Актуальним є створення енергозберігаючого обладнання і відповідних технологій для виробництва компостів із забезпеченням ефективної ферментації в умовах аграрних підприємств. Для формування буртів компосту та їх аерації запропоновано робочі органи у вигляді барабана з радіальним розміщенням лопаток. Запропоновано аналітичну модель, яка дозволяє встановити характер руху частинок компосту в процесах утворення буртів та аерації

Ключові слова: бурти компосту, лопатевий барабан, рух частинки по лопаті, траєкторії руху

Актуальным является создание энергосберегающего оборудования и соответствующих технологий для производства компостов с обеспечением эффективной ферментации в условиях аграрных предприятий. Для формирования буртов компоста и их аэрации предложены рабочие органы в виде барабана с радиальным расположением лопаток. Предложена аналитическая модель, которая позволяет установить характер движения частиц компоста в процессах образования буртов и аэрации

Ключевые слова: бурты компоста, лопастной барабан, движение частицы по лопате, траектории движения

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ANALYTICAL RESEARCH INTO THE MOTION OF ORGANIC MIXTURE COMPONENTS DURING FORMATION OF COMPOST CLAMPS

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1. Introduction

One of the ways to improve efficiency of agricultural production is the use of organic substances as fertilizers [1]. Effective means of such utilization of organic substances is composting [2, 3].

Composting is a biological process of biochemical transformation of organic raw materials under specified conditions. The result is obtaining the high-quality organic fertilizers. During composting, organic matter decomposes, the synthesis of the biomass of microorganisms takes place, the preservation of nitrogenous substances is ensured. The homogeneous substrate received in this case is enriched with mineral nutrients and contains no harmful substances and microorganisms. All this is impossible without a process of intensive fermentation of organic matter.

For this purpose, it is necessary to form the clamps of rational shape and to aerate the substrate. This provides for the necessary access of oxygen to the microorganisms and the fermentation process [4, 5].

Therefore, it is a relevant task to devise energy-saving equipment and appropriate technologies for the production of composts providing for effective fermentation under conditions of agricultural enterprises.

2. Literature review and problem statement

Technology of composting under conditions of agricultural production consists of the preparation of original components of a mixture, the process of fermentation, maturation of compost [2, 6]. The first stage implies the balancing of initial indicators of compost mixes by the content of nutrients, moisture and structure. Most commonly used is the open technique of producing compost [3]. In this way, using the technical means enables the ordering of organic raw materials, which are arranged in clamps, stacks, and piles [7, 8]. When using the open method of composting, important role is played by the shape of clamps, which affects air access to the components of compost, as well as its arrangement [1, 3, 8].

That is why the stage of fermentation involves control over technological parameters, the dosage of necessary organic ingredients, forming the clamps of rational form, periodical loosening for conducting aeration [9, 10]. The frequency of conducting the loosening depends on the chemical composition of the mixture, season, climatic conditions and varies from 3 to 15 days [1, 9]. The number of loosening in the process of composting is from 2 to 6 times [11]. Aeration is performed by periodic loosening of a compost mixture by movable technical means or by feeding air into the substrate by the ventilation equipment under stationary conditions [4, 5]. When forming and aerating the clamps, the processes of motion of the raw materials in plane and space are considered [1, 10]. A shape of the clamp is formed, rational for the course of chemical and physical processes. At subsequent aeration, carbon oxide is released while the raw materials are oxygenated [11, 12]. Although articles [7–10] address the influence of the shape of a clamp and appropriate aeration [4, 5, 11] on the compost formation process, but the parameters of machines that can perform the required technological operations are not sufficiently formalized.

In addition, at present, Ukraine lacks serial machines and equipment for composting the organic raw materials [1, 11, 12]. This is primarily due to the fact that there are no clearly established dependences of relationship between design and kinematic parameters of working bodies of the machines and the parameters of clamps. One of the steps towards the establishment of such a relationship is the analytical study of motion of the organic mixture components during the formation of compost clamps.

3. The aim and tasks of research

The aim of present work is the establishment of analytical relation between working bodies of machines for the formation of clamps and the character of motion of the particles of compost.

To accomplish the aim, the following tasks had to be solved:

– to conduct analytical substantiation of motion of the particles of compost in the interaction with a working body of a clamp turner;

– to define parameters of motion of the particles of compost during work of a clamp turner.

