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Determination of the parameters of the use of water-lifting equipment in the conditions of livestock farms

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Abstract. The main task of water supply systems is to expand the technological capabilities of the water supply process, increase its reliability, reduce its capital and operating costs, and simplify design. The purpose of the article is to determine the optimal parameters for the use of the proposed constructive solution of water-lifting equipment in the conditions of livestock farms. The research was conducted in laboratory conditions with further use of mathematical statistics methods. The criteria for optimizing the use of the proposed design of water-lifting equipment in the conditions of livestock farms include the amount of water flow and the speed of the flow. The article establishes the most optimal structural and technological parameters of water-lifting equipment, namely: head height; volume of transit tanks; pipeline diameter; pipeline length. The principle of operation of the proposed constructive solution of water lifting equipment for use in livestock farms is based on increasing the necessary pressure for the water supply network by direct repeated use of gravity forces in the form of the weight of the liquid column from natural or artificial pressure. The ratio of criteria for optimizing the process of using water-lifting equipment in the conditions of livestock farms and optimal structural and technological parameters of the proposed solution was determined. The use of technology in compliance with the recommended structural and technological parameters will solve the problem of improving the quality of water supply to consumers in the conditions of livestock farms, reducing energy consumption during the operation of the water supply system and maintaining the necessary pressure in the water supply network

Keywords: farm mechanization, farms, evaluation of the quality of the technological process, animal husbandry, structural and technological parameters

INTRODUCTION

One of the most important problems in livestock farms is the creation of a modern water supply system. Water supply systems are complex engineering structures that provide both water supply to consumers and drainage and wastewater treatment. The use of water supply systems requires a lot of energy, so the creation of systems that will contribute to energy saving is necessary for the development of the industry in the country.

If an effective water supply system is used, the productivity of livestock farms increases. Water consumption on dairy and fattening farms can reach several thousand cubic meters. To create operational water supplies, water towers are used, the filling of which requires significant energy costs.

Thus, the task of water supply systems is to expand the technological capabilities of the water supply process, increase its reliability, reduce its capital and operating costs, and simplify design. Therefore, it is proposed to carry out the process of increasing the pressure by gravity in the form of the weight of a liquid column of the required height by implementing a system of gravity water lifting equipment, which provides

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an automatic process of reusing the pressure that exists in the water supply system of livestock farms.

The given data demonstrate a tendency to reduce livestock in livestock farms of Ukraine [1]. Researcher O. Zakharchenko analyzed the quantitative composition and dynamics of livestock and poultry and, taking this into account, calculated the volume of technical water used in livestock and poultry farming [2]. As the cost of energy continues to rise, the development of more efficient equipment will contribute to energy conservation [3]. The functioning of cattle fattening farms is based on the compliance of the technical characteristics of livestock facilities with modern requirements and the efficiency of production [4]. During the development of technical solutions for cattle fattening farms, key aspects of EU regulatory requirements should be taken into account [5].

Let's consider the points of view of foreign researchers on the investigated problem. M. Ali identified opportunities to reduce the energy consumption of the pumping system by means of intelligent design, modernization and operation [6]. The authors P. Rajkova & Z. Kubik analyzed the relationship between farm mechanization and the need for labor, increasing the level of farm mechanization reduces the demand for hired labor [7]. The authors Y. Zhang *et al*. determined that the suction of coarse solid particles in a hydraulic collector is effective in the context of working with particles of different densities [8]. The article by J. Qian *et al*. presents a comprehensive review of the progress made in recent years on cavitation in valves, including check valves [9]. The article by R. Aryal *et al*. presents a semi-analytical model that facilitates the optimal design of small hydropower systems so that the maximum possible energy can be collected under conditions of low head and flow in channel conditions [10]. E. Katsuno cites several practical applications in fluid mechanics aimed at reducing energy dissipation by reducing resistance or pressure drop [11]. However, when adapting and applying energy benchmarking methodologies elsewhere, site-specific factors such as different discharge conditions, topographic boundary conditions, volume and composition of wastewater must be considered and these factors must be taken into account by practitioners. during the assessment of energy comparative analysis [12].The development of water resources, especially hydropower, is an important source of renewable energy. In the work of F. Tian, this relationship was investigated using data on the construction of reservoirs, the use of hydropower and water [13]. Water engineering modeling tools and mathematical tools provide an information resource for practitioners who want to learn more about different water engineering methods and models and their practical applications and case studies [14].

The device for raising water [15], proposed by researchers Y.F. Samedov & E.S. Strelskyi is distinguished by the fact that the pipe for raising water in the upper part has an extended part, which is located at a height of 10 meters. A shut-off valve is placed in the lower part of the pipe for raising water, which is below the water level in the source of supply. The disadvantages of the device include the fact that the height of the water rise is limited, it is affected by the magnitude of the water level drop.

Also known is the device for raising and supplying water [16], proposed by the inventors D.G. Parmenova & G.G. Deligiosis. It is equipped with an additional pipeline with a pump. A siphon line contains a gate valve that is installed at its discharge end before the reservoir or power supply being filled. The siphon pipeline is connected to an additional valve with a filling tank. But the design dimensions of the device limit the length of the water transportation path.

The authors investigated separate agricultural production [17] and mathematical modeling of the technology of processing agricultural products [18], but determining the efficiency of using water-lifting equipment in the conditions of livestock farms was not a special subject of research.

The analysis of literary and patent information sources devoted to the problem of using water-lifting equipment in the conditions of livestock farms makes it possible to conclude that:

- the lack of modern water-lifting equipment in the conditions of livestock farms does not allow to fully realize the possibility of providing them with easy-to-use and energy-efficient systems;
- the study of known solutions of equipment for raising water, makes it possible to conclude that the functioning of the system becomes possible only under the condition of creating a constant necessary pressure of water in the supply pipeline;
- in literary sources, there is a limited number of technically justified constructive solutions of water supply systems for the consumer in conditions of insufficient pressure from the water supply source.

