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TECHNICAL SOLUTION FOR APPLYING LIQUID FERTILIZERS WITH IRRIGATION WATER

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Abstract

Applying liquid fertilizers (mineral and/or livestock-derived) with a precise irrigation technology is an important agricultural practice aimed at utilizing the nutrients contained in fertilizers to enhance soil fertility and crop yields. However, this method requires adherence to certain regulations to prevent negative environmental impacts.

This article presents an effective method for applying fertilizers while simultaneously irrigating agricultural land. For this purpose, a special device is used to inject liquid fertilizers into a pressure irrigation pipeline. Transportation through the pipeline is accomplished automatically using the potential energy of the water, using an ejector and a pressure differential between the ejector's inlet and outlet. The device comprises a pressure pipeline, a liquid fertilizer tank, and a dosing pump. The pump has working chambers with a piston kinetically coupled to a hydraulic motor via a drain line, distributor, and connecting fittings. The end of the discharge pipeline is equipped with a nozzle designed as a vacuum chamber. The bottom of the chamber is connected to feed and discharge pipes. The chamber contains an ejector unit, feed pipes, and a nozzle facing the annular bell.

Use of this device will improve the efficiency of mixing liquid fertilizers, enhance operational reliability, and regulate the fertilizer flow rate. Experimental studies were conducted to determine the effects of pipeline pressure, suction energy, and water supply to the power cylinders, which are associated with installing the ejector unit on a main clean water pipeline.

Keywords: pipeline, fertilizer, irrigation water, fertilizer mixing device, characteristics, operation.

ТЕХНИЧЕСКОЕ РЕШЕНИЕ ДЛЯ ВНЕСЕНИЯ ЖИДКИХ УДОБРЕНИЙ С ПОЛИВНОЙ ВОДОЙ

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Реферат

Применение жидких удобрений (минеральных и (или) животноводческих) с выверенной технологией дождевания является важной практикой в сельском хозяйстве, направленной на использование питательных веществ, содержащихся в удобрениях для повышения плодородия почвы и урожайности сельскохозяйственных культур. Вместе с тем, данное мероприятие требует соблюдения определенных правил для предотвращения негативного воздействия на окружающую среду.

В статье представлен эффективный способ внесения удобрений с одновременным орошением сельскохозяйственных угодий. Для этой цели используется специальное устройство для внесения жидких удобрений в напорный трубопровод оросительной воды. Транспортировка по трубопроводу осуществляется с использованием потенциальной энергии воды в автоматическом режиме, в котором устроен эжектор и перепад напоров между входом и выходом эжектора. Устройство содержит напорный трубопровод, емкость для жидких удобрений, насос-дозатор. Насос имеет рабочие полости с поршнем, кинетически связанным с гидродвигателем, сообщенным через сливную линию, распределитель и соединительную арматуру. Конец напорного трубопровода снабжен насадкой, выполненной в виде камеры разрежения. Дно камеры подключено к питающим и сбросной трубкам. Камера содержит блок эжектора, питающие трубки и сопло в сторону кольцевого раструба.

Использование данного устройства позволит улучшить эффективность смешивания жидких удобрений, повысить надежность работы, а также регулировать расход подачи удобрений. Проведены экспериментальные исследования по определению влияния напора в трубопроводах, энергии всасывания и подачи воды в силовые цилиндры, что связано с установкой узла эжектора на магистральном трубопроводе чистой воды.

Ключевые слова: трубопровод, удобрения, оросительная вода, устройство по смешиванию удобрений, характеристика, функционирование (работа).

Introduction

Environmental requirements for irrigation systems prioritize reducing the negative impact of irrigation on the environment. One of the main directions of scientific and technological progress in land reclamation is the improvement of techniques and technologies for delivering liquid fertilizers to irrigated fields, as well as their efficient application to the soil [1–2].

Another crucial factor in increasing the efficiency of agricultural production on irrigated lands is creating a gross level of plant nutrient supply. Complete and timely supply of fertilizers to irrigated crops allows for maximizing their productive capacity, avoiding nutrient losses, ensuring economical water consumption, and accelerating the payback of funds invested in irrigation infrastructure.