4. Materials and methods to study parameters of the equipment for the formation of compost clamps

In order to conduct theoretical studies into the character of motion of the particles of compost (Fig. 1), we used a mathematical modeling of the process of work of its working body – a drum with radial arrangement of blades.

Fig. 1. Formation of clamp based on a mixture of organic substances

To develop a mathematical model of the process of interaction between a drum with clamp and organic mixture particles, we accepted the following assumptions:

– design of the drum was considered flat in a cross section (Fig. 2);

– frontal surface of the original clamp was at an angle α of repose to the horizon, and its hulling occurred along the plane inclined at an angle of repose;

– unloading of compost from a blade of the working organ started when its edge left the region of the original clamp.

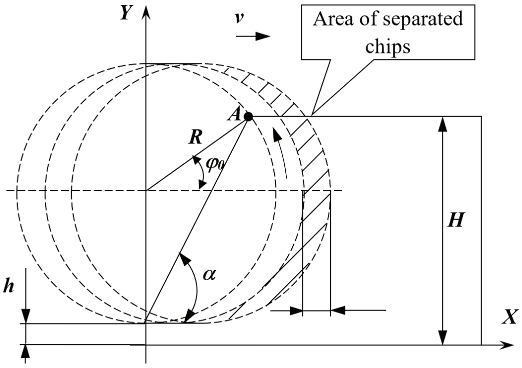

Fig. 2. Calculation scheme to determine the angle of the start of unloading the compost from a blade

The types of working bodies, which are used in the formation of clamps and their aeration, were represented in the form of a drum with a radial arrangement of the blades.

5. Results of examining parameters of the process of motion of the compost components in the process of formation of clamps

Let us consider a critical point A, which is characteristic for the process of interaction between the blades of the drum and a clamp. This is the only point at which there is the intersection of line of the clamp repose, line of the clamp height and the outline of blade rotation of the drum mixer-aerator. The height of clamp should be of the required height. Compost that is above the clamp height line (Point A, Fig. 2) will fall down by gravity onto the blades of the drum. This will lead to the deterioration in quality of compost loosening. If the clamp height is lower than the level of the clamp height line that passes through point A, performance efficiency will be insufficient.

In this case, the angle of the start of unloading the compost from the blade can be determined by expression:

$$H - h - R - R\sin\varphi_0 = 0; \;\; \sin\varphi_0 = \frac{-h}{R} - 1;$$

$$\varphi_0 = \arcsin\left(\frac{-h}{R} - 1\right), \qquad (1)$$

where H is the height of clamp, m; h is the height of the drum assembly, m; R is the radius of the drum, m.

It is common knowledge that the high point of a blade simultaneously executes translational and rotational motion, moving in this case by trochoid, whose equation is written in the form:

$$\begin{cases} x(t) = R\sin(\omega t) + vt, \\ y(t) = R\left(1 - \cos\ (\omega t)\right), \end{cases} \qquad (2)$$

where t is the time, s; x, y are the coordinates of a point, m; R is the outer radius of the working body, m; ω is the angular speed of rotation of a working body blade, s^{-1}; v is the speed of translational motion of the working body, m/s.

From the second equation of this system we can determine the time of drum turning from the vertical axis to the blade exiting the compost:

$$y(t) = H = R\left(1 - \cos(\omega t)\right); \quad \cos(\omega t) = 1 - \frac{H}{R};$$
$$t = \frac{1}{\omega}\arccos\left(1 - \frac{H}{R}\right). \qquad (3)$$

In the initial period, a blade is at an angle $\varphi_0 = B$ to the horizon. At this point of time, the first batch of compost, which is at the edge of the blade, leaves it. At turning angle $\varphi_0 + \Delta\varphi = B + \omega t$, the last batch of compost arrives to the edge of the blade and leaves it. Thus, the last batch of compost travels some distance along the blade during unloading time t. To determine relative velocity of a particle motion along the radial blade of rotating drum, one takes into account the resistance of medium. Medium resistance is proportional to the motion speed (Fig. 3). In this case, differential equation of motion will take the following form:

$$m\frac{dv_R}{dt} = m\frac{d^2r}{dt^2} = mrw^2 - mfk_1wr - 2fmw\frac{dr}{dt} -$$
$$-mk_1\frac{dr}{dt} - mg\left[f\cos(B + wt) + \sin(B + wt)\right], \qquad (4)$$

where m is the weight of a particle, kg; w is the angular speed of drum rotation, rad/s; r is the current radius of particle position on a blade, m; g is the acceleration of the Earth's gravity, m/s^2; f is the friction coefficient of particle against the material of a blade, rel. units; B is the initial turning angle of a drum blade, rad.; t is the drum rotation time, s; υ_R is the relative velocity of particle motion along the blade, m/s; mrw^2 is the centrifugal force of inertia, N; $2mw\frac{dr}{dt}$ is the Coriolis force, N.; mg – gravity force, N; mfk_1rw is the force of friction due to the air resistance that presses a particle to the blade, N; $mk_1\frac{dr}{dt}$ is the air resistance force that counteracts the motion of a particle in radial direction, N; k_1 is the proportionality coefficient at an air laminar flow over a particle, s^{-1}.

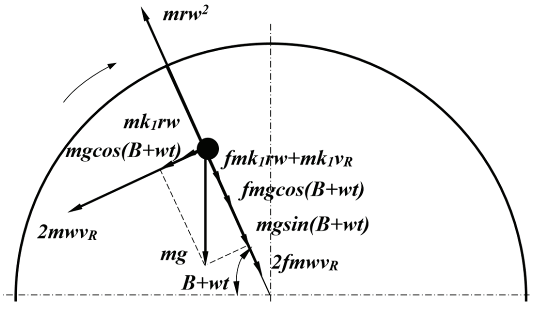

Fig. 3. Calculation scheme of action of forces on a compost particle, which leaves the blade of a working body

Proportionality coefficient k_1 determines the force of medium resistance. Resistance force is directed opposite to the direction of velocity of the particles and is proportional to velocity flight of a particle in the first power when the air flows around the particles by a laminar flow at Reynolds numbers less than 5. Based on this, we can write:

$$k_1 = \frac{3\pi\eta d_E}{m} = \frac{3\pi\eta d_E}{\rho V} = \frac{18\eta}{\rho d_E^2}, \qquad (5)$$

where η is the dynamic viscosity of medium, N s/m^2; d_E is the dimensions of a particle through a diameter of equivalent layer, m; ρ is the density of particle material, kg/m^3; V is the volume of particle, m^3.

Based on equation (4), we can write:

$$r'' + (2fw + k_1)r' - (w^2 - fk_1w)r =$$
$$= -g\left[f\cos(B + wt) + \sin(B + wt)\right]. \qquad (6)$$

This equation is a linear second order differential equation with constant coefficients and right side in the form of a trigonometric polynomial. A uniform differential equation, corresponding to it, will take the form:

$$r'' + (2fw + k_1)r' - (w^2 - fk_1w)r = 0, \qquad (7)$$

and its roots:

$$\lambda_1 = -\left(fw + \frac{k_1}{2}\right) + \sqrt{w^2(1 + f^2) + \frac{k_1^2}{4}}\ ; \qquad (8)$$

$$\lambda_2 = -\left(fw + \frac{k_1}{2}\right) - \sqrt{w^2(1 + f^2) + \frac{k_1^2}{4}}, \qquad (9)$$

where λ_1, λ_2 are roots of characteristic equation, s^{-1}.

General solution of differential equation will take the form:

$$r = C_1\exp(\lambda_1 t) + C_2\exp(\lambda_2 t) + r_{PS}. \qquad (10)$$

Partial solution of non-uniform differential equation will be found in the form of a trigonometric polynomial:

$$r_{PS} = M\cos(B + wt) + N\sin(B + wt), \qquad (11)$$

where r_{PS} is the partial solution of a non-uniform differential equation, m.