Thus, the task of water supply systems for livestock farms is to expand the technological capabilities of the water supply process, increase its reliability, reduce its capital and operating costs, and simplify construction.

To solve it, it is proposed to implement a constructive solution of water-lifting equipment in the conditions of livestock farms, equipped with a device that provides an automatic process of multiple use of the pressure that exists in the system for supplying water to the consumer.

The task of the constructive solution proposed by the authors is to increase the efficiency by reducing the energy consumption of water supply systems, ensuring optimal pressure in the water supply network and improving the quality of water supply to consumers.

The purpose of the article is to determine the parameters of using the proposed constructive solution of water-lifting equipment in the conditions of livestock farms, to conduct experimental studies and to prove the effectiveness of the use of similar devices in the conditions of agriculture.

MATERIALS AND METHODS

The methods of physics, hydraulics, analysis and modeling were used to solve the research tasks. The methods of physics and hydraulics were used to study the patterns of fluid movement using the balance equation of the specific energy of the moving fluid in the pipe. The process of raising water using the proposed constructive solution of water-raising equipment in the conditions of livestock farms is based on the use of three laws in one process: the basic law of hydrostatics, the Boyle-Marriott law of gas dynamics and the law of connected vessels with liquid. Hydraulic dependencies were used to determine the required volume of water consumption and the speed of movement of the liquid flow. In the case of the proposed constructive solution of water-lifting equipment in the conditions of livestock farms, the law of fluid movement in the gap from one transit container to another is considered. For this purpose, the regularity of fluid movement is considered using the balance equation of the specific energy of the moving fluid in the pipe (D. Bernoulli's equation). For the sudden expansion of the pipeline, when a pipeline with a smaller diameter passes into a pipeline with a larger diameter, the head loss during a sudden expansion of the pipeline was determined by Borda's formula. Based on these dependencies, the area of the pipeline diameter is theoretically determined.

Reference literature for process and plant engineers [19], water treatment plant operators, and environmental consultants [20] was used in the design of the laboratory plant. An analysis of the main technical achievements in the design of water-lifting devices with an emphasis on modern hydraulic engineering technologies was also performed [21].

The study of technological parameters of water-lifting equipment was carried out in laboratory conditions by methods of mathematical statistics [22] with data processing on a PC. Experimental studies of water lifting by water-lifting equipment were carried out on a specially designed installation. The program of experimental research involves checking the structural scheme of water-lifting equipment in the conditions of livestock farms, determining the quality indicators of the technological process (height of the liquid column; volume of transit tanks; pipe diameter; pipe length) according to the following optimization criteria: volume of water consumption, speed of flow. Optimization of structural and technological parameters was carried out using a full factorial experiment.

- factors that least affect the technological process were equaled to zero, and the number of significant factors should not exceed two; otherwise, the study of the response surface on a two-dimensional plane is impossible;
- taking the derivatives of each of the two remaining factors, the center of the response surface was located, where the value of the optimization criterion was determined; in the case of the absence of the center or its location outside the experimental zone, the center was placed in the zone of the optimal combination of factors;
- the regression equation was reduced to the canonical form, after which contour curves of two-dimensional intersections were constructed;
- alternately equating the factors to zero, leaving any two others not equal to zero, we get the regression equation for the volume of water consumption and the speed of the flow.

RESULTS AND DISCUSSION

Theoretical justification of the application of the proposed constructive solution of water-lifting equipment in the conditions of livestock farms

The process of raising water in the proposed constructive solution of water lifting equipment in the conditions of livestock farms is based on the use of three laws in one process: the basic law of hydrostatics, the Boyle-Marriott law of gas dynamics and the law of connected vessels with liquid [23]. It was this set of laws that made it possible to create a system of the proposed constructive solution of water-lifting equipment in the conditions of livestock farms. At the same time, the force of gravitational action appears in the form of the weight of a column of liquid, which is equal to the pressure, that is, the force of gravitational action F is equal to:

$$F = \frac{m_1 M_2}{r^2} \gamma_{\text{cgr.const}}, \quad (1)$$

where, m_1 is the weight of the liquid column, kg; M_2 – weight of land, kg; r – is the distance between the centers of gravity, m; $\gamma_{gr.\,const}$ is the gravitational constant.

The basic equation of hydrostatics establishes a relationship between the hydrostatic pressure at a point of the liquid, its location (coordinates) in the liquid, and the density of the latter. It is an equation of an applied nature, with its help in engineering practice the hydrostatic pressure at any point of the liquid is found.

To substantiate the basic equation of hydrostatics, consider the case when a liquid in a state of equilibrium is in a vessel and only the force of gravity acts on it. In this case, the projections of mass forces on the axis of coordinates, related to a unit of weight, will be equal to:

$$x = 0, y = 0, F_z = -g. \quad (2)$$

Let's substitute the value of the projections into the equation $dp=\rho(F_x\,dx+F_y\,dy+F_z\,dz)$, we will get the dependence:

$$dp = -\rho g dz. \quad (3)$$

By integrating this equation with the condition that and that $\rho=const$ within the volume of the liquid under consideration, the change in the acceleration of free fall can be neglected, i.e. $g=const$, we get:

$$p = -\rho g z + c, \quad (4)$$

where c is an arbitrary constant.

Dividing equation (4) by ρg, we get:

$$z + \frac{p}{(\rho g)} = const. \quad (5)$$

Dividing equation (4) by ρ, we get:

$$gz + \frac{p}{\rho} = const. \quad (6)$$

Note that the terms of equation (5) are assigned to a unit of weight, and (6) to a unit of mass. Boundary conditions on the surface of the liquid are known: $z=z_0$, $p=p_0$, and, then:

$$c = z_0 + \frac{p_0}{(\rho g)}. \quad (7)$$

Substituting this expression for constant integration into formula (4), we get:

$$\frac{z_0+p_0}{(\rho g)} = \frac{z+p}{(\rho g)}. \quad (8)$$

Equation (8) is called the basic equation of hydrostatics.