Irrigated farming creates prerequisites for obtaining high and stable yields of agricultural crops. Realizing the existing potential is primarily associated with the rational interaction of irrigation and chemicalization. This is confirmed by experience gained in the process of cultivating crops.

Applying fertilizers in conjunction with timely irrigation is a powerful agronomic technique aimed at improving crop quality and optimizing irrigation costs. This process is associated with the improvement of the water and nutrient regimes of plants, the intensification of their growth and the metabolic activity of the root system, the enhancement of biological processes, and changes in the intensity of metabolism and the formation of generative organs.

Yield increase can also be achieved through phosphorus top dressing during the flowering and fruiting periods. Such top dressings can also be used to accelerate fruit ripening and improve product quality. Top dressing can satisfy the changing nutrient requirements of plants during different growth periods and yield better results.

The timing and methods of fertilizer application should ensure high labor productivity and contribute to reducing the financial and energy costs of these operations [3–14]. Furthermore, fertilizer application should be coordinated with other agrotechnical measures.

Currently, due to the improvement of irrigation techniques and technology, much attention has been paid to methods of applying liquid fertilizers with irrigation water during sprinkling.

Fertilizer application with irrigation water can be carried out both before crop sowing and with vegetative irrigations. The timing and doses of nutrient supply under regular irrigation should be established depending on the biological characteristics of the crops, soil conditions, and fit into the irrigation schedule.

Recently, ejectors have found the widest application in fertigation systems for low-intensity irrigation. Operation is based on the principle of a jet pump. When delivering liquid fertilizers to the place of use and distribution over the area of the site, main irrigation pipelines are used, where, due to the maximum kinetic flow rates formed in the central part of the pipeline, the injected fertilizer solution is absorbed. Unlike known types and designs of pumps, jet pumps lack any rotating or moving elements, which determines their high operational reliability [15–16]. Furthermore, the hydraulic method involves pre-mixing water and fertilizers for irrigation using irrigation systems, including both localized networks and sprinkler irrigation [5].

Materials and Methods

The aim of the work was to develop the structural and technological parameters of a device for applying liquid fertilizers with irrigation water.

As an example, consider the proposed technological scheme of a system for introducing liquid fertilizers into the pressure pipeline of irrigation water with the subsequent possibility of transportation through the pipeline using the potential energy of water in an automatic mode, facilitated by an ejector and the pressure differential between its inlet and outlet [17–19].

The mode of application of concentrated fertilizers with irrigation water must correspond to the device's operating design. The concentration of fertilizers in the irrigation water at an irrigation rate of more than 500 m³/ha should not exceed 0,2…0,3 % during dry and hot periods. During rainy and cool periods, this limit can be increased to 0,5 %. For example, with a rate of 300 m³/ha, the water concentration usually should not exceed 0,01…0,1 %, or 0,1…1,0 g/l, and with an irrigation rate of 600...900 m³/ha – 0,2…0,3 % or 2…3 g/l.

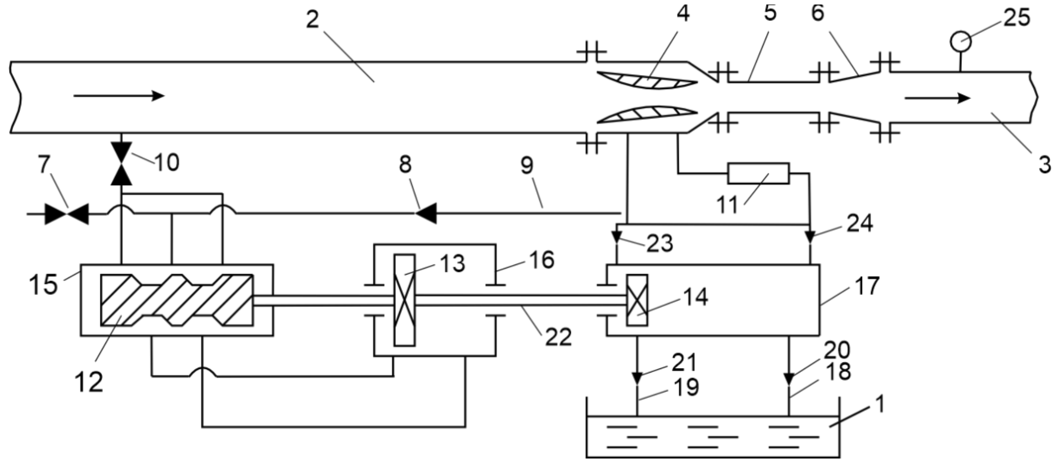
When applying liquid concentrated fertilizers with water after harvest under fall plowing, a solution concentration of up to 2…3 % is allowed.

