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DEVELOPMENT OF THEORETICAL PREREGUISITES FOR THE TECHNOLOGY OF WATER LIFTING FROM WELLS USING THE SUBMERSIBLE ELECTRIC HIGH PRESSURE ELECTRICAL CENTRIFUGAL PUMP AND AIR-SUCKING DEVICE

Abstract. A new alternative technology of water lifting from wells using the submersible electric high pressure electrical centrifugal pump and air-sucking device developed in Kazakh national agrarian university NJSC is proposed, in order to reduce the specific weight of the lifted water in the water-lifting pipes and accordingly, to reduce the demand pressure and increase the pump unit supply.

The results of theoretical studies of the technological process of water lifting from wells with the use of a submersible electric pump and a suction device of the above-established dynamic level of water in a well to suck atmospheric air during the process in water-lifting pipes are presented.

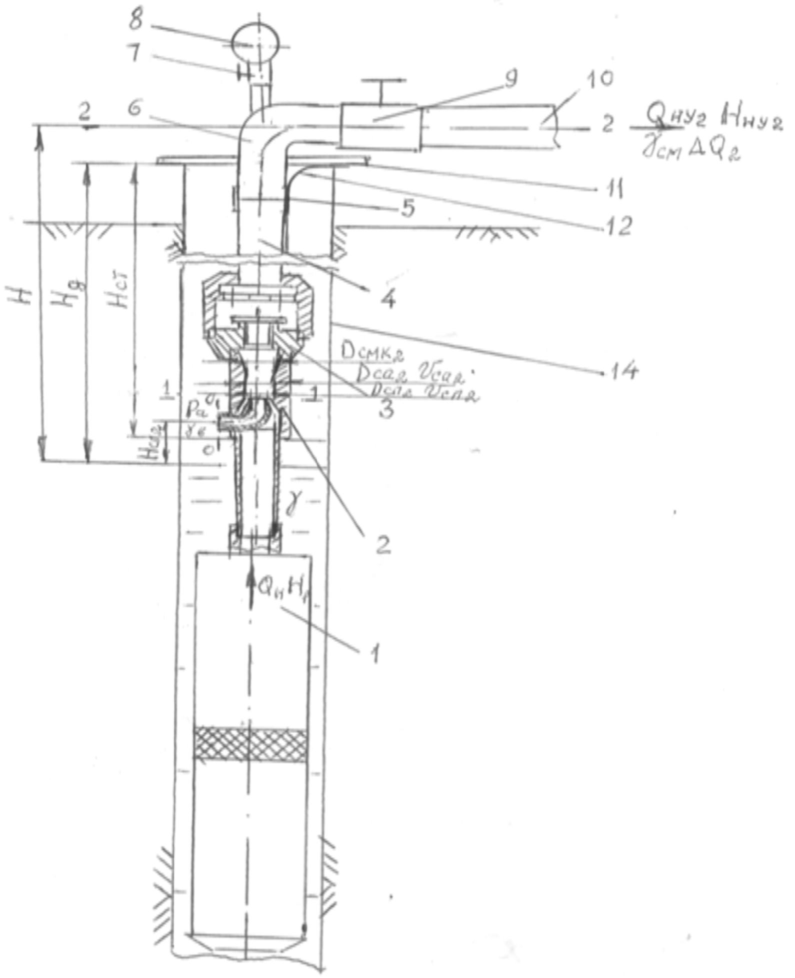
Keywords: alternative technology of water lifting from wells, pump installation**,** well, submersible electric pump, suction device, water-lifting pipe, technological process, dynamic water level, supply, water head.

Introduction. There is a new alternative technology for lifting water from wells by a pumping unit using a submersible electric pump and a suction device, installed above the dynamic level to suck atmospheric air into the water-lifting pipes, proposed in Kazakh National Agrarian University NJSC based on the results of the conducted studies [1-4].