It follows from equation (8):

$$p = p_0 + \rho g(z_0 - z), \quad (9)$$

that is, that the pressure in the liquid, which is in a state of equilibrium, is greater than the pressure on the surface by an amount equal to the weight of the column of liquid above this point. Since $z_0-z=h$, formula (9) will take the form:

$$p_{\text{abs}} = p_0 + \rho g h, \quad (10)$$

where p_{abs} is the absolute pressure at the point; p_0– pressure on the free surface; h – is the immersion depth of the point in the liquid; ρ – water density; g – the acceleration of free fall.

Equation (10) is called the basic equation of hydrostatics for absolute pressure.

Thus, according to equation (10), the pressure at the point of the liquid, which is in a state of equilibrium at a depth h below the free surface, is equal to the sum of the pressure on the free surface p_0 (in open vessels it is equal to the atmospheric pressure) and the pressure due to the weight of the liquid column, located above the point, i.e. ρgh.

In open vessels, usually only the pressure ρgh is taken into account, and the atmospheric pressure is mutually balanced, and equation (10) will take the form:

$$p = \rho g h. \quad (11)$$

Equation (11) is the basic equation of hydrostatics for excess pressure. Thus, excess pressure at any point inside the liquid arises only from the weight of its column located above the point.

Given that $p_{abs}=p_a+p$, from where $p=p_{abs}-p_a$, and taking into account equation (10), we get:

$$p = p_0 + \rho g h - p_a = (p_0 - p_a) + \rho g h = \Delta p + \rho g h, \quad (12)$$

where $\Delta p=p_0-p_a$.

Thus, in this case, as well as for the proposed design solution of water-lifting equipment in the conditions of livestock farms, the excess pressure at any point of the liquid is created both by the weight of the liquid column and by the excess pressure on the free surface, the value of which is Δp.

According to the Boyle-Marriott law:

$$PV = const, \quad (13)$$

where P is the air pressure in the specified volume V, the conditions for obtaining the required degree of atmospheric air compression in the hermetic volume of the basic capacity of the proposed structural solution of the water-lifting equipment in the conditions of livestock farms (compressor) have been created.

The third law of the process of raising water in the proposed constructive solution of water lifting equipment in the conditions of livestock farms is the law of connected vessels with liquid, which provides a justification for the balance of liquids in connected vessels.

As you know, connected vessels are called vessels that are connected to each other by hydraulic lines or structural elements. Consider a system consisting of two connected vessels filled with two different liquids that do not mix, and pressures p_1 and p_2, which are not the same, act on the free surface of the liquid.

The specific gravity of liquids is also different - in the first vessel γ_1, and in the second γ_2.

Let's take the comparison area 0-0 at the level of the liquid interfaces, then the positions of the free liquid surfaces in the vessels relative to it will be h_1 and h_2.

According to the basic equation of hydrostatics, the pressure at any point of the liquid at the level of the plane of comparison in the first vessel will be $p=p_1+\gamma_1 h_1$, and in the second – $p=p_2+\gamma_2 h_2$. Since the system (liquid) is in equilibrium, these pressures will be the same, i.e

$$p_1 + \gamma_1 h_1 = p_2 + \gamma_2 h_2. \quad (14)$$

In the case of the proposed constructive solution of water-lifting equipment in the conditions of livestock farms, we are interested in the supply of liquid to a higher level. And for this, you need to consider the law of fluid movement in the gap from one transit container to another. For this purpose, the regularity of fluid movement is considered using the balance equation of the specific energy of the moving fluid in the pipe (D. Bernoulli's equation), so it is necessary to turn to the methods of physics and hydraulics. Solving the issue of moving flow in pipes, between transit containers, we determine, using known hydraulic dependencies, the amount of water consumed by the consumer and the speed of movement of the liquid flow. According to the theorem of mechanics, here we consider the equation about the change in the kinetic energy of a moving body, in which its difference is equal to the sum of the work of all forces acting on the moving body during this movement. At the same time, the equation for an ideal liquid is written as follows:

$$z + \frac{p}{\rho g} + \frac{U^2}{2g} = const, \quad (15)$$

where z is the specific energy of the liquid position; $\frac{p}{\rho g} = \frac{p}{\gamma}$ – specific pressure energy; $\frac{U^2}{2g}$ is the specific kinetic energy of a moving liquid.

So, let's apply the above equations to the proposed constructive solution of water lifting equipment in the conditions of livestock farms. To do this, let's consider a simple mathematical model in the form of a system consisting of the first and second transit containers, with a lower cross-section of 1-1 and a higher cross-section of 2-2.

For sections 1-1 and 2-2, apply the Bernoulli equation and get:

$$H_1 + \frac{P_1}{\gamma} + \frac{U_1^2}{2g} = H_2 + \frac{P_2}{\gamma} + \frac{U_2^2}{2g} + h_w, \quad (16)$$

where H_1=0 – pressure in section 1-1; H_2=H_1– pressure in section 2-2; since the distance between the transit containers is small, it can be neglected: H_1–H_2=0;$\frac{P_1}{\gamma} - \frac{P_2}{\gamma} = 0$. Since P_1=P_2=P_{atm}; $\frac{U_1^2}{2g} = 0$ is the specific kinetic energy in the section 1-1, since; U_1=0; $\frac{U_2^2}{2g} = \frac{U^2}{2g} = H_{distr}$ – pressure; h_w=h_l+$h_м$ – total head loss; h_l – head losses along the length; $h_м$ – local head losses. Then the liquid pressure in the pipeline between the transit containers will be found according to the formula:

$$H_{distr} = \frac{U^2}{2g} + h_w, \quad (17)$$

where, according to Bord's formula $h_w = \xi_w \cdot \frac{U^2}{2g}$ – pressure loss; ξ_w – drag coefficient of the system,

$$\xi_w = \xi_{in} + \xi_{out} + \lambda \frac{l}{d}, \quad (18)$$

here ξ_{in} is the input resistance coefficient; ξ_{out} – output resistance coefficient; $\lambda \frac{l}{d}$ – head loss along the length of the pipeline, where λ – coefficient of hydraulic friction of the pipe; l – pipe length; d – pipe diameter. U is the average speed of fluid movement in the cross-section according to the local resistance.

