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Modern Methods of Irrigation Water Purification by a Mesh-Filter Using Influence of Low Frequency Vibration

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Abstract. The article is devoted to the analysis of different methods of irrigation water purification from suspended particles. There have been considered the problems of irrigation water purification by using the low-frequency vibration technology and the effects arising from the influence of vibration on the water with different floating impurities. Vibration parameters that allow obtaining the effect of standing wave was substantiated. Also in the article have been disclosed the influence of low-frequency vibration on the quality of water purification depending on the types of pollution and their granulometric composition. Obtained the hydraulic characteristics of the mesh such as the effect of vibration on the pressure loss.

Keywords: irrigation water, low-frequency vibration, standing wave, floating impurities

INTRODUCTION

It is very important in the difficult economic conditions in Ukraine to obtain the maximum possible yield of agricultural crops. The quality and quantity of the harvests are influenced by the water-air regime that is created during the growing season. In order to maintain the optimum water-air regime during the growing season irrigation water is supplied to plants as an additional to the natural precipitation, prevents periodic droughts and stimulates the growing of plants. Timely supply the required irrigation rate can significantly increase the quality and quantity of harvest obtained from one hectare [14].

Irrigation can be implemented by the various methods. Such methods as spraying and drip irrigation with using of water from open irrigation network systems are widely used in recent years. The main problem of irrigation is insufficient quality of irrigation water [9-13, 15].

Surface water resources such as rivers, lakes, etc. used for irrigation is characterized by the variability of its composition due to the livelihoods of the various plant organisms and the organisms of animal origin located in the water. The great influence on the water quality as well has the wastes of an industrial production [1, 2].

Impurities are in the natural waters may be in a different states depending on the size of a particle. There are three groups of the impurities:

- suspended substances;
- colloid-soluble substances;
- soluble substances.

The suspended particles are include a unit of substance which size is greater than 1 microns. Such pollutions are held up by a filter paper. The particles with density bigger than the density of the water are capable to precipitate for a certain time.

Colloid-soluble impurities in an intermediate position between suspended and soluble substances. The size of colloidal particles is in the range from 1 to 100 microns. They pass freely through a filter paper. Such particles are not precipitated even for a long time.

Soluble substances have a molecular or ionic degree of grinding and the size of such particles is less than one microns, it is means that the molecules of the dissolved substance are evenly allocated between molecules of water [3].

Usually the natural surface waters are characterized by high turbidity, mineralization and colourlessness.

Turbidity occurs in most cases due to mechanical contamination, which are in the form of fine dispersible floating impurities. Quantitative, granular, chemical composition and contamination structure varies in a wide range and depends of the using of the liquid. In the water for irrigations purposes, it is usually some silt, sand and particles of vegetable origin.

Depending on the purpose and the requirements for the water quality, purification of natural water is provided by the mechanical, physical, physical-chemical, chemical or biological methods.

In case of using the natural waters, the suspended matter is present in the form of particles of mineral and organic origin. The suspended matters of large size are caused of the work deterioration of the irrigation machines.

Recently farms with an irrigation area of over 1,000 hectares are using foreign sprinkler machines that are offered by such well-known firms as "Bauer" (Austria), "Valley", "Lindsay" (USA). For irrigation of areas from 5 to 30 hectares are used of drum sprinklers, and on areas from 50 to 200 hectares - wide-reaching sprinkler system.

The water quality is one of the important factors for the determination of irrigation norm during the season. With the deterioration of water quality - litter, flowering, etc., increases the pressure loss in sprinklers that leads to lower productivity and affects the quality and energy intensity of irrigation.

Obviously, that in case of a sprinkler working on heavily clogged canals especially in the summer time during the period of alga's flowering the protective effect of the cleaning nets and gravel filters is insufficient. As a result small particles of the impurities in the water come in to the suction pipeline and then through the pumping station to the closed irrigation system. These particles getting into the sprinkler cause the unpredicted changes in the local resistance and it leads to changes in distribution of the precipitation along the sprinkler's pipeline. Because of the sprinkler's design peculiarities, the sprinkler nozzles are located on the bottom of the hanging pipes; the work to clean them up from pollution is quite labour-intensive and takes a lot of time. To improve the quality of the irrigation water it is recommended to provide its additional cleaning.