Studies on the technology of water lifting from wells for a pumping unit with a submersible electric pump according to a technological scheme using a suction device with atmospheric air intake into water-lifting pipes showed, that the technological process of water lifting according to the developed technological scheme of the pumping unit (figure) has not been theoretically studied and is used for the first time.

The peculiarity of the technological process of water lifting is the use of atmospheric air suction to the water-lifting pipes by means of a suction device, installed on the pressure line of the submersible electric pump above the dynamic level of water in the well, in which, when water moves from the pump through the active nozzle, a negative pressure is created in the passive nozzle of the suction device due to the entrainment in it of atmospheric air according to the law of continuity of its movement, As a result, atmospheric air is sucked through the passive nozzle of the suction device into the water-lifting pipes, creating in them a water-air mixture with specific gravity$\gamma_{см2}$, thereby reducing the specific gravity γ of the water to be lifted and reducing the required headH_{p2}submersible pump and pump installation $H_{ну2}$at the required height of the water lift$H$and increasing the supply of the pumping unit by an amount ΔQ_2.

Lets consider the technological process of the water lifting of the pumping unit according to the developed technological scheme under the established operating mode, determining the analytical dependencies between the main input and output parameters, using the law of continuity of the flow of water and atmospheric air in the pumping system, Bernoulli equation for the cross sections at the inlet and outlet of the suction atmospheric motion in the passive nozzle and the water supplied from the electric submersible pump in the active nozzle of the suction device and the law of similarity of submersible electric pumps by supply in the proposed process flow diagram [5-7].



Technological scheme of a variant of a pumping unit using a submersible electric pump and a suction device with a suction of atmospheric air into the water-lifting pipes:
1 - submersible electric pump; 2 - air suction device; 3 - check valve; 4 - water pipe section; 5 - clutch; 6 - branch pipe; 7 - tap; 8 - manometer; 9 - valve; 10 - pipeline; 11 - wellhead; 12 - electrical cable; 13 - a control station (not shown); 14 - well; ΔQ_2 - increasing the pump system from using a suction device for atmospheric air, m^3/s; $\upsilon_{са2}$, $\upsilon_{сп2}$ - speed of water movement in the active and passive nozzles of the suction device, m/s; $Dса_2$, $Dсп_2$, $Dсмк_2$ - internal diameters of the active and passive nozzles and the mixing chamber of the suction device, m; $Q_{н2}$, $Q_{ну2}$ - Submersible electric pump and pump set, m^3/s; $H_{р2}$, $H_{ну2}$ - pressure of submersible electric pump and pump installation, m; H - height of water lift, m; H_g, $H_{ст}$ - dynamic and static water levels i the well, m; $H_в$ - height of the inlet of the passive nozzle of the suction device from the dynamic level, m; γ, $\gamma_{см}$ - specific weight of water and lifted water-air mixture in water-lifting pipes, H/m^3; P_a - Atmosphere pressure, H/m^2.

The technological scheme of the considered version of the pumping unit (see figure) consists of a submersible electric pump 1, Suction device for atmospheric air connection 2 with check valve 3, sections of water-lifting pipes 4, connected with each other by threaded couplings 5, branch pipe 6, equipped with a tap 7 with a manometer 8, valve 9 with a pipeline 10, transporting water to the consumer, also the head of the well 11, which holds the water-lifting pipes and submersible electric pump, electric cable 12, control station 13 (not shown in the picture) and wells 14 inside the well. The flow chart shows the input parameters of the pumping unit and the main output technological and technical parameters of the technological process of the water lifting and the suction device with the suction of atmospheric air.

Research methodology. Was included in the definition of the following conditions:

- establishment of input and output parameters in the researched technology of water lifting of the pumping unit;
- determination of functional dependencies between the input and output parameters of a pumping unit using a submersible electric pump and a suction device with a suction of atmospheric air into the water-lifting pipes;

- determination of analytical dependencies between the main input and output technological and technical parameters of the pumping unit using a submersible electric pump and a suction device with a suction of atmospheric air into the water-lifting pipes.