Thus, for a sudden expansion of the pipeline, when a pipeline with a smaller diameter passes into a pipeline with a larger diameter, the head loss during a sudden expansion of the pipeline is determined by Bord's formula:

$$h_{se} = \frac{(U_1 - U_2)^2}{2g}, \quad (19)$$

where U_1 and U_2 are the average speeds of fluid movement in sections 1-1 and 2-2, respectively.

Let's find the coefficient of local resistance due to average speeds U_1 or U_2.

Taking into account the equation of flow continuity $U_1\omega_1=U_2\omega_2$, the head losses depending on the velocities are equal to:

$$h_{se1} = \left(1 - \frac{\omega_1}{\omega_2}\right)^2 \cdot \frac{U_1^2}{2g}; \quad h_{se2} = \left(\frac{\omega_2}{\omega_1} - 1\right)^2 \cdot \frac{U_2^2}{2g}. \quad (20)$$

Whence the coefficients of local resistance are equal to:

$$\xi_{se1} = \left(1 - \frac{\omega_1}{\omega_2}\right)^2; \ \xi_{se2} = \left(\frac{\omega_2}{\omega_1} - 1\right)^2. \quad (21)$$

So for a sudden narrowing of the pipeline, while the pipeline with a larger diameter passes into a pipeline with a smaller diameter.

The coefficient of local resistance at $d_2 \lhd 0.5d_1$ is found by the formula:

$$\xi_{sn} = 0.5\left(1 - \frac{d_2^2}{d_1^2}\right). \quad (22)$$

The case of entering the pipe from the tank is similar to a sudden narrowing, and therefore formula (22) can be applied here $d_2 << d_1$ and at $d_2 \approx 0$, $\xi_{BX}=0.5$.

Then the Bernoulli equation will take the form:

$$H_{distr} = \frac{U^2}{2g} \cdot (1 + \xi_w). \quad (23)$$

Solving this equation with respect to speed, we get:

$$U = \frac{1}{\sqrt{1+\xi_w}} \cdot \sqrt{2g \cdot H_{distr}}, \quad (24)$$

where $\frac{1}{\sqrt{1+\xi_w}} = \phi$ – is the speed coefficient (for pipes $\phi=\mu=0.61$).

Therefore, the equation for the speed will take the form:

$$U = \phi \cdot \sqrt{2g \cdot H_{distr}}. \quad (25)$$

Then from the continuity equation

$$U_1 \cdot \omega_1 = U_2 \cdot \omega_2 = Q = const; \quad (26)$$

We find the difference –

$$Q = U \cdot \omega. \quad (27)$$

Substituting Q into the value U we have:

$$Q = 0.61 \cdot \omega \cdot \sqrt{2g \cdot H_{distr}}, \quad (28)$$

where ω – is the cross-sectional area of the pipe.

The obtained equations are also used for all subsequent transit capacities of the gravity water lift system. As a result of the theoretical analysis of the process of raising water with the help of the proposed constructive solution of water lifting equipment in the conditions of livestock farms, it was substantiated that the process of raising water is based on the use of three laws in one process: the basic law of hydrostatics, the Boyle-Marriott law of gas dynamics and the law of connected vessels with liquid It was also established that the main optimization criteria used to assess the quality of the technological process were: the volume of water consumption and the speed of the liquid flow.

The principle of operation of the proposed constructive solution of water-lifting equipment in the conditions of livestock farms

The principle of operation of water-lifting equipment in the conditions of animal farms is based on increasing the necessary pressure for the water supply network due to the use of a column of liquid from the pressure, created naturally or artificially, using the forces of gravity. Artificial pressure can be obtained as a result of the use of a water supply network, which needs to meet the needs of consumers, while natural pressure is obtained due to the use of water column differences in reservoirs.

To explain the principle of operation of water-lifting equipment in the conditions of livestock farms, a drawing is attached (Fig. 1).

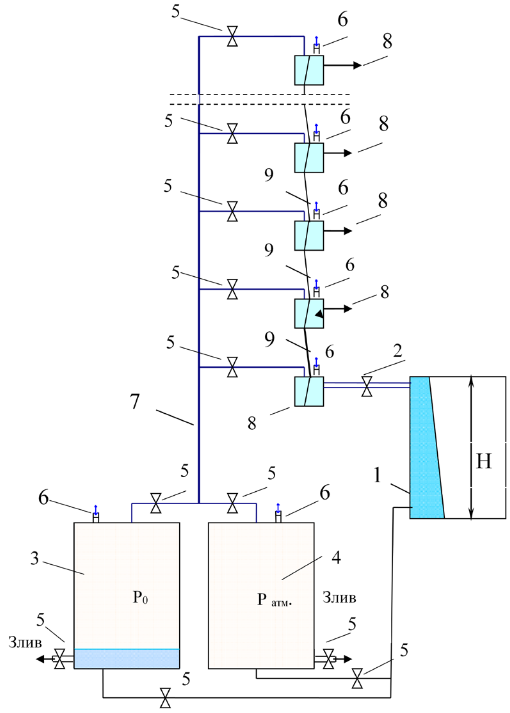

Figure 1. *Scheme of water-lifting equipment in the conditions of livestock farms*

Note: *1-pressure tank, 2-tap for filling the transit container with water, 3-base container right, 4-base container left, 5-ball or screw valve, 6-valve for pressurization or depressurization, 7-pipeline of compressed atmospheric air, 8-transit tanks, 9-pressure lines*

