Results of using the hydro-impact method of water lifting from watercourses

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Abstract. The developed new types of hydraulic RAM pumping units with a drive from an energy-saving and environmentally friendly water source of energy in watercourses, their design and technological schemes for water lifting from watercourses for irrigation of pastures and land plots, a brief device, operating principle, novelty, distinctive features and advantages in comparison with analogues are considered. The following research methods were used: patent method with a review of works, theoretical and experimental. The theoretical prerequisites of the hydro-impact method of water lifting to determine the dependencies: supply, pressure and efficiency ratio of the total water flow and experimental studies to confirm the reliability of the proposed formulas are given. Positive results of laboratory tests and economic verification of two developed variants of hydraulic RAM pumping units are given. Research results have shown that the proposed hydro-RAM pumping units have significant advantages over their analogues: increase in feed by 1.8-3.5 times and efficiency by 1.9 times.

1. Introduction
Currently in Kazakhstan and foreign countries, in connection with the shortage of traditional energy source (fuel) in the fuel and energy system and for its savings, also to reduce the rate of environmental degradation, they come to the use of renewable energy sources (wind, water and solar), including to the system of agricultural supply, primarily the use of water power in watercourses [1-10].

However, due to the lack of alternative pumping units on the market for water lifting from watercourses, agricultural and other consumers located in the areas of watercourses are forced to use traditional centrifugal pumping units powered by internal combustion engines, which require high operating costs, including expensive fuel.

The problem of effective water supply with the use of natural energy resources of water in modern conditions is promising and relevant, the solution of which is rational to implement from watercourses pumping installations by using, under certain conditions, a hydro-impact method of water lifting, the design of which is technically simple and reliable in operation and does not worsen the environment.

A hydro-RAM pumping unit is a type of installation that uses the kinetic energy of moving water to create a pressure and feed. The working principle is based on the creation of pumping system from water impact periodic opening and closing of the impact valve in the supply pipe from which it is cyclically pressurized and the water through the discharge valve is forced into the capacity of the air cap and water pipeline is supplied to the consumer [11-17].
2. Methods

The following research methods were used: patent with a review of works, theoretical and experimental.

Patent research with a review of works was performed using existing methods: identifying close analogues, analyzing existing works and using them in development.

Theoretical studies were carried out by using the law of continuity of flow raised the water in the nutrient and water-lifting pipes, the hydraulic law of process in feed pipes and in the use of Bernoulli’s equation in the technological process of water lifting, as the result theoretical prerequisites of the process of hydraulic method, water lifting from streams were provided [1, 18-20].

Experimental studies were carried out by studying the technological process of the hydro-impact method of water lifting and to verify the reliability of the theoretical assumptions obtained with a discrepancy of 5%.

3. Results and Discussions

Using Work on the development of pumping units driven by hydro power of the streams has been on applied research performed in the KazNAU (2012-2020 g), which was developed two constructive and technical scheme hydro-ram pumping unit: one (option 1) the pre-patent for invention KZ No. 17789 [21] and patent KZ No. 29911 [22] (Figure 1), the other (option 2) the patent for invention of KZ No. 34027 "hydraulic RAM pumping system" [23] (Figure 4), the patentee of which is the KazNAU.

Hydraulic RAM pumping system (option 1) (see Figure 1) consists of a body 1 with impact 2 and 3 discharge valves, air cap 4 of the water supply pipe 5 and feed pipe 6, the receiving portion 7, which communicates with the watercourse, the output part 8 with the tube 9 of the body 1, and at the outlet 10 and mid 11 tubes of the body impact valve 2 and discharge valves 3 are mounted. The tube 11 of the discharge valve 3 is connected to the air cap 4 [1, 21, 22].

![Figure 1. Structural and technical diagram of a hydraulic RAM pumping unit of the KazNAU design (option 1): 1 - impact valve body; 2,3 - impact and discharge valves; 4 - air cap; 5 - water supply pipeline; 6 - feed pipeline; 7 - receiving part; 8 - outlet part of the feed pipeline; 9, 10, 11 - inlet and outlet tubes, middle tubes; 12 - telescopic connection; 13 - shield frame; 14-impact valve body; 15 - impact valve guide; 16 - impact valve seat; 17 - counterweight; 18 - hemispherical disk; 19,20,21 - rod, bracket and counterweight load; 22 - expansion diffusor – confusor tube; 23-body knee; 24 – knob; H, Ng – height of the water lift, geometric pressure](image-url)

The receiving part 7 is made of a pipeline 12 which is adjustable in height and width by means of a telescopic connection and has a frame-shield 13 to increase the support, and the main part consists of sections of pressure pipes. The impact valve 2 includes a cylindrical body 14, inside which there is a
Poppet-type valve with a guide 15 coaxially installed in the opening of the seat 16 and re-moved by the force of a ball-shaped counterweight 17 on the cylindrical body 14, consisting of a hemispherical disk 18, a rod 19, a bracket 20 and a load 21.