A mandatory condition for the use of fertilizing irrigation is the prevention of gravitational discharge of solutions outside the irrigated area – into drainage collectors, pipelines, and water bodies.

We base our parameters on objects where the following data are used: for example, irrigation water is supplied at a rate of 400 m³/ha to the irrigation fields through an 800 mm diameter pipeline, and before its distribution by sprinkler machines (units), nutrient solutions are added in the required quantity directly into the pipeline. The permissible pressure drop after the mixing unit is up to 75 m, and the pressure increase before the mixing unit is up to 85 m. The mixing unit must ensure the supply of nutrient solutions into the pipeline up to 25 l/s. Liquid fertilizers are stored in designated holding ponds, the depth of which does not exceed three meters.

Research Results

In this study, a scaled-down model setup at a ratio of 1:8.5, resembling the actual equipment (Froude number modeling), was constructed. It incorporates two double-acting power cylinders with pistons 13 and 14 (Figure 1) and two single-acting pressure-suction cylinders.



1 – tank for liquid fertilizers; 2 – inlet pressure pipeline; 3 – outlet pressure pipeline; 4 – ejector; 5 – acceleration pipe;6 – diffuser; 7 – gate valve; 8 – check valve; 9 – bypass pipe;10 – gate valve; 11 – flow meter; 12 – spool distributor; 13, 14 – piston; 15 – water distribution chamber; 16 – power cylinder; 17 – discharge cylinder; 18, 19 – suction pipelines; 20, 21, 23, 24 – check valves; 22 – rod; 25 – pressure gauge

Figure 1 – Schematic diagram of the automatic device for fertilizer application into a closed network

The working process begins with opening valve 10. Water from the supply pressure pipeline 2 flows through the open valve 10 into the spool valve-water distributor 12 (hydraulic distributor) and then into one side (e. g., the left side) of the double-acting power cylinder 16. Under the influence of water pressure, piston 13 of cylinder 16 moves to the left, and correspondingly, moves piston 14 of the discharge cylinder 17, which is mechanically connected to it. Simultaneously, the working chamber of cylinder 17 fills with fertilizer solution from the liquid fertilizer tank 1 through the suction pipeline 18 with check valve 20. The solution then passes through pipeline 24 with check valve 24 into the ejector 4 and through the accelerating pipe 5, into the discharge pressure pipeline 3. Water from the supply pressure pipeline 2 now enters the double-acting power cylinder from the other side, moving the piston to the right. The piston 13 of the cylinder pushes the used water into the settling tank. That is, all the above-described rightward movement operations are repeated. The cycle is completed by the actuation of the spring synchronizer-pusher, which moves the rod of the spool valve-water distributor 12 to its extreme right position. The cycles then repeat automatically. The gate valve 10 regulates the flow rate of the nutrient solution. Stopping (turning off) the device is also accomplished by closing the gate valve 10.

Taking into account the modeling scale, the following were determined: pressure, pipe diameter, cylinder diameters, ejector nozzle diameter, main pipeline flow rate, liquid fertilizer flow rate, total mixture flow rate, and accordingly, the areas of pipelines, cylinders, ejector nozzle, mixing chamber, piston stroke, and cylinder working volumes.