Therefore, the actual problem is the substantiation of the technology of irrigation water purification using low-frequency vibration that allows improving the quality of cleaning and the duration of operation the filter and the sprinkler as a whole.

As a result of analysis of the methods of water purification from various types of pollution, we concluded that cleaning the water from suspended matter is expedient to use a mechanical method such as filtering using a mesh.

In the process of filtering by using a mesh, there are simultaneous water purification and formation of a layer of siege on the mesh, which leads to gradual clogging of the filter element increase of pressure losses and deterioration of the water quality. To prevent the occurrence of the negative events, additional measures must be provided for the purification (regeneration) of the filtering element (mesh).

There are a large number of different mesh filters. They have different parameters and depending on the task, different designs. The main purpose of the variety of constructive solutions is to provide long-term work without degrading the technological parameters of cleaning and simplifying the mesh regeneration process.

Regeneration of a mesh can be carried out in different ways: hydraulic, pneumatic, mechanical, chemical, vibration and sound. The hydraulic method is most often used, but it is often used in a combination of some others methods, which greatly accelerates the process itself and reduces energy costs [4].

Mostly common the hydraulic cleaning method. This method allows automatizing of the mesh regeneration process, but it has some shortcomings. The main one is the insufficient restoration of the mesh and using a large amount of wash water. As a result, it is necessary to carry out regeneration of mesh and, for their complete purification, to apply others methods, which leads to a shortening life service or the destruction of the mesh [5].

Purification from big, hard and heavy pollutions provides under the action of gravitational forces. It is could be implemented by using sediment bowls, sand-catchers, etc.

If we need to purify the water from pollutants with density a little bit more than water density, than mostly hydrocyclones and centrifuges are used. In the hydrocyclones the centrifugal forces are obtained as a result of twisting of the flow of the fluid, and in the centrifuges are obtained due to the rotation of the moving part (rotor).

Hydrocyclones are quite compact, easy to maintain, but not efficacious for purified liquids containing small particles. To improve the efficiency of cleaning, multi-stage hydrocycle plants are used.

Centrifuges as well as hydrocyclones are low effective. In addition of the rotating parts (rotor) in it, low productivity and the needs for electricity are limited their widespread using.

Using of electric and magnetic fields for cleaning liquids is limited by the specifics of the impurities so these methods are used only when necessary to clean water from contaminations that respond to the influence of the electric or magnetic fields.

Using of vibration in the filtration process greatly increases the filtration cycle and improves the process of regeneration of the mesh. Therefore, vibration filters are widely used in various industries such as chemical, mining, enriching, and others industry sectors.

One of the first scientists applied vibration oscillations to accelerate the filtration process was N. A. Burenkov. After him a number of researchers such as Babayev I. S., Lashkivsky Y.P. began to experiment with vibration mesh filters in the water supply systems. The researches had been implemented by M.G. Nurayev [6] proved vibration using to clean the mesh allows the creation of high-performance vibration mesh filters, and I. S. Babayev established the relationship between the amplitude of vibration and the pressure loss on the mesh [4]. These authors had developed a series of filters designs with direct vibration of the filter element.

To intensify the process of cleaning the liquid from solid impurities could apply the acoustic oscillations. Vibrational effects are widely applied in flotation, centrifugation, settling and filtering.

MAIN IDEAS AND METHODS

The main tasks of research the low-frequency vibration influence on the quality of cleaning are:

- determining the influence of vibration on the working environment;
- checking the effect of vibration on hydraulic losses on the mesh;
- developing a technology and technical solution that can improve the quality of irrigation water purification.

There are a number of designs of filters with a reciprocating movement of the filter element, which provide water purification, but have certain disadvantages.

After analysing technical solutions for water purification from various types of contamination it can be concluded that for purification of irrigation water, it is expedient to use mesh filters with moving filtering element.

To solve this problem a design of a vibration filter (Fig. 1) was developed that allows two processes to be realized simultaneously such as water purification and regeneration of the filter element.

The technical solution is a vibration filter for cleaning the irrigation water consisting of a body 1. Inside the body, there is a cylindrical perforated mesh 2. An inlet pipe 3 that is designed to direct the flow of fluid to the upper plate 4. The vibrator 5 that is mounted on a platform based on shock absorbers 6. A rod 7 that transmits vibration from the platform to the mesh and the nozzle for filtrate drainage 8. There is wave-reflecting grid 9 at the bottom of the mesh for creating a steady wave. In the bottom of the mesh nozzle discharge pipe 10.