Source: *submitted by the author*

The process of operation of water-lifting equipment in the conditions of livestock farms in technological processes of agricultural production is carried out as follows. Through the tap to fill the transit tank 2 with water, the transit tank 8 is filled with water from the pressure tank 1 and sealed with the sealing or depressurizing valve 6. At the same time, the right base tank 3 is sealed and filled with water through the ball or screw valve 5, creating in it, the pressure of compressed air P_0=P_{atm}+γh, where γ is the specific volumetric weight of water, and h is the height of the water column of the pressure H. Then, through the ball or screw valve 5, the compressed air from the right basic container 3 enters the pipeline of the compression atmospheric air 7, and then through the valve for sealing or depressurization 6 into the transit tank 8, from which water is pushed out by compressed air through the pressure line 9, into the transit tank 8 and fills it, and then the cycle of pushing water out of the transit tank 8 is repeated, i.e. after filling it with water, it is also sealed only with the help of a valve for sealing or depressurization 6. In n the process of filling and expelling water in the step-down transit tanks takes place according to the principle described above. At the same time, each passing capacity of the device for raising water, starting with the second one, ensures the amount of water pressure H=γh at a specific level of its elevation.

In order to ensure the stability and continuity of the supply of compressed air to the pipeline of compressed atmospheric air 7 of the device for raising water, the sequential and synchronous inclusion of two containers is provided: the right basic container 3 and the left basic container 4.

Thus, the process of increasing the pressure in water risers of this type can be implemented not only for the purpose of water supply, but also to use it for the purpose of obtaining ecologically clean and cheap energy due to the creation of high-pressure hydroelectric power plants of a wide range of capacities. Equipment for raising water of this type does not require the presence of a person due to the full automation of the process of increasing the gravitational pressure. The proposed equipment for lifting water can be widely used in the conditions of livestock farms, i.e. this branch of agriculture needs autonomy in the context of energy and water supply.

Mathematical model of the technological process of using the proposed constructive solution of water-lifting equipment in the conditions of livestock farms

The quality of the technological process of using the proposed constructive solution of water-lifting equipment in the conditions of livestock farms is evaluated by the amount of water consumption (*WC*) and the speed of the flow (*CRP*). These parameters (optimization criteria) depend on four main independent factors: the height of the liquid column – H, m (X_1); volume of transit tanks – V, m³ (X_2); pipe diameter – d, m (X_3); pipe length – l, m (X_4). The independent factors listed above were chosen as the main ones in this technological process by conducting preliminary experiments and ranking them according to the degree of influence on the quality of work. The levels of setting independent variables (factors) and the range of their variation adopted during the experiments are shown in Table 1.

Table 1. *Levels and range of factor variation*

Factors	Variation levels			Variation interval	Dimensionality
	–1	0	+1		
X_1 (H)	3	6	9	3	m
X_2 (V)	2	4	6	2	m^3
X_3 (d)	0.02	0.04	0.06	0.02	m
X_4 (l)	3	6	9	3	m

Source: *calculated by the author based on the obtained experimental data*

The frequency of experiments for each of the optimization criteria was three times. For each line of the plan, the average value of *VCW, CRP* is calculated.

Mathematical models adequately describe the technological process of raising water in the conditions of livestock farms. Presented regression equations:

- by volume of consumption:

$$OSV = 12.5 + 0.58 \cdot X_1 + 5.4 \cdot X_2 + 2.1 \cdot X_3 - 2.6 \cdot X_4 + 0.63X_1 \cdot X_2 - 0.6X_1 \cdot X_3 - 1.3X_1 \cdot X_4 - 2.8X_2 \cdot X_3 - 1.06X_2 \cdot X_4 + 1.5 \cdot X_3 \cdot X_4 + 2.1 \cdot X_1^2 - 5.4 \cdot X_2^2 - 1X_3^2 + 1{,}8X_4^2; \quad (29)$$

- by speed of movement:

$$CRP = 0.83 - 0.025 \cdot X_1 - 0.017 \cdot X_2 + 0.020 \cdot X_3 - 0.011 \cdot X_4 - 0.012 \cdot X_1 \cdot X_2 + 0.0056X_1 \cdot X_3 - 0.042X_1 \cdot X_4 + 0.048X_2 \cdot X_3 - 0.013X_2 \cdot X_4 + 0.0097 \cdot X_3 \cdot X_4 + 0.12 \cdot X_1^2 - 0.09 \cdot X_2^2 - -0.012 \cdot X_3^2 + 0.014 \cdot X_4^2. \quad (30)$$

Analysis of regression equations obtained after statistical processing is usually performed with coded values of factors [22]. The study of optimization criteria depending on the change of independent factors will be carried out by the method of two-dimensional intersections.

When replacing X_3=0 and X_4=0 the regression equations will have the form:

$$VCW = 12.5 + 0.58 \cdot X_1 + 5.4 \cdot X_2 + 0.63 \cdot X_1 \cdot X_2 + 2.1 \cdot X_1^2 - 5.4 \cdot X_2^2, \quad (31)$$

$$CRP = 0.83 - 0.025 \cdot X_1 - 0.017 \cdot X_2 - 0.012 \cdot X_1 \cdot X_2 + 0.12 \cdot X_1^2 - 0.09 \cdot X_2^2. \quad (32)$$

After calculations, the regression equation in the canonical form will take the form: for the volume of water consumption: $VCW-17.218=2.183 \cdot X_1^2-5.493 \cdot X_2^2$; for the flow speed: $CRP-0.8=0.119 \cdot X_1^2-0.093 \cdot X_2^2$.

The two-dimensional section of response surfaces is shown in Figure 2. Consistently fixing the other two factors at the level of 0 and performing calculations similar to the above, we obtain the regression equation in the usual form with a new combination of factors.