For the experiments, the discontinuity of the flow of movement of the supplied water and the suction of atmospheric air in the suction device and water-lifting pipes was used,in the use of the Bellni well for the inlet and outlet ends of the suction device and water-lifting tanks and the theoretical foundations of the vacuum created in the suction device [4-6].

The main input parameters of the pumping unit are: submersible electric pump supply $Q_н$ and the pressure created by him in the pumping unit H_P,and the main output parameters are: technological parameters of the pumping unit: feed increase ΔQ_2, pumping unit supply $Q_{ну2}$, pump head $H_{ну2}$, specific gravity $\gamma_{см2}$ lifted water-air mixture in water-lifting pipes, usefull $N_{п2}$ and spent $N_{ну2}$ power and Efficiency $\eta_{ну2}$ pumping unit and technological and technical parameters of the suction device for atmospheric air: vacuum head $H_{вак2}$, internal diameters of active $D_{са2}$ and passive $D_{сп2}$ nozzle, speed of water movement in the active $\upsilon_{са2}$ and passive $\upsilon_{сп2}$ nozzles, inner diameter $D_{смк2}$ and lenght $L_{смк2}$ mixing chamber of the suction device.

To determine these basic output parameters, the following functional dependencies were considered:

1) by definition of increasing the flow ΔQ2 of the pumping unit

$$\Delta Q_2 = f\,(Q_{н2},\, н,\, \gamma,\, \gamma_{см2}), \tag{1}$$

2) by definition of feed Q_{pu2} of the pumping unit $Q_{ну2}$

$$Q_{ну2} = f\,(Q_{н2},\, \Delta Q_2,\, \gamma,\, \gamma_{см2}), \tag{2}$$

3) by definition of the pressure of the pumping unit $H_{ну2}$

$$H_{ну2} = f\,(H,\, H_{р2},\, Qну_2,\, h\ell_2,\, hм_2,\, \gamma_{см2}), \tag{3}$$

4) by definition of specific gravity $\gamma_{см2}$ lifted water-air mixture in water-lifting pipes

$$\gamma_{см2} = f\,(\gamma,\, \gamma_в,\, \upsilon_{сп1},\, \upsilon_{са1},\, к_1,\, \upsilon_{сп2},\, \upsilon_{са2},\, к_2,\, H), \tag{4}$$

5) by definition, useful $N_{п2}$and spent $N_{ну2}$power and efficiency $\eta_{ну2}$pumping unit

$$N_{п2} = f\,(H_{р2},\, Q_{ну2},\, \gamma_{см2}), \tag{5}$$

$$N_{ну2} = f\,(H,\, H_{Р2},\, Q_{ну2},\, \gamma_{см2},\, \eta_{ну2}), \tag{6}$$

$$\eta_{ну2} = f\,(N_{п2},\, N_{ну2},\, \eta_{г2},\, \eta_{о2},\, \eta_{м2}), \tag{7}$$

6) by definition, technological and technical parameters of the suction device for atmospheric air:

- vacuum head $H_{вак2}$

$$H_{вак2} = f\,(P_а,\, P_{са2},P_{сп2},\, Q_{н2},\, D_{са2},\, D_{сп2},\, \upsilon_{са2},\, \upsilon_{сп2},\, к_2), \tag{8}$$

- internal diameters of active $D_{са2}$and passive $D_{сп2}$nozzles

$$D_{са2} = f\,(Q_{н2},\, H_{р2},\, \upsilon_{са2}), \tag{9}$$

$$D_{сп1} = f\,(Q_{н2},\, H_{р2},\, \upsilon_{са2},\, \upsilon_{сп2},\, к_2), \tag{10}$$

- speed of water movement in the active $\upsilon_{са2}$and the velocity of atmospheric air in the passive $\upsilon_{сп2}$ nozzles

$$\upsilon_{са2} = f\,(Q_{н2},\, H_{р2},\, D_{са2}), \tag{11}$$

$$\upsilon_{сп2} = f\,(Q_{н2},\, H_{р2},\, D_{сп2},\, \upsilon_{са2},\, к_2), \tag{12}$$