The mesh filter works as follows.

Water from an open irrigation network flows through the inlet pipe 3 under pressure into the mesh 2. The water with impurities is directed to the upper plate 4 by inlet pipe. The stream bumps into the upper plate of the mesh, reflects from it, washes the mesh and washes the algae and impurities accumulated under the top plate and on the mesh itself, into the lower part of the mesh.

The vibrator 5 through the rod 7 transmits the oscillations to the mesh and, due to the action of the upper plate, a longitudinal wave appears in the liquid, which spreads vertically from the upper plate to the wave reflecting grid 9. The wave that hit the grid 9 is reflected from it and moves in the opposite direction toward the upper plate.

At a definite ratio of frequency, amplitude of oscillation and dimensions of the filter element, a stable wave phenomenon occurs. Due to this phenomenon, part of the algae and impurities are coagulated and, under its own weight, precipitates in the lower part of the mesh without getting into it. This way the separation of suspended particles is achieved.

Water containing suspended particles passes through the working surface of the mesh and through the outlet of the nozzle for filtrate drainage 8 it is fed into the pressure pipeline of the sprinkler machine. The suspended particles that are retained on the filter element, under their own weight and directed flow, fall into the lower part of the mesh from where they are removed through the nozzle discharge pipe 10.

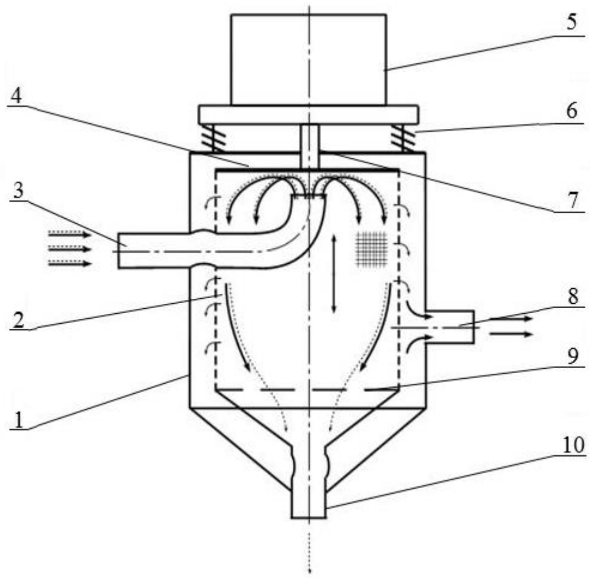

Fig. 1. Scheme of the vibration filter: 1 – body; 2 - mesh; 3 – inlet pipe; 4 – upper plate; 5 – vibrator; 6 – shock absorbers; 7 – rod; 8 – nozzle for filtrate drainage; 9 – wave reflecting grid; 10 – nozzle discharge pipe

In order to determine the influence of the vibration process on the purification of irrigation water, theoretical studies of the dependence between the geometric dimensions of the filter element and the basic parameters of vibration such as frequency ω and amplitude a were carried out.

Consider in details process of the wave motions of the liquid in the vibration filter, the scheme of which is shown on Fig. 1. We can see that the waves generated by vibrator are longitudinal and directed along the vertical axis of the filter.

In general, the equation of a plane wave has the form [7, 13]:

$$\xi(x,y,z;t)=a\cos(\omega t-k_x x-k_y y-k_z z+\alpha) \quad (1)$$

In this formula:

$$k_x=\frac{2\pi}{\lambda}\cos\alpha;\quad k_y=\frac{2\pi}{\lambda}\cos\beta;\quad k_z=\frac{2\pi}{\lambda}\cos\gamma, \quad (2)$$

here k_x, k_y, k_z are projections of the vector of the wave number k on the coordinate axis, α, β, γ angles between the wave vector and the corresponding coordinate axes and λ the wavelength, m.

Let us choose the coordinate system so that the Z-axis coincides with the direction of propagation of the waves that are formed inside the mesh cylinder. For a case where the wave propagation direction coincides with the coordinate axis, the equation 1 could be written as follows:

$$\xi = a\cos(\omega t - kz + \alpha) \text{ or } \xi = a e^{i(\omega t - kz + \alpha)}. \quad (3)$$

here z is the coordinate of the point where the oscillation is considered.