The values of coefficients are:

$$N = \frac{\begin{vmatrix} -2w^2 + fk_1w & -gf \\ -2fw^2 - k_1w & -g \end{vmatrix}}{\Delta} =$$
$$= \frac{2gw^2 - fk_1wg - 2f^2gw^2 - fk_1wg}{w^2(4w^2 + k_1^2)(1 + f^2)} = \frac{2g\left[w(1 - f^2) - fk_1\right]}{\omega(4w^2 + k_1^2)(1 + f^2)};$$

$$M = \frac{\begin{vmatrix} -gf & 2fw^2 + k_1w \\ -g & -2w^2 + fk_1w \end{vmatrix}}{\Delta} =$$
$$= \frac{2gfw^2 - f^2k_1wg + 2fw^2g + k_1wg}{(4w^4 + k_1^2w^2)(1 + f^2)} = \frac{g\left[4fw + k_1(1 - f^2)\right]}{w(4w^2 + k_1^2)(1 + f^2)}.$$

Then the partial solution of a non-uniform differential equation will take the form:

$$r_{PS}=\frac{g\left[4fw+k_1\left(1-f^2\right)\right]}{w\left(4w^2+k_1^2\right)\left(1+f^2\right)}\cos\left(B+wt\right)+$$
$$+\frac{2g\left[w\left(1-f^2\right)-fk_1\right]}{w\left(4w^2+k_1^2\right)\left(1+f^2\right)}\sin\left(B+wt\right). \qquad (12)$$

After subsequent mathematical transformations, complete solution of a non-uniform differential equation (6), as the sum of general and partial solutions, will take the form:

$$r=C_1\exp\left(\lambda_1 t\right)+C_2\exp\left(\lambda_2 t\right)+$$
$$+\frac{g}{w\sqrt{4w^2+k_1^2}}\sin\left(B+\mathrm{arctg}\frac{4fw+k_1\left(1-f^2\right)}{2\left[w\left(1-f^2\right)-fk_1\right]}+wt\right). \qquad (13)$$

Relative motion speed of a particle along the blade will be:

$$v_R=\frac{dr}{dt}=\lambda_1 C_1\exp\left(\lambda_1 t\right)+\lambda_2 C_2\exp\left(\lambda_2 t\right)+$$
$$+\frac{g}{\sqrt{4w^2+k_1^2}}\cos\left(B+\mathrm{arctg}\frac{4fw+k_1\left(1-f^2\right)}{2\left[w\left(1-f^2\right)-fk_1\right]}+wt\right). \qquad (14)$$

Accept initial conditions:

$$t=0;\quad r=R_П=R-0.5d_E;\quad v_R=v_{RП}=0. \qquad (15)$$

Find the constants of integration:

$$C_1=\frac{\lambda_2}{\lambda_2-\lambda_1}\left[R_П-\frac{g}{w\sqrt{\left(4w^2+k_1^2\right)}}\sqrt{1+\frac{w^2}{\lambda_2^2}}\times\right.$$
$$\left.\times\sin\left(B+\mathrm{arctg}\frac{4fw+k_1\left(1-f^2\right)}{2\left[w\left(1-f^2\right)-fk_1\right]}-\mathrm{arctg}\frac{w}{\lambda_2}\right)\right], \qquad (16)$$

$$C_2=\frac{\lambda_1}{\lambda_2-\lambda_1}\left[\frac{g}{w\sqrt{\left(4w^2+k_1^2\right)}}\sqrt{1+\frac{w^2}{\lambda_1^2}}\times\right.$$
$$\left.\times\sin\left(B+\mathrm{arctg}\frac{4fw+k_1\left(1-f^2\right)}{2\left[w\left(1-f^2\right)-fk_1\right]}-\mathrm{arctg}\frac{w}{\lambda_1}\right)-R_П\right]. \qquad (17)$$

Results of calculations are shown graphically in Fig. 4 and 5. Drum diameter is 0.3 m, blade diameter in the cross section of the drum is 6, blade width is 0.07 m, compost density is 500 kg/m^3, compost turner speed is 0.1 m/s.

Increasing the magnitude of kinematic indicator of the drum operation mode of a compost clamp turner from 60 to 120 through a change in the angular velocity of the drum from 20 to 40 rad/s leads to a decrease in the equivalent diameter of compost particles on the blade from 7.6 to 6 cm. Compost particles motion time prior to leaving a blade – from 0.033 to 0.014 s. In this case, initial angle of throwing and absolute flight velocity of compost particles from the blade increases from 41 to 47 degrees and from 6.3 to 12.6 m/s, respectively. The calculation model developed allows us to set the parameters for loading and unloading the blades of the drum in a wide range of values of design and technological parameters.

