to the value of the corresponding actual head pressure of the borehole pumps $H_{(XX)}$ in idle mode, and nonlinear internal hydroresistance R_{PBH} is equal to the input resistance of the two-port network.

In conclusion, a mathematical model (1) - (12) for estimating the energy efficiency of a well pumping unit based on the change in the actual flow rate of the well has been proposed..

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