Let us write the equation of two planar waves propagating along the Z-axis in opposite directions:

$$\xi_1 = a\cos(\omega t - kz); \ \xi_2 = a\cos(\omega t + kz). \quad (4)$$

Adding these equations and transforming them we get:

$$\xi = \xi_1 + \xi_2 = 2a\cos kz \cos \omega t. \quad (5)$$

Equation 5 is the standing wave equation. Such waves arise from the background of the interference of two opposing plane waves with the same frequency.

Substituting in the equation 5 the value of the wave constant k, we obtain the following expression:

$$\xi = 2a\cos 2\pi \frac{z}{\lambda} \cos \omega t. \quad (6)$$

From this equation, we can see that at each point of the standing wave, the co-occurrence of the same frequency occurs as in opposing waves, and the amplitude depends on z:

$$A = \left| 2a\cos 2\pi \frac{z}{\lambda} \right|. \quad (7)$$

At the points that coordinates satisfy the condition:

$$2\pi \frac{z}{\lambda} = \pm\left(n + \frac{1}{2}\right)\pi \ \ (n = 0, 1, 2, \ldots). \quad (8)$$

the amplitude of oscillations reaches the maximum value. These points are called the antinodes of a standing wave.

At the points that coordinates satisfy the condition:

$$2\pi \frac{z}{\lambda} = \pm \pi n \ \ (n = 0, 1, 2, \ldots). \quad (9)$$

the amplitude of the oscillation is zero. These points are called standing-wave nodes.

At $\omega = 28.0$ s^{-1}; $k = 63.7$ m^{-1}; $\lambda = 0.099$ m wave profile in the filter has some antinodes distance between them multiple of wavelengths: at $z_1 = 0$ and at $z_2 = 10$ mm. In the antinodes the suspended particles - algae and impurities i.e. the solid phase of the suspension are collected.

During the above-mentioned processes in the vibration filter, the algae are localized by the influence of the direct and the reverse wave. Such localization points are appeared in the same horizontal plane. The algae localization in those points is followed by their coagulation. Localization is a dynamic process in a vibration filter, during which the algae are accumulated in designated areas of the fluctuating fluid. Solner and Bondy first discovered this phenomenon in 1938 [8].

King and Gorky obtained approximate analytical expressions for the force acting on a particle in an oscillating medium. This force is called radial pressure. In the general case for a standing wave, the potential of the velocity F_p and the pressure P on the particle can be written as follows:

$$F_p = \frac{1}{2}|a|\left[e^{-ik(z+z_в)} + e^{ik(z+z_в)}\right]e^{i\omega t} \quad (10)$$

$$P = \pi\rho|a|^2 \sin 2kz_в (kr)^3 \frac{1 + \frac{2}{3}\left(1 - \frac{\rho}{\rho_r}\right)}{2 + \frac{\rho}{\rho_r}} \quad (11)$$

here a is the amplitude of the wave, m; k is a wave number, m^{-1}; ω is a vibration frequency, s^{-1}; $z_в$ is a distance from the center of the particle to the node of speed, m; ρ - liquid density, kg / m^3; ρ_r is a particle density, kg / m^3; i is a imaginary unit; t is a time, s; z is a coordinate, m.

Analysing the King-Gorkov's motion equation of a suspended solid in a liquid under influence of vibration, R.F. Ganiev and L.E. Ukrainskyi found that the particles with density $\rho_r > 2/5\rho_0$ should migrate in the antinodes, and at $\rho_r < 2/5\rho_0$ in the node. For algae, the first inequality is correct, therefore, the localization takes place in the midst of a standing wave. At the same time occurs partial coagulation of algae.

To confirm the theoretical results, laboratory studies of the processes occurring in the vibration filter were performed. Experiments were carried out in two stages: a hydraulic test for determining the hydraulic resistance of the mesh filter element; and the determination of the purification factor for different types of contaminants and for different sizes of fractions.

The filter performance and purity of the filtrate depend on the filter element used in the filter. A properly selected filtering element must provide the required degree of delay of the solid part-knock at a minimum hydraulic resistance.

The main factors affecting the quality of water purification are the dimensions of the live cross section of the mesh filter element (cell dimensions). The smaller the size of the cross-section of the openings, the smaller the size of the contamination pass through the grid, but at the same time, the hydraulic resistance of the filtering element increases and the filter cycle is reduced.