The body 1 with input 9 and output 10 pipes is made in the form of an expansion diffusor-confusor tube 22 with a knee 23 connected to the passage section of the check valve 3 of the air cap 4.

The technological process of a hydraulic RAM pumping unit (option 1) (see figure 1) is carried out by starting the impact valve 2 by lifting and lowering the counterweight 17, while the optimal mode (frequency of the impact valve), depending on the initial parameters of the watercourse (geometric pressure and velocity head), is regulated by setting the counterweight 17, moving the rod 19, disk 18 and load 21.

To stop the hydraulic RAM pumping unit, the knob 24 of the water supply pipeline 7 is closed and the movement of the impact valve 2 is disabled by raising the counterweight 17 to a vertical position. In order to restart the pump unit again: the counterweight 17 of the impact valve is lowered, the knob 24 opens and the process of operation of the pump unit is repeated. In General, the developed design and technical scheme of a hydro-RAM pumping unit for lifting water from watercourses has novelty and advantages in comparison with its analogues [1, 21, 22].

The receiving part of the hydraulic RAM pumping unit is made in the form of a Z-shaped feed pipe with a telescopic connection and adjustable in height and width by means of grooved holes in the flange mounts, and is equipped with a shield frame to create additional water backup at the inlet tube of the receiving part and keep the pumping unit in the watercourse. The inlet feed pipe is communicated with the watercourse, and the output is with the input tube of the impact valve body, the central part of the body of the impact valve is connected through the discharge valve with an air cap and at the outlet tube comes with impact valve, creating hydraulic impact when it closes, with the possibility of the return movement under the force of the ball-shaped counterweight and regulation in the axial direction on the optimal mode (frequency shift) [21, 22].

At the basis of prepared laboratory and experimental prototypes of the hydraulic RAM pumping unit (Figure 2) laboratory and commercial tests were conducted (Figure 3) with positive results, the main parameters include: the supply of pumping units -3...5 m3/h, pressure -10...17m, the water flow of the watercourse to the drive -0,01...0. 04m3/c, the input water pressure to the receiving side of the pumping units– 0,5...3,0 m, the efficiency ratio of the pumping units - 0.5 to 0.55, which was the basis for further implementation of the development in the system of agricultural water supply Agricultural RK.

Figure 2. General view of the Gpu - 5-15 hydraulic RAM pumping unit of the KazNAU design (option 1)
Figure 3. Fragment of testing of the GNU - 5-15 hydraulic RAM pumping unit of the KazNAU design (option 1)

A hydro-RAM pumping unit (option 2) (see Figure 4) consists of a supply pipeline 1 with impact 2, discharge 3 and return 4 elastic valves, an air cap 5 with a water supply pipeline 6 and a feed jumper 7 on the receiving part 8 with a lattice mesh 9 of the supply pipeline, creating a hydraulic drop [11, 23].

Figure 4. Constructive-technological scheme of the hydraulic RAM pumping unit designed by KazNAU (option 2): 1 – supply pipeline; 2,3,4 - impact, elastic valves and discharge check valve; 5 - air cap; 6 – water supply pipeline; 7 - feed jumper; 8 - receiving part of the supply pipeline; 9 - the lattice mesh; 10 – supply pipeline chamber; 11 - supporting seat of discharge valve; 12 - device for launch and stopping of hydraulic process (gate valve); 13 – non-return valveseat; 14 – body of the non-return valve; 15 - impact valve seat; 16 – body of the impact valve; 17 - through hole of the impact valve seat; 18 - knob; 19-pressure gauge; 20,22-thrust screw; 21,23-bushing; Ng, H-which creates a hydraulic drop and the height of the water lift.