When substituting X_1=0 and X_2=0 the regression equation: for the volume of water consumption:

$$VCW = 12.5 + 2.1 \cdot X_3 - 2.6 \cdot X_4 + 1.5X_3 \cdot X_4 - 1X_3^2 + 1.8 \cdot X_4^2. \quad (33)$$

For the flow speed:

$$CRP = 0.83 + 0.020 \cdot X_3 - 0.011 \cdot X_4 - 0.0097 \cdot X_3 \cdot X_4 - 0.012 \cdot X_3^2 + 0.014X_4^2. \quad (34)$$

For the volume of water consumption: X_3=-1.23; X_4=0.27; for the flow speed: X_3= -1.153; X_4=0.795;

The regression equations in canonical form will have the form: for the volume of water consumption: $VCW-11.10=2.0032X_3^2-1.153 \cdot X_4^2$; for the flow speed: $CRP-0.83=0.0179X_3^2+0.0805X_4^2$.

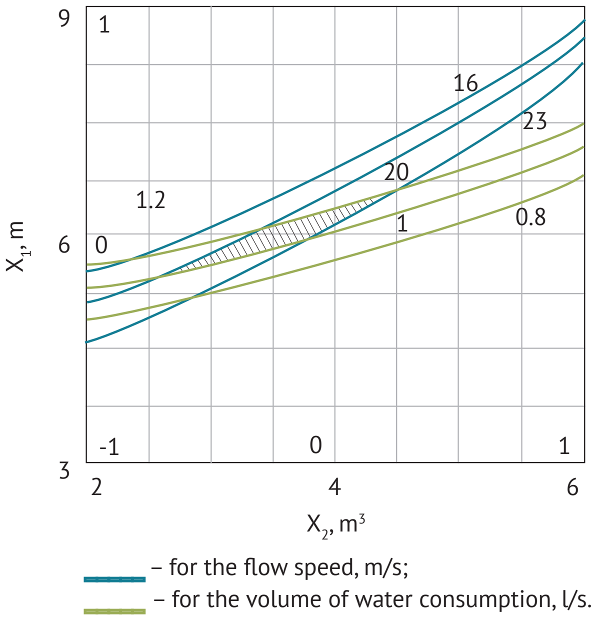

Figure 2. *Two-dimensional cross section of the response surfaces at X_3=0 and X_4=0.*
Source: *calculated and formed by the author using the data in Table 1*

After analyzing two-dimensional cross-sectional surfaces (Fig. 2), the following conclusions can be drawn. With an existing pressure value of 5.5-6.5 m and a volume of transit tanks of 3-4.5 m³ the volume of water consumption will be within 20-23 l/s, and the speed of the flow will be 1-1.2 m/s (shaded area, Fig. 2).

When substituting X_2=0 and X_4=0, the regression equations have the form: for the volume of water consumption:

$$VCW = 12.5 + 0.58X_1 + 2.1X_3 - 0.6X_1 \cdot X_3 + 2.1X_1^2 - 1X_3^2. \quad (35)$$

For the flow speed:

$$CRP = 0.83 - 0.025X_1 + 0.020X_3 + 0.0056X_1 \cdot X_3 + 0.12X_1^2 - 0.012X_3^2 \quad (36)$$

In accordance: for the volume of water consumption: X_1=-0.427; X_3=-0.96; for flow speed: X_1=0.084; X_3=0.852; Regression equation in canonical form: for the volume of water consumption: VCW-12.5=2.2X_1^2–1.035X_3^2; for the flow speed: CRP-0.94=0.12X_1^2-0.0121X_3^2.

The two-dimensional section of response surfaces is shown in Figure 3.

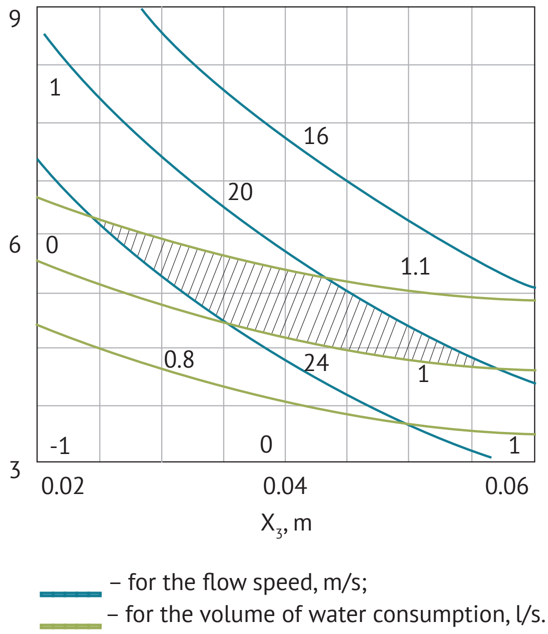

Figure 3. *Two-dimensional cross section of the response surfaces at X_2=0 and X_4=0*
Source: *calculated and formed by the author using the data in Table 1*

The diameter of the pipeline is 0.04 m, the length of the pipeline is 6 m. Moreover, with increasing pressure, the flow rate increases, and the speed also increases. And if the volume of transit tanks increases, the speed of the flow begins to increase, but the volume of water consumption decreases. With an existing pressure of 4.5-6 m and a pipeline diameter of 0.025-0.055 m, the volume of water consumption will be within 20-24 l/s, the flow speed will be 1.1 m/s. The volume of transit tanks will be 4 m^3, the length of the pipeline will be 6 m (shaded area, Fig. 3).

When substituting X_1=0 and X_3=0 the regression equations have the form: for the volume of water consumption:

$$VCW = 12.5 + 5.4X_2 - 2.6X_4 - 1.06X_2 \cdot X_4 - 5.4X_2^2 + 1.8X_4^2. \quad (37)$$

For the flow speed:

$$CRP = 0.83 - 0.017X_2 - 0.011X_4 - 0.013X_2 \cdot X_4 - 0.09X_2^2 + 0.014X_4^2. \quad (38)$$

In accordance: For the volume of water consumption: X_2=0.41; X_4=0.841; for the flow speed: X_2=-0.121; X_4=0.336; Regression equation in canonical form: for the volume of water consumption: VCW–10.67=1.894X_2^2–5.51X_4^2**;** for the flow speed: CRP–0.709=0.0144X_2^2–0.0904X_4^2.