- inner diameter $D_{смк1}$ and length $L_{смк1}$mixing chamber

$$D_{смк2} = f\,(Q_{ну1},\, H_{р2},\, D_{са1},\, D_{сп2},\, \upsilon_{са2},\, \upsilon_{сп2},\, \gamma_{см2}), \tag{13}$$

$$L_{смк2} = f\,(Q_{ну2},\, H_{р2},\, D_{са2},\, D_{сп2}), \tag{14}$$

where ΔQ_2 - Increasing the pump system from using a suction device for atmospheric air, m^3/s; υ_{ca2} - speed of water movement in the active nozzle of the suction device for atmospheric air, m/s; $\upsilon_{cп2}$ - speed of atmospheric air in the passive nozzle of the suction device for atmospheric air, m/s; $D_{cп2}$ - internal diameter of the passive nozzle of the suction device for atmospheric air, m; κ_2 - the coefficient of decrease in the speed of movement of atmospheric air in the passive nozzle with respect to the speed of movement of water in the active nozzle of the suction device with a suction of atmospheric air.

Research results. Theoretical prerequisites are developed according to the above methodology and the adopted functional dependencies (1)–(14).One of the main technological parameters of a pumping unit with a suction device with a suction of atmospheric air is to increase the flow by an amount ΔQ_2, which according to the accepted functional dependence (1) is determined using the law of similarity of centrifugal pumps by supply in the form of equation:

$$\frac{\Delta Q_2 + Q_{н2}}{Q_{н2}} = \frac{\gamma \cdot H}{\gamma_{см2} \cdot H}, \quad (15)$$

where $Q_{н2}$ - submergible centrifugal pump feed, m^3/s; γ, $\gamma_{см2}$ - specific weight of water and lifted water-air mixture in water-lifting pipes, H/m^3.

Solving equation (15) with respect to ΔQ_2, a formula is obtained for determining the increase in the delivery of a pumping unit in accordance with the technological scheme when using a suction device for sucking atmospheric air into water-lifting pipes:

$$\Delta Q_2 = Q_{н2} \cdot \left(\frac{\gamma}{\gamma_{см2}} - 1\right). \quad (16)$$

Supply of $Q_{ну2}$ pumping unit according to the accepted functional dependence (2) is determined by the total addition of the submerged electric pump $Q_н$and feed increase ΔQ_2 pump installation from the use of a suction device to suck atmospheric air into the water-lifting pipes, creating in them a water-air mixture of a smaller specific gravity$\gamma_{см2}$ than the specific weight of the water to be lifted, according to the formula:

$$Q_{ну2} = Q_{н2} + \Delta Q_2, \ m^3/s \quad (17)$$

or when replacing ΔQ_2 from (16) the formula (17) takes the form:

$$Q_{ну2} = Q_{н2} + Q_{н2} \cdot \left(\frac{\gamma}{\gamma_{см}} - 1\right), \ m^3/s \quad (18)$$

When formula (18) is simplified, the supply $Q_{ну2}$ of pumping unit is determined by the formula:

$$Q_{ну2} = Q_{н2} \cdot \frac{\gamma}{\gamma_{см}}, \ m^3/s. \quad (19)$$

From the formula (19) it follows that the delivery of the pumping unit depends on the supply of the used electric submersible pump and the specific weight of the lifted water and the specific gravity of the water-air mixture created in the water-lifting pipes by means of a suction device with atmospheric air.

Pumping unit head $H_{ну2}$according to the accepted functional dependence (3) is determined on the basis of the Bernoulli equation, compiled with respect to the cross sections of the input and output parameters of the pumping system (1-1 and 2-2, see Picture 1):

$$\frac{P_1}{\gamma} + \frac{\upsilon_{Ca2}^2}{2g} = \frac{H \cdot \gamma_{см}}{\gamma} + \frac{\upsilon_2^2}{2g} + h_{l2} + h_{м2}, \quad (20)$$

where $\frac{P_1}{\gamma} = H_{ну2}$ - required pump head, m; P_1 - the overpressure created by the submersible electric pump in the cross section 1-1 of the suction device, H/m^2.