In order to establish the hydraulic characteristics of the mesh filter element and the effect of vibration on these characteristics, the pressure and flow characteristic of the filter element (fig. 2) was determined.

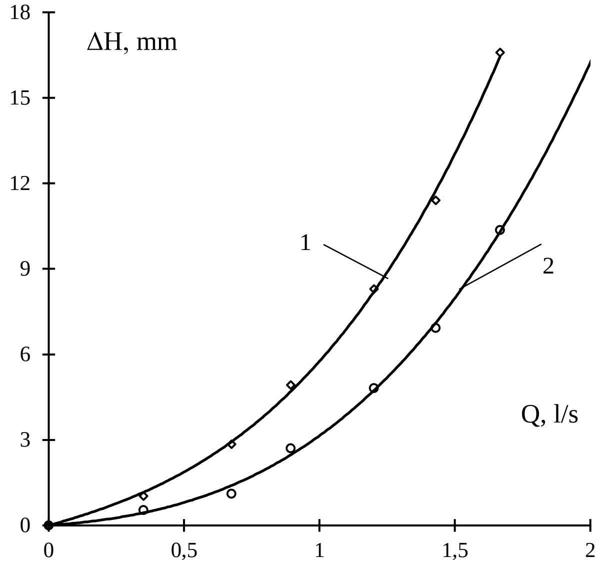

Fig. 2 The pressure-consuming characteristic of a filter element with a cell size 1.0x1.0 mm: 1 - without vibration; 2 - with vibration

To determine the effect of vibration on the quality of water purification, the coefficient of water purification from impurities was determined in two modes - without vibration and under the influence of low-frequency vibration.

There were investigated the coefficients of purification of the model environment that using the contaminant, the granulometric composition of which is divided into the following groups:

I - 2 mm and more;

II - from 2 mm to 1 mm;

III - from 1 mm to 0.5 mm;

IV - from 0.5 mm to 0.25 mm;

V - 0.25 mm or less.

For each of these groups the coefficient of purification of irrigation water was defined as the ratio of the mass of the precipitate that was held by the filtering element to the total mass of pollution.

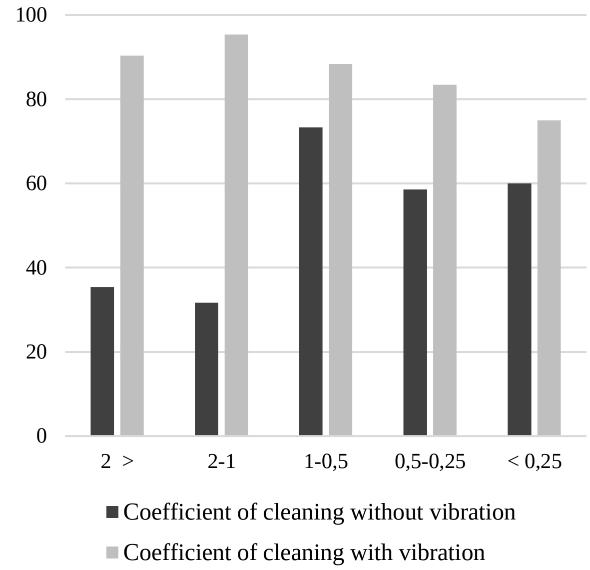

Fig. 3 Diagram of the coefficient of purification by different factions

CONCLUSIONS

According to the results of theoretical studies and laboratory researches, the following conclusions were made:

1) To achieve the effect of standing wave, the height of the filter must be taken multiple times *10 mm*, the frequency of vibration should be $28\ s^{-1}$, and the amplitude of forced oscillations should be *1 mm*.
2) In a case when the contaminant forms a dispersed environment capable for coagulation due to the effect of vibration and the formation of the standing wave, there is a partial coagulation of the particles of the contaminant, which increases the efficiency of the filtration by more than 50%.
3) Due to the effect of low-frequency vibration on the working environment, there is a decrease in the hydraulic losses on the mesh.
4) Under the influence of low-frequency vibration, the purification efficiency for a contaminant which particle size is commensurate with the size of the cell of the mesh filter element increased by 2.5-3 times, and for particles of the contaminant, which is much smaller cell size by 15-25%.

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