X_2=0 and X_3=0 the regression equations have the form: for the volume of water consumption:

$$VCW = 12.5 + 0.58X_1 - 2.6X_4 - 1.3X_1 \cdot X_4 + 2.1X_1^2 + 1.8X_4^2; \quad (39)$$

for the flow speed:

$$CRP = 0.83 - 0.025X_1 - 0.011X_4 - 0.042X_1 \cdot X_4 + 0.12X_1^2 + 0.014X_4^2. \quad (40)$$

In accordance: for the volume of water consumption: $X_1 = 0.098$; $X_4 = 0.757$; for the flow speed: $X_1=0.235$; $X_4=0.74$;

Regression equation in canonical form: for the volume of water consumption: $VCW-12.21=2.69X_1^2+1.32X_4^2$; for the flow speed: $CRP-0.87=0.12X_1^2+0.0099X_4^2$.

When substituting $X_1=0$ and $X_4=0$ the regression equations have the form: for the volume of water consumption:

$$VCW = 12.5 + 5.4X_2 + 2.1X_3 - 2.8X_2 \cdot X_3 - 5.4X_2^2 - 1X_3^2 \tag{41}$$

For the flow speed:

$$CRP = 0.83 - 0.017X_2 + 0.020X_3 + 0.048X_2 \cdot X_3 - 0.09X_2^2 - 0.012X_3^2 \tag{42}$$

In accordance: for the volume of water consumption: $X_2=1.225$; $X_3=-2.71$; for the flow speed: $X_2=0.273$; $X_3=1.38$;

Regression equation in canonical form: for the volume of water consumption: $VCW-12.86=-0{,}58X_2^2-5.89X_3^2$; for the flow speed: $CRP-0.78=-0.0052X_2^2-0.0968X_3^2$.

The two-dimensional section of response surfaces is shown in Figure 4.

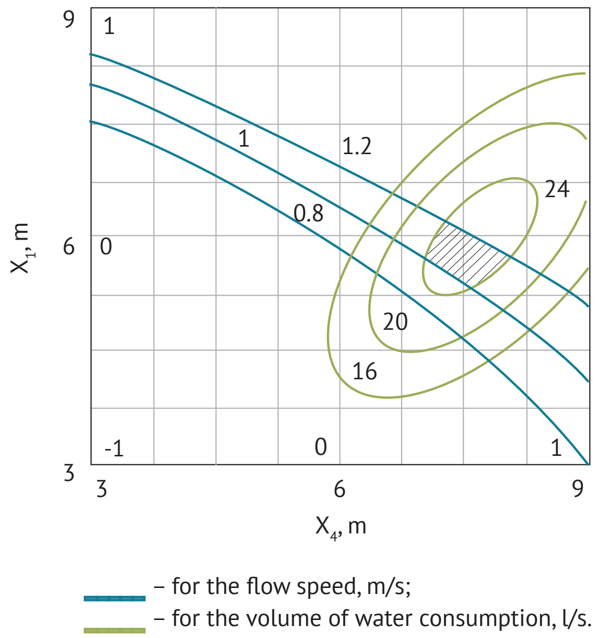

Figure 4. *Two-dimensional cross section of the response surfaces at $X_2=0$; $X_3=0$*

Source: *calculated and formed by the author using the data in Table 1*

With an existing pressure level of 6-6.5 m and a pipeline length of 7-8 m, the volume of water consumption will be 23-24 l/s with a flow speed of 1-1.2 m/s (shaded area, Fig. 4). At the same time, the diameter of the pipeline will be 0.04 m, and the volume of the transit tanks will be 4 m. But as the length of the pipeline increases, the volume of water flow and the speed of the flow decrease.

The optimal structural and technological parameters of water-lifting equipment can be considered: head height X_1=5... 6.5 m; volume of transit tanks X_2=4...4.5 m^3; pipeline diameter X_3=0.04...0.05 m; the length of the X_4 pipeline = 6...7 m. The optimization criteria are within the following limits: the volume of water consumption of the *VCW*=23-24 l/s; the speed of the flow of the *CRP*=1.1-1.2 m/s.

In the context of the discussion of the topic under investigation, it should be noted that water supply is one of the most important tasks in the field of animal husbandry. During the analysis of the current state of agricultural enterprises of the livestock profile in Ukraine, it was determined that one of the main development trends is the introduction of modernized equipment and modern technologies that save resources and, accordingly, production costs [24]. The mechanization of animal husbandry and the use of separate technological lines or equipment is characterized by rather high complexity [25].

In the conditions of livestock farms, most technological operations require the use of water: watering of livestock, feed preparation, processing and further processing of milk, washing operations, etc. Surface sources can be used for water intake, namely: rivers, lakes, canals, other types of water bodies and groundwater. Water intake structures of the shore or channel type are used to take water from surface sources. If it is necessary to draw water from underground sources, mine or tube wells are used. In the case of water intake of the shore type, the following equipment is usually used: a water receiver, gravity pipes, a valve, a shore well, and a pumping station can be used. Mine wells are usually used for the purpose of taking water lying at a depth of 30-40 m. They include: a pipe for ventilation, a clay lock, a head, a mine, a part for receiving water, a filter or a sump [19]. A complex of elements for treatment, collection, delivery and distribution of water is combined into a water supply system, which can be gravity-fed or pressurized. Water supply systems of livestock enterprises in cases of pump shutdown in order to create the required pressure in the network use tower-type water-pressure structures designed by A.A. Rozhnovsky. Centrifugal or vane-type pumps are also used to raise and move water, but all of them require electricity consumption [26], which is minimized in the case of using the proposed constructive solution of water-lifting equipment in the conditions of livestock farms.