Solving equation (20) with respect to $\frac{P_1}{\gamma} = H_{ну2}$, have received the formula for determining the required head of the pumping unit:

$$H_{ну2} = \frac{H\cdot\gamma_{см}}{\gamma} - \frac{\upsilon_{са2}^2 - \upsilon_2^2}{2g} + h_{l2} + h_{м2}, \quad (21)$$

where H - height of water lifting, determined by the formula, m:

$$H = H_g + h_o, \quad (22)$$

where H_g - dynamic water level in the well, m; h_o - height from the head of the well to the outlet of the lifted water from the water-lifting pipes, m; $\frac{\upsilon_{Ca2}^2}{2g}$ - high-velocity head of water in the active nozzle of the suction device, m; $\frac{\upsilon_2^2}{2g}$ - high-speed water pressure at the outlet of the water-lifting pipes, m; h_{l2} - loss of pressure along the length of water-lifting pipes, m:

$$h_l 2 = \lambda\cdot\frac{L}{D_н}\cdot\frac{\upsilon_н^2}{2g} = \lambda\cdot\frac{L}{D_н}\cdot\frac{16Q_{ну2}^2}{\pi^2\cdot D_н^4\cdot 2g} = A\cdot L\cdot Q_{ну2}^2, \quad (23)$$

where λ - coefficient of water resistance in pipes; L - total length of pressure pipes of the pumping unit, m; $D_н$ - inner diameter of pressure pipes, m; $\upsilon_н$ - speed of water movement in pressure pipes, is determined by the formula, m/s:

$$\upsilon_н = \frac{4Q_{ну2}}{\pi\cdot D_H^2}, \text{ m/s} \quad (24)$$

g - acceleration of gravity, m/s (g = 9,81 m/s^2); $Q_{ну2}$ - delivery of the pumping unit, m^3/s; A - resistivity of water-lifting pipes:

$$A = \lambda\cdot\frac{8}{\pi^2\cdot D_н^5\cdot g}. \quad (25)$$

$h_{м2}$ - loss of pressure from local resistance in the water-lifting system, m:

$$h_{м2} = \sum_{i=1}^{n}\zeta.\frac{V^2{}_м}{2g}, \text{ m} \quad (26)$$

where $V_м$ - water velocity in devices that create local resistance, m/s.

Specific gravity $\gamma_{см2}$(4) is determined from the Bernoulli equation (20) or from the formula (21) by determining the required head of the pumping unit, solving them with respect to$\gamma_{см2}$:

$$\gamma_{см2} = \frac{\gamma}{H}\cdot(H_{ну2} + \frac{\upsilon_{са2}^2 - \upsilon_2^2}{2g} - h_{l2} - h_{м2}), \quad (27)$$

It follows from formula (27) that the specific gravity of the created water-air mixture in the water-lifting pipes depends on the specific weight of the lifted water, the height of the water lift, the head of the pumping unit, the total head losses and the parameters of the suction device for drawing atmospheric air into the water-lifting pipes.

Usefull $N_{п2}$ and spent $N_{ну2}$ power and efficiency $\eta_{ну2}$ pumping units are theoretically determined on the basis of functional dependences (5), (6) and (7) according to known formulas:

- useful$N_{п2}$pumping unit power

$$N_{п2} = p\cdot g\cdot Q_{ну2}\cdot H_{ну2} = \gamma\cdot Q_{ну2}\cdot H_{ну2}, \text{ W} \quad (28)$$

$$\text{or } N_{п2} = 9{,}81\cdot Q_{ну2}\cdot H_{ну2}, \text{ kW}, \quad (29)$$

where γ – specific gravity of the lifted water, H/m^3 (γ = 9810 H/m^3):

$$\gamma = p\cdot g, \quad (30)$$

where p – Density of the lifted water, kg/m^3 (p = 1000 kg/m^3);