In this case impact valve 2 is positioned in the body 16 connected to the chamber10 at the outlet of the supply pipeline, the discharge valve 3 is located on top of the chamber on a flat support seat 11 inside
and connected to the centric air cap 5 which is located hermetically with the water supply pipeline 6 and non-return valve 4 on the supply pipeline. The supply pipeline 1 is provided with a device 12 to launch and stop the hydraulic process in a gate valve installed at the inlet chamber 10 of the supply pipeline 1. The non-return valve 4 of the supply pipeline is installed at the outlet of the valve 12 and is formed as a vertically suspended axial elastic flat valve 4 in contact with the valve seat 13, and hermetically connected to the supply pipeline 1 which is located inside the body 14 hermetically connected to the supply pipeline 1 and the chamber 10. In this case, the non-return valve 4 is provided with an adjustable limiter for its closing stroke, made in the form of two thrust screws 22 that touch the inner surface of the non-return valve and are moved by means of a threaded connection in the bushings 23, rigidly connected to the body flange 14, and fixing with lock nuts.

The impact valve 2 is made in the body 16, flanged and hermetically connected to the chamber 10 of the supply pipeline 1, in the form of an elastic flat valve 2 suspended at an angle in the horizontal surface, in contact with the seat 15 of the body 16. In this case, the stroke of the impact valve is made adjustable to the optimal mode of its operation by supplying the body 16 of the impact valve 2 with a thrust screw 20, which contacts the outer surface of the valve 2 and is moved by a threaded connection in the bushing 21 and a locking locknut.

The through hole 17 of the seat 15 is cylindrical or rectangular in shape with an area equal to the passage section of the chamber 10 of the impact valve 2, and is connected to the atmosphere. The receiving part 8 of the feed pipeline 1 is provided with a lattice mesh 9, and the water supply pipeline 6 of the air cap 5 is made inside the cap with its hermetic design and is equipped with a gate valve 18 and a pressure gauge 19 [23].

The technological process of a hydraulic RAM pumping unit (option 2) (see Figure 4) is carried out as follows.

Water of the watercourse fills the feed pipeline through the receiving part 8 with a lattice mesh 9 when the valve 12 is closed with the help of geometric pressure (from the height difference of the immersion), creating additional water backup in the Ng watercourse from the hydraulic drop of the feed jumper 7 and a high-speed head (from the speed of water movement) along the feed pipe 1, and when opening the gate 12 of the device for starting and stopping the hydro-impact process, water rushes at an increased speed into the chamber 10 of the feed pipeline and flows out at an increasing speed through the cylindrical or rectangular opening 17 of the seat 15 of the body 16, dragging the elastic impact valve 2 with it and creating a vacuum.

As a result, the impact valve 2 closes quickly, creating a hydraulic impact in the body 16 of the impact valve and in the chamber 10, the pressure in which becomes greater than in the air cap 5, the discharge valve 3 opens and water enters the air cap 5. Simultaneously the non-return valve 4 closes to the thrust screws 22 from the force of the hydraulic impact, increasing the duration of water injection into the air cap at high pressure.

When the water pressure drops in the chamber 10 of the supply pipeline 1 and the impact wave action in the opposite direction, a vacuum is created and the impact valve 2 opens from the force of its own weight and rarefaction, and the discharge valve 3 closes.

Water from the air cap 5 under the pressure of compressed air in its upper part will flow when opening the valve 18 through the water supply pipeline 6 to the consumer, which is controlled by a pressure gauge 20.

In the future, the technological process will be repeated automatically, while the hydraulic RAM pumping unit will operate at the optimal frequency of closing and opening the impact valve, which is set automatically depending on the initial parameters of the water flow (geometric and velocity heads) and regulating the stroke of the impact valve with a thrust screw 20.

To stop the hydraulic impact process, the valve 12 is closed, and to completely stop the hydraulic RAM pumping unit, the valve 18 of the water supply pipeline 6 is closed.
When the hydro-RAM pumping unit is restarted, the valve 12 opens again, thereby starting the hydro-impact process, and by opening the valve 18 of the water supply pipeline 6, water is supplied to the consumer at a height of $H$ and the process of operation of the hydro-RAM pumping unit is repeated [23].

Hydro-RAM pumping unit (option 2) of KazNAU designed in comparison with analogues, including the pumping unit (option 1) has a novelty and significant differences:

Feed pipe provided with a device for launch and stopping of hydraulic process, the non-return valve of the supply line is installed at the outlet of the device to start and stop the process of hydraulic impact, and the impact valve is made in the form of angle suspended in the horizontal surface of the flat elastic valve in contact with the body seat hermetically connected to the chamber supply pipeline and is made with adjustable speed of closing of the impact valve.

Non-return valve of the supply pipeline is made in the form of vertically suspended axial elastic flat valve in contact with the seat, tightly connected to the supply pipe and located within the body hermetically connected to the supply pipe and chamber and provided with an adjustable stroke limiter for its closing.