The application of modern approaches to the technological systems of water supply of livestock enterprises makes it necessary to introduce energy-efficient technical means for extracting, transporting, and delivering water to consumption points on farms and complexes. The use of pumping devices for water supply is effective, but at the same time energy-consuming, material-consuming and requires significant funds. Presented studies of the use of devices of this type and their modernization with the application of these measures can have a positive effect on the technical and economic indicators of water and heat supply equipment for buildings of the agro-industrial complex [27], but the use of a natural power source (rivers, lakes), as in the case of the proposed constructive solution was not considered. There are also known works related to water supply systems, the problems that exist in these systems, and the optimization of the operating modes of centralized water supply systems, which do not take into account the specifics of livestock farms with significant water consumption [28]. Solving the problem of water supply requires scientific and practical approaches in environmental, engineering, economic and other spheres [29]. Attention is paid to the use of domestic wastewater for the needs of technical water supply in order to reduce the intake of fresh water from natural reservoirs, which is a promising direction in reducing resources for water supply of livestock farms [30], as well as the use of energy-efficient equipment for raising water. Considering the fact that the known technical solutions for raising water in the conditions of livestock farms require significant energy consumption, they are also not always technological when increasing the pressure and maintaining it at the required level. Thus, there is a need to resolve the issue of improving the quality level of water supply for livestock enterprises, which can be implemented using the proposed constructive solution of water lifting equipment in the conditions of livestock farms. The process of increasing the pressure in water risers of this type can be implemented not only for the purpose of water supply, but also to use it to obtain sources of cheap, environmentally friendly energy. Such installations can be widely used in agriculture, namely in the conditions of livestock farms, which, like no other industry, needs autonomous water and energy supply. The implementation of installations of this type requires full automation of the process of increasing the gravitational pressure, which excludes the presence of a person.

However, modern achievements of science and technology, without a doubt, allow creating control systems equipped at a high technical level, including for the proposed constructive solution of water-lifting equipment in the conditions of livestock farms. And this, in turn, makes it possible to repeatedly use the same pressure drop in the same place of the flow of any water source. That is, in modern equipment for lifting the movement of water, the difference (pressure) performs the work only once, and in the proposed constructive solution this pressure can be used repeatedly, thereby increasing its value by the same number of times. Prospects for further investigations may be an increase in the volume of water consumption and research on the use of the proposed constructive solution in other enterprises of the agro-industrial complex.

CONCLUSIONS

A review of literary sources regarding the use of water lifting equipment made it possible to conclude that known structural and technical solutions in the field of water supply require significant costs in the process of operation and have a rather low coefficient of effectiveness. Also, they do not always solve the issue of maintaining the required level and further increasing the pressure in the water supply network. Therefore, the issue of reducing energy consumption during the operation of the water supply system and improving the quality of water supply to consumers due to maintaining the necessary pressure in the water supply network by designing water lifting equipment in the conditions of livestock farms. The theoretical substantiation of the application of the proposed constructive solution of water-lifting equipment in the conditions of livestock farms has been carried out.

It was established that the main optimization criteria for assessing the quality of the technological process were: the amount of water consumption of the *WSW*=23-24 l/s and the speed of the flow of the *SRP*=1.1-1.2 m/s. On the basis of theoretical and experimental studies, it was established that these optimization criteria depend on four main independent factors: head height – H, m; volume of transit tanks – V, m; pipe diameter – d, m; the length of the pipe is l, m. The most advantageous structural and technological parameters of the water-lifting equipment are also established, namely: head height X_1=5-6.5 m; volume of transit tanks X_2=4-4.5 m; pipeline diameter X_3=0.04-0.05 m; pipeline length X_4=6-7 m.

On the basis of experimental studies of the process of raising water in laboratory conditions, a methodology for calculating and optimizing the structural and technological parameters of water-lifting equipment has been developed, which can be used during research and design work on the creation of a water-lifting equipment installation in the conditions of livestock farms in order to increase the pressure. The developed technology is expected to be implemented for water supply of agricultural facilities, including livestock farms.

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Визначення параметрів використання водопідйомного обладнання в умовах тваринницьких ферм

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Анотація. Основним завданням систем водопостачання є розширення технологічних можливостей процесу водопостачання, підвищення його надійності, зниження його капітальних і експлуатаційних витрат, спрощення проектування. Метою статті є визначення оптимальних параметрів використання запропонованого конструктивного рішення водопідйомного обладнання в умовах тваринницьких ферм. Дослідження проводилися в лабораторних умовах з подальшим використанням методів математичної статистики. До критеріїв оптимізації використання запропонованої конструкції водопідйомного обладнання в умовах тваринницьких ферм відносяться кількість витрати води та швидкість руху потоку. У статті встановлено найбільш оптимальні конструктивно-технологічні параметри водопідйомного обладнання, а саме: висота напору; об'єм транзитних резервуарів; діаметр трубопроводу; довжина трубопроводу. Принцип дії запропонованого конструктивного рішення водопідйомного обладнання для використання в умовах тваринницьких ферм заснований на підвищенні необхідного тиску для водопровідної мережі шляхом прямого багаторазового використання сил гравітації у вигляді ваги стовпа рідини від природного або штучного тиску. Визначено співвідношення критеріїв оптимізації процесу використання водопідйомного обладнання в умовах тваринницьких ферм та оптимальних конструктивно-технологічних параметрів запропонованого рішення. Використання технології із дотриманням рекомендованих конструктивно-технологічних параметрів вирішить проблему підвищення якості водопостачання споживачів в умовах тваринницьких ферм, зниження енерговитрат при роботі системи водопостачання та підтримання необхідного тиску у водопровідній мережі

Ключові слова: механізація господарств, ферми, оцінка якості технологічного процесу, тваринництво, конструктивно-технологічні параметри