A batch of compost is torn off the drum blade (Fig. 6) at speed

$$v=\sqrt{v_R^2+\left(wR\right)^2}$$

at angle:

$$\alpha_i=\frac{\pi}{2}-\varphi_0-wt+\mathrm{arctg}\left(\frac{v_R}{wR}\right). \qquad (18)$$

After separation from a blade, a compost particle is exposed to the gravity force and air resistance force.

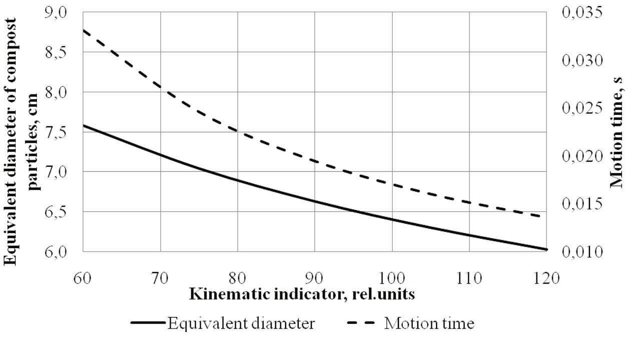

Fig. 4. Change in the equivalent diameter of compost particles on the blade and the time of their motion prior to leaving a blade depending on the kinematic indicator of drum operation mode

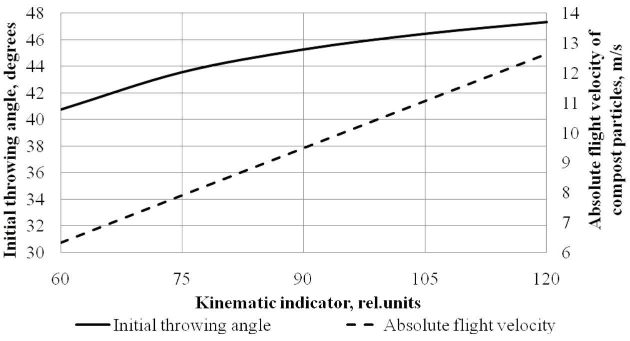

Fig. 5. Change in the initial throwing angle and absolute flight velocity of compost particles from the blade depending on the kinematic indicator of drum operation mode

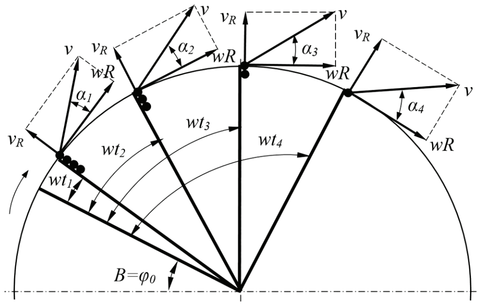

Fig. 6. Calculation scheme to determine a flight trajectory of particles from the first and the last batches of material

Fig. 7 shows dependences of the initial throwing angle and the absolute flight velocity of compost particles. Dependences are given in the order of increasing the radius of loading the compost by a blade. A compost particle is divided into four equal pieces. Graph (Fig. 7) shows that the first compost particle will leave the blade at the lowest absolute flight velocity due to a weak acceleration of particle in motion along the blade and at the largest throwing angle. For each following particle, which has a less value of loading radius, the absolute flight velocity will increase due to the acceleration of a particle in motion along the blade while the throwing angle will decrease.

Trajectories of a compost particle motion without its division to particles and when it is split into four equal pieces are shown in Fig. 8.

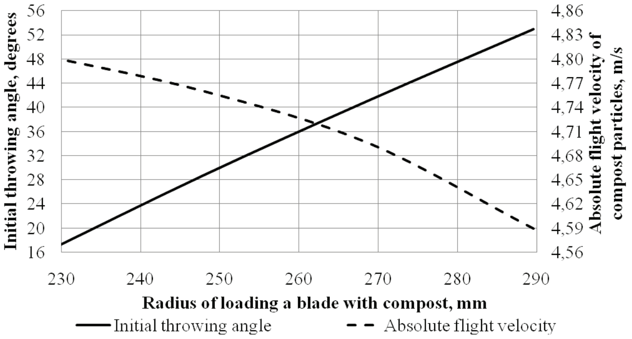

Fig. 7. Dependences of the initial throwing angle and absolute flight velocity of compost particles at increasing the radius of loading a blade with compost for the case when a compost particle is divided into four equal pieces