The optimal ratio of the power cylinder diameter to the discharge cylinder diameter was achieved at a ratio of 1:1.83, where the power cylinder diameter was 55 mm (467 mm full-scale), and the discharge cylinder diameter was 30 mm (255 mm full-scale).

Ejector research was conducted to clarify the magnitude of pressure reduction in the mixer and the flow capacity of its nozzle at given inlet and outlet pressures, as well as in the absence of fertilizer supply to the mixer.

Experiments were conducted for two ejector nozzle diameters: 23 mm (195,5 mm full-scale) and 20 mm (200 mm full-scale) at fixed outlet pressures – 64 m, 68 m, 72 m, 76 m, and 80 m of water column (full-scale).

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Table 1 presents the results of hydraulic studies of the device for introducing liquid (mineral) fertilizers into the pressure pipeline (converted to full-scale).

Figure 2 shows the nature of the change in the ejector's flow capacity.

In the operational technological mode, the device ensures the supply of fertilizer into the pressure main pipeline.

Figure 3 shows a schematic diagram of the ejector assembly.

This system is universal and applicable for both liquid fertilizer delivery and transporting the finished mixture via pipeline to the irrigation site. As established during the study, the throughput of the system for fertilizer tank 1 (see Figure 1) is limited by the maximum lifting height of the pump given the existing elevation difference and pressure in the pipelines. With a correct calculation, the mixing unit will meet all technological requirements under these conditions.

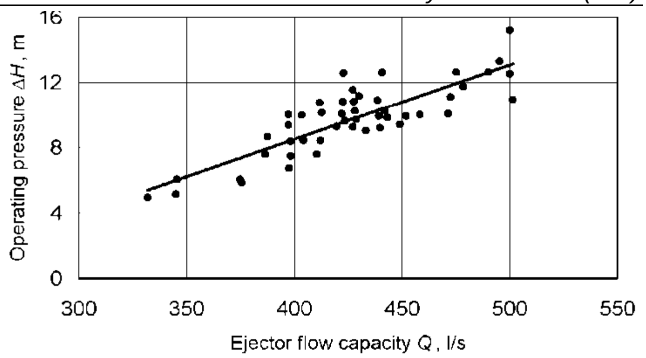
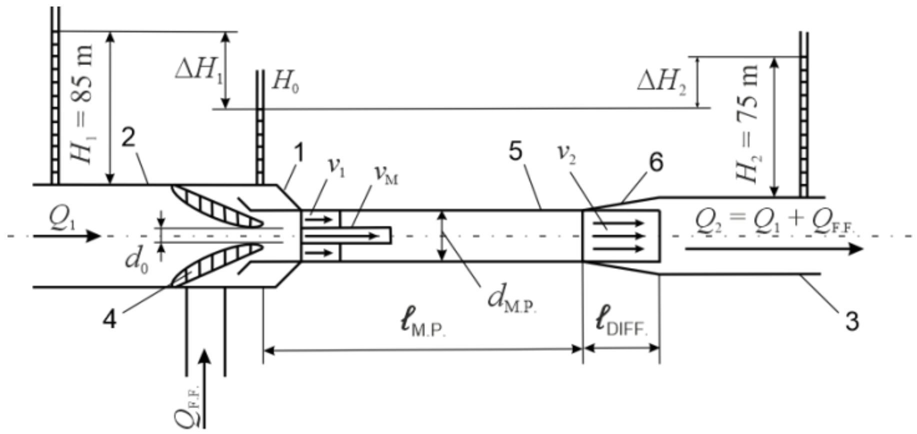


Figure 2 – Ejector flow capacity (*Q, l/s*) depending on the operating pressure (*ΔH, m*)

Table 1 – Results of hydraulic studies (converted to full-scale)