- spent $N_{ну2}$ pumping unit power

$$N_{ну2} = \frac{N_{n2}}{\eta_{ну2}} \quad (31)$$

- efficiency $\eta_{ну2}$ of pumping unit

$$\eta_{ну2} = \frac{N_{n2}}{N_{ну2}} \quad (32)$$

or

$$\eta_{ну2} = \eta_{г2} \cdot \eta_{о2} \cdot \eta_{м2}, \quad (33)$$

where $\eta_{г1}$ – hydraulic efficiency of the pumping unit:

$$\eta_{г1} = \frac{H_{НУ2}}{H_m} \quad (34)$$

where $H_{НУ2}$ - the required pressure of the pumping unit is determined by formula (21), m; $H_т$ - theoretical head of the pumping unit, m:

$$H_т = \frac{U_2 V_2 \cos\alpha_2 - U_1 V_1 \cos\alpha_1}{g}, \quad (35)$$

where U_1, U_2 - circumferential water velocities at the inlet and outlet of the impeller of the electric submersible pump used, m/s; V_1, V_2 - averaged absolute water velocities at the inlet and outlet of the pump impeller, m/s; α_1,α_2 - Angles between absolute and peripheral speed at the inlet and outlet of the impeller pump, ^{o}; $\eta_{о2}$ - volumetric efficiency of the pumping unit:

$$\eta_{о2} = \frac{Q_{ну2}}{Q_{ну2} + Q_у}, \quad (36)$$

where $Q_у$ - volumes of leaks (water losses), m^3/s; $Q_{ну2}$ - the delivery of the pumping unit is determined by formula (17) or (18) and (19),m^3/s; $\eta_{м2}$ - mechanical efficiency of the pumping unit:

$$\eta_м = \frac{N_{ну2}}{N_{дв}} \quad (37)$$

where $N_{ну2}$ - the power consumption of the pumping unit is determined by the formula (31), kW; $N_{дв}$ - power consumed by the submersible pump motor, kW.

Determination of technological and technical parameters of the suction device for the connection of atmospheric air into the water-lifting pipes. The vacuum head $H_{вак2}$, according to the adopted functional dependence (8), is determined on the basis of the Bernoulli equation, made with respect to the cross sections (see figure) 0 -0 and 1-1:

$$\frac{P_a}{\gamma} + \frac{\upsilon_{cn}^2}{2g} = \frac{P_{cn2}}{\gamma} + \frac{\upsilon_{ca}^2}{2g}, \quad (38)$$

where P_a - Atmosphere pressure, H/m^2; $P_{сп2}$ - pressure at the outlet of the passive nozzle in the cross section 1-1, H/m^2; $\upsilon_{са2}$, $\upsilon_{сп2}$ - speed of water movement in the active and passive nozzles of the suction device, m/s.

We transform equation (38) in the form:

$$\frac{P_a}{\gamma} - \frac{P_{cn2}}{\gamma} = \frac{\upsilon_{ca}^2 - \upsilon_{cn}^2}{2g}, \quad (39)$$

where the left-hand side of the equation and the right-hand side are formulas for determining the vacuum head:

$$H_{вак2} = \frac{P_a}{\gamma} - \frac{P_{сп2}}{\gamma}, \text{ m} \quad (40)$$

or

$$H_{вак2} = \frac{\upsilon_{ca2}^2 - \upsilon_{cn2}^2}{2g} - H_в, \text{ m} \quad (41)$$

Internal diameters of active $D_{ca2}$and passive $D_{сп2}$ nozzles are theoretically determined on the basis of functional dependences (9) and (10) according to known formulas:

$$D_{ca2} = \left(\frac{4Q_{ну2}}{\pi \cdot \upsilon_{ca2}}\right)^{1/2}, \quad (42)$$

$$D_{сп2} = \left(\frac{4Q_{ну2}}{\pi \cdot \upsilon_{cn2}}\right)^{1/2}. \quad (43)$$