The device for starting and stopping the hydraulic impact process is made in the form of a gate valve installed at the inlet of the feed pipe chamber.

Stroke control of the impact valve is performed by supplying the impact valve body with a thrust screw that contacts the outer surface of the valve and is moved by means of a threaded connection in the sleeve, rigidly connected to the body, and a locking locknut.

Adjustable stroke limiter of the non-return valve of the supply pipeline comprises two resistant screws which are in contact with the inner surface of the non-return valve and moveable by threaded connection in the sleeve, rigidly connected with the flange of the body, and fixing lock nuts.

The through hole of the impact valve seat, which has a cylindrical or rectangular shape, is made over an area equal to the passage section of the impact valve chamber and is connected to the atmosphere.

The receiving part of the supply pipeline is equipped with a lattice mesh.

The water supply pipeline of the air cap is made inside the cap with its hermetic design and is equipped with a gate valve.

The main advantage of constructive-technological scheme of the hydraulic RAM pumping unit (option 2) in comparison with its analogues is to increase the reliability of the pump installation, easy maintenance and to improve the energy performance of the hydraulic RAM pumping installations: hydraulic pressure, flow, head and efficiency [23].

A fragment of the test of a hydraulic RAM pumping unit (option 2) is shown in Figure 5.

![Image](image.png)

**Figure 5.** Fragment of testing of a hydraulic RAM pumping unit of the KazNAU design (option 2)
Based on theoretical research, formulas are given for determining the main technological parameters of a hydro-RAM pumping unit: $Q_{pu}$ supply, $N_{pu}$ head, $\eta_{pu}$ spent power and $N_{pu}$ efficiency [1, 11].

The $Q_{pu}$ feed is determined by the formula:

$$Q_{pu} = Q \left( 1 - \frac{t_{wd}}{t_c} \right), \text{m}^3/\text{c}$$  \hspace{1cm} (1)

$q$ – total water consumption, m$^3$/c; $t_{wd}$, $t_c$ – the time of water discharge through the hydraulic impact valve per cycle and the cycle time of the hydraulic impact process:

$$t_{wd} = t_c - t_p, \text{c}$$  \hspace{1cm} (2)

$t_p$ – the time of pumping the raised water into the tank of the air dome.

The created pressure $H_{pu}$ is determined by the formula:

$$H_{pu} = H_p + \left( \frac{\sqrt{4Q}}{\pi D_{vsp}^2} - v_s^2 \right) \frac{2L_{pl}}{t_{ac}} \cdot t_c, \text{m}$$  \hspace{1cm} (3)

Where $H_p$–own pressure of the hydraulic ram pumping unit:

$$H_p = H_g + \frac{1}{2g} \cdot \left( u_{vsp}^2 - v_f^2 \right) - h_{lr}, \text{m}$$  \hspace{1cm} (4)

$H_g$ - geometric pressure, m; $g$ - acceleration of gravity m/c$^2$; $u_{vsp}, v_r$-water velocity in the supply pipeline and its receiving part, m/c; $h_{lr}$-head loss in the receiving part and in the supply pipeline, m; $t_{ac}$-the actual closing time of the impact valve (according to experimental data in open pipelines $t_{ac}=0,1 \ldots 0,3c$), c; $t_c$-the duration of the hydraulic impact cycle, c:

$$t_c = \frac{60}{n},$$  \hspace{1cm} (5)

where $n$ - impact valve switching frequency, min$^{-1}$; $L_{pl}$- pressure pipeline length, m.

The power expended $H_{pu}$ and the efficiency rate of a hydraulic ram pumping unit are determined by the formulas:

$$N_{pu} = 9,81 \cdot Q \cdot (H_g + \frac{v_f^2}{2g}) \cdot \text{kBr},$$  \hspace{1cm} (6)

$$\eta_{pu} = \frac{Q_{pu}}{Q \cdot (H_g + \frac{v_f^2}{2g})},$$  \hspace{1cm} (7)

The results of theoretical and experimental studies of the technological process of a hydraulic RAM pumping unit are presented with graphs of dependencies $Q_{pu}, N_{pu}, \eta_{pu} = f (Q)$ (Figures 6, 7 and 8). The validity of the theoretical formulas (1), (3) and (7) has been confirmed experimentally (the discrepancy does not exceed 3-5%).

The results of theoretical research have been tested on an experimental stand that simulates water flow.