Inlet Pressure, H_{in}, m	Nozzle Pressure, H_o, m	Outlet Pressure, H_{out}, m	Pressure differential, H_n, m	Flow in pipeline before ejector, Q_1, l/s	Cycle Duration, T_c, s	Liquid fertilizer flow rate, l/s		
						1st feed cylinder, Q_{f1}	2nd discharge cylinder, Q_{f2}	Total Q_f
83,3	67,2	68,0	15,3	400	6,23	4,00	4,36	8,36
80,7	67,2	68,0	12,7	400	6,29	2,34	3,53	5,87
79,9	69,7	70,6	9,3	400	7,89	2,41	3,54	5,95
84,1	69,7	71,4	12,7	420	7,42	2,61	4,13	6,74
82,4	69,7	70,6	11,8	473	9,49	1,13	1,77	2,90
81,6	69,7	71,4	10,2	414	6,02	1,77	3,86	5,63
80,7	67,2	68,0	12,7	400	6,37	3,91	5,94	8,85
80,7	66,3	67,2	13,5	408	6,23	6,06	11,85	17,91
79,9	66,3	67,2	13,6	414	6,23	3,09	4,76	7,85
81,6	70,6	71,4	12,7	400	7,40	4,61	6,17	10,78



1 – vacuum chamber; 2 – inlet pressure pipeline; 3 – outlet pressure pipeline; 4 – ejector; 5 – acceleration pipe; 6 – diffuser

Figure 3 – Calculation scheme of the ejector unit

When determining the area of the ejector nozzle, the given flow rate of the main pipeline and the flow coefficient of the ejector nozzle are used

$$\omega = \frac{Q}{\mu\sqrt{2gH_0}}, \quad (1)$$

where *ω* – area of the ejector nozzle, m²; *Q* – water flow rate in the pipeline, m³/s;

μ – flow coefficient of the nozzle, taken as 0,9; *g* = 9.81 m/s² – acceleration due to gravity; H_0 – pressure in the ejector, m.

The diameter of the ejector nozzle can be determined by the formula $d_0 = \sqrt{4\omega/\pi}$.

For the proposed scheme (Figure 3), during research, the pressure H_1 and flow rate Q_1 in the inlet pipeline, as well as the pressure H_2 and flow rate Q_2 in the outlet pipeline, were set. Then the value of the pressure at the device inlet and the fertilizer application rate at pressure H_1 are refined using the formulas

$$H_1 = \frac{H_0\left(1-\delta K\right)}{\delta \cdot K}, \quad (2)$$

$$\delta = \frac{2\varphi\left(\lambda+1\right)^2}{m^2}, \quad (3)$$

where *φ* – coefficient of velocity of outflow from the nozzle, equal to 0,93; $\lambda = Q_{F.F.}/Q_1$ – required degree of dilution of fertilizers with irrigation water; *m* – ratio of the diameter of the acceleration mixing pipe to the nozzle diameter depends on *λ*

$$m = \frac{d_{a.p.}}{d_0}, \quad (4)$$

The coefficient *K* is determined by the formula

$$K \le \frac{m(m-1+\lambda)}{(\lambda+1)^2 \cdot (m-1)} - 0,5\left(1+\xi_{\text{diff.}}\right), \tag{5}$$

where $\xi_{diff.}$ – loss coefficient in the diffuser (0.08…0.15).

The pressure H_0 before the nozzle is determined from formula (2)

$$H_0 = \frac{H_1(\delta \cdot K - H_2)}{(1-\delta \cdot K)}. \tag{6}$$

It should be noted that if adjustment of pressure H_0 is necessary, the diameter of the acceleration mixing pipe is changed and H_0 is refined using formulas (4–6).

Based on the obtained value of the ejector nozzle pressure, other design parameters of the ejector are determined: nozzle length, length of the acceleration mixing pipe, diffuser length, and, accordingly, the geometric parameters of the horizontal diaphragm with a hole, which is located below the body at the bottom of the chamber. The diffuser length $\ell_{diff.}$ is determined by the formula

$$l_{diff.} = \frac{\left(D_{pip.} - l_{m.p.} \cdot \frac{ctg\beta}{2}\right)}{2}, \tag{7}$$

where D_{pip} – diameter of the outlet reclamation pipeline, m; β – cone angle of the diffuser; $\ell_{m.p.}$ – length of the mixing pipe, m.