The speed of movement of water in the active atmosphereυ_{ca2} and the velocity of atmospheric air in the passive$\upsilon_{сп2}$nozzles are theoretically determined on the basis of functional dependences (11) and (12) according to known formulas:

$$\upsilon_{ca2} = \frac{4Q_{ну2}}{\pi \cdot D_{ca2}^2}, \quad (44)$$

$$\upsilon_{сп2} = \frac{4Q_{ну2}}{\pi \cdot D_{cn2}^2}. \quad (45)$$

Inner diameter $D_{смк2}$ and length $L_{смк2}$ mixing chamber of the active nozzle of the suction device are theoretically determined on the basis of functional dependences (13) and (14) according to known formulas:

$$D_{смк2} = \left(\frac{4Q_{ну2}}{\pi \cdot \upsilon_{смк2}}\right)^{1/2}, \quad (46)$$

$$L_{смк2} = (6 \ldots 8) \cdot D_{смк2}. \quad (47)$$

Conclusions. The theoretical assumptions obtained are the basis for determining the main technological parameters of a pumping unit with a submersible electric pump and a suction device,installed on the pump discharge line above the dynamic level of water in the well, and the determination of technological and technical parameters of the suction device with the suction of atmospheric air into the water-lifting pipes, on the basis of which the required sizes of the suction device can be calculated for any type of submersible electric pump.

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ЭЦВ БАТПАЛЫ ЭЛЕКТРОСОРҒЫНЫҢ ҚОЛДАНЫЛУЫМЕН САҢЫЛАУЛАРДАН СУТАРТҚЫШ ТЕХНОЛОГИЯСЫ БОЙЫНША ТЕОРИЯЛЫҚ АЛҒЫШАРТТАРДЫ ЖӘНЕ АУА СОРҒЫШ ҚҰРЫЛҒЫЛАРЫН ӨҢДЕУ

Аннотация. Сутартқыш құбырларда көтерілетін судың салыстырмалы салмағын төмендету және тиісінше қажет тегеуріндi азайту және сорап қондырғысын ұлғайтумақсатында, ҚазҰаУ ҒАҚ өңделген ЭЦВ және ауа сорғыш батпалы электросорғының қолданылуымен саңылаулардан сутартқыштың жаңа баламалы технологиясы ұсынылды. Сутартқыш құбырларында технологиялық үдерістер кезінде атмосфералық ауаны тарту үшін саңылауларда судың динамикалық деңгейінен жоғары бекітілген батпалы электросорғының және сорушы құрылғының қолданылуымен, саңылаулардан су тартылудың технологиялық үдерісінің теориялық зерттеулерінің нәтижелері келтірілген.

Түйін сөздер: саңылаулардан сутартқыштың баламалы технологиясы, сорушы құрылғы, саңылау, батпалы электросорғы, сорушы құрылғы, сутартқыш құбыр, технологиялық үдеріс, судың динамикалық деңгейі, жіберу, тегеурін.

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РАЗРАБОТКА ТЕОРЕТИЧЕСКИХ ПРЕДПОСЫЛОК ПО ТЕХНОЛОГИИ ВОДОПОДЪЁМА ИЗ СКВАЖИН С ИСПОЛЬЗОВАНИЕМ ПОГРУЖНОГО ЭЛЕКТРОНАСОСА ЭЦВ И ВОЗДУХОВСАСЫВАЮЩЕГО УСТРОЙСТВА

Аннотация. Предложена разработанная в НАОКазНАУ новая альтернативная технология водоподъёма из скважин с использованием погружного электронасоса ЭЦВ и воздуховсасывающего устройства, с целью снижения удельного веса поднимаемой воды в водоподъёмных трубах и соответственно уменьшению потребного напора и увеличения подачи насосной установки. Приведены результаты теоретических исследований технологического процесса водоподъёма из скважин с использованием погружного электронасоса и всасывающего устройства, установленного выше динамического уровня воды в скважине для подсоса атмосферного воздуха во время технологического процесса в водоподъёмные трубы.

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