The graph (see Figure 7) shows that the flow $Q_{pu}$ of a hydraulic RAM pumping unit under different flow modes increases with the increase in its total water flow $Q$ and changes in a curvilinear dependence from 0.5 - 0.62 dm$^3$/c to 4.14-5.19 dm$^3$/c at a water flow rate from 5 to 41.4dm$^3$/c.

From the graph (see Figure 7), it follows that the head of the NPU of a hydro-RAM pumping unit under different flow modes increases with an increase in its total water flow $Q$ and changes in a curvilinear dependence from 5-6.7 m to 31-32M with water flow rate from 5 to 41, 4dm$^3$/s.
Figure 6. Dependence of the supply $Q_{pu}$ of a hydraulic RAM pumping unit on the total flow of water from the watercourse $Q$ to its drive.

Figure 7. Dependence of the head of the $N_{pu}$ of a hydraulic RAM pumping unit on the total flow of water of the watercourse $Q$ on its drive.

Figure 8. Dependence of the efficiency of the $P_{nu}$ of a hydro-RAM pumping unit on the total flow of water of the watercourse $Q$ on its drive.
Figure 9. The results of laboratory tests of two variants of a hydraulic ram pumping unit according to the dependences of the pressure $H_{pu}$ and efficiency $\eta_{pu}$ on the flow $Q_{pu}$ at a watercourse head $H_h = 5.08$ m

The graph (see Figure 8) shows that the efficiency of the PNU of a hydro-RAM pumping unit under different flow modes increases with an increase in its total water flow $Q$ and changes in a curvilinear relationship from 0.132 - 0.146 to 0.778 - 0.871 with a water flow rate from 5 to 41.4 dm$^3$/s.

The graph (Figure 9) shows the results of comparative laboratory tests of two variants of a hydro-RAM pumping unit on the dependence of the head of the Npu and the efficiency of the Npu on the supply of the $Q_{pu}$ at the head of the $Npu = 5.08$ m.

From the graph (see Figure 9), it follows that the hydro-RAM pumping unit (variant 2) has a significant advantage compared to the hydro-RAM pumping unit (variant 1): the feed increases at a head of $Npu=25$m from 0.8 dm$^3$/c to 2.8 dm$^3$/c (3.5 times), and at a head of $Npu=10$m from 2.9 dm$^3$/c to 5.2 dm$^3$/c (1.8 times); the maximum efficiency of the $Ppu$ increases from 0.41 to 0.78 (1.9 times).

On the basis of the research review papers and patent research in the technology of lifting water from streams and technical solutions for its implementation, developed two variants of constructive-technological schemes of the hydraulic RAM pumping units, which are protected by: option 1 a pre-patent KZ No. 17789 [21] and the invention patent KZ No. 29911 [22], a variant of the 2 invention patent KZ No. 34027 [23], which in comparison with analogues has the best energy performance on the main parameters: hydraulic pressure, flow, the head and efficiency were adopted for the development of experimental and pilot models for agricultural and pastoral water-supply objects of agribusiness.

4. Conclusions
1. Based on the results of patent research, review of work and own research in KazNAU, two designs and technological schemes of a hydraulic RAM pumping unit have been developed, one of which (option 2) in comparison with its analogues (and option 1) provides an increase in the reliability of its operation, creating convenience and ease of maintenance, increasing energy indicators: hydro-impact pressure, feed, head and efficiency.
2. In these constructive – flow charts two variants of the hydraulic ram pump installations were provided with the device description, process, distinguishing features and novelty in comparison with analogues, the construction of which is protected by patents KZ No. 17789 and two invention patents
KZ n KZ 29911 and No. 34027, one of them is the patent KZ No. 34027 which was adopted for the development of prototypes for pasture water supply on the objects of agribusiness.

3. Experimental researches have studied the technological process of the hydropercussion method of lifting water from watercourses and confirmed the reliability of the obtained basic formulas for determining the supply Qp, the required pressure Hpw and the efficiency ηnu of a hydraulic ram pumping unit with a watercourse head of 3.42 m and 5.08 m.

4. On the basis of comparative analysis, a hydro-RAM pumping unit (option 2) has a significant advantage in comparison with a hydro-RAM pumping unit (option 1): the flow increases at a head of Npu=25m from 0.8 dm³/c to 2.8 dm³/c (3.5 times), and at a head of Npu=10m from 2.9 dm³/c to 5.2 dm³/c (1.8 times); the maximum efficiency of the ηpu increases from 0.41 to 0.78 (1.9 times).

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