Considering the above conditions, the ratio of the diameter of the power cylinder to the discharge cylinder can be taken in the range from 1,8 to 2,0. The piston stroke of the fertilizer feed pump is taken from one to two diameters of the power cylinder. The optimal cycle duration for the injection devices is from 2,0 to 2,5 seconds and depends on the diameter of the discharge cylinder, piston stroke, and the flow rate of fertilizers supplied to the irrigator; they are related by the ratio

$$Q_{\text{F.F.}} = \frac{d_{\text{D.C.,}} \cdot \ell_{\text{P.S.}}}{T_{C.}}, \tag{8}$$

where $Q_{F.F.}$ – flow rate of liquid fertilizers, cm³/s; $d_{D.C.}$ – diameter of the discharge cylinder, cm; $\ell_{P.S.}$ – piston stroke of the discharge cylinder, cm; T_C – cycle duration, sec.

The ratio of the power cylinder diameter to the outlet pipeline diameter ranges from 2,7 to 3,0.

The speed of movement of the hydraulic cylinder rod depends on the direction of fluid supply, which can be found from the expression

$$V_M = \frac{4 \cdot Q \cdot \eta_0}{\pi \cdot D_{CYL}^2}, \tag{9}$$

where D_{CYL} – internal diameter of the hydraulic cylinder; η_0 – volumetric efficiency.

Hence, the ratio of the rod movement speeds in the indicated directions depends on the ratio of the hydraulic cylinder diameters. The force developed by the hydraulic cylinder when supplying fluid to the piston cavity is determined by

$$\mathrm{P}_P = \frac{\pi \cdot D_{CYL}^2}{4} \eta_0 \cdot \mathrm{P}. \tag{10}$$

It should be noted that the piston stroke of the hydraulic cylinder is linked to the design of the spool distributor, which prevents the piston from striking the covers in the hydraulic cylinders.

The results obtained during the research show that the calculation of the flow areas of spool hydraulic distributors is performed according to the formula

$$F_m = q \cdot h = \frac{Q}{V}, \tag{11}$$

where F_m – flow area of the spool gap; *q* – perimeter of the gap; *h* – gap opening value; *Q* – flow rate through the gap; *V* – permissible fluid velocity through the gap.

Laboratory studies of the model showed the feasibility of the device, which ensures the injection of liquid fertilizer into the pressure pipeline using the potential energy of the water in the same pipeline, and also allowed for the refinement of the calculated ratios of structural parameters and the technical characteristics of the device. All this allows for the reduction of construction costs for production and mitigates the negative impact of liquid fertilizers during irrigation on the environment.

This device ensures a high degree of mechanization and automation of the fertilizer application process with irrigation water and does not require additional energy costs for supplying liquid fertilizers into the irrigation water flow. This factor improves the uniformity of nutrient application to the irrigated field, increasing crop yield while saving on fertilizer.

Conclusion

The developed technical design for a system for mixing various liquid fertilizers, as well as a pump equipped with an ejector unit for collecting and transporting the resulting mixture, minimizes environmental risks associated with the use of these fertilizers in irrigation. The proposed solution provides design organizations with an opportunity to modernize traditional technological schemes for supplying fertilizers, aimed at eliminating the shortcomings inherent in existing technologies. When substantiating the structural parameters of the technology for applying liquid fertilizers with irrigation water noted in the article, we have formed the main technical requirements for the device:

– the device provides an improved layout of distribution fittings, promoting uniformity of fertilizers applied with irrigation water across the reclamation system;

– the elements of the device are unified in manufacturing for closed reclamation systems by assembling from parts produced industrially at relevant factories;

– the device provides a high degree of automation of the process of applying fertilizers with irrigation water; does not require additional energy costs for supplying the fertilizer solution into the flow of irrigation water; improves the uniformity of nutrient application in the field; allows for top dressing at any time and during any plant development phase; improves nutrient uptake, increases crop yields while saving fertilizers.

A new technical solution, protected by patents, has been developed, ensuring the implementation of key research directions related to the technology of applying liquid fertilizers with irrigation water.

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