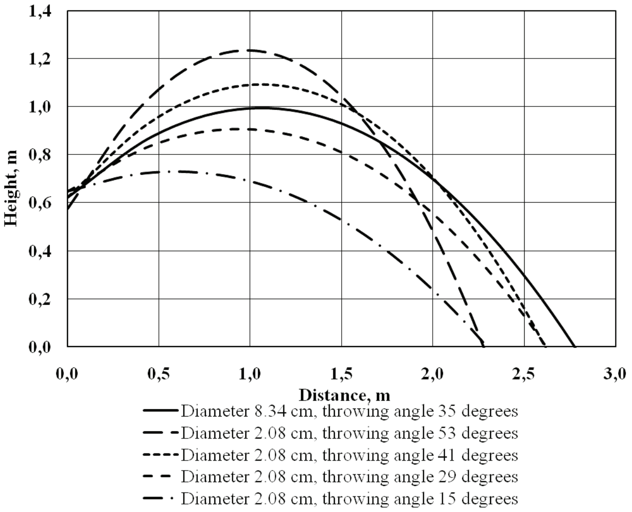

Fig. 8. Trajectories of motion of a compost particle without its division into particles (particle diameter is 7.6 cm) and when it is split into four equal pieces

6. Discussion of results of examining the equipment parameters for the formation of compost clamps

Based on the conducted analysis, one can argue that in order to control a clamp height, it is necessary to change the kinematic indicators of drum performance.

The studies presented could also be used for the substantiation of parameters of aerators with a drum working body.

The research conducted into the character of organic particles motion in the interaction with a drum working body does not allow us to estimate the energy efficiency of its operation.

Therefore, further research should be conducted in the direction of examining the influence of equipment parameters on the reduction in energy costs in the production of compost.

Results of the research reported here theoretically confirmed working ability of the designed equipment; however, it needs to be checked under industrial conditions.

After experimental verification, the analytical models proposed could be used for determining the parameters of working bodies of compost clamp turners and their aerators.

6. Conclusions

1. Developed analytical model makes it possible to set the parameters for loading and unloading the drum blades within the rational values of design and technological parameters. Based on the analysis conducted, it can be argued that in order to control a clamp height, it is necessary to change the kinematic indicators of drum performance.

2. Increasing the magnitude of kinematic indicator of the drum operation mode of a compost clamp turner from 60 to 120 leads to a decrease in the equivalent diameter of compost particles on the blade from 7.6 to 6 cm. This is due to a change in the angular velocity of the drum from 20 to 40 rad/s. Compost particles motion time prior to leaving a blade – from 0.033 to 0.014 s. In this case, initial throwing angle and absolute flight velocity of compost particles from a blade increases from 41 to 47 degrees and from 6.3 to 12.6 m/s, respectively.

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Досліджено причини відмов та значення питомого параметра потоку відмов металевих водопровідних труб. Аналіз статистичних даних щодо відмов дозволив побудувати залежності питомого параметра потоку відмов від діаметра трубопровода. Виконано порівняльний аналіз отриманих даних та розроблені відповідні висновки та пропозиції. Отримані дані корисні для розрахунків надійності систем водопостачання

Ключеві слова: водопостачання, водопровідні мережі, металеві труби, надійність, безвідмовність, причини відмов труб

Исследованы причины отказов и значения удельного параметра потока отказов металлических водопроводных труб. Анализ статистических данных об отказах позволил построить зависимости удельного параметра потока отказов от диаметра трубопровода. Выполнен сравнительный анализ полученных данных и разработаны соответствующие выводы и предложения. Полученные данные полезны для расчетов надежности систем водоснабжения

Ключевые слова: водоснабжения, водопроводные сети, металлические трубы, надежность, безотказность, причины отказов труб

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ESTIMATION OF FAILURE-FREE OPERATION OF METAL WATER PIPES

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1. Introduction

Water supply networks are the most extended water supply system element, and, therefore, the most vulnerable in terms of reliability. Emergency situations in water supply networks lead to many negative consequences for both utilities companies and consumers of water. On the one hand, damaged sections in the existing water supply networks lead to the loss of a valuable resource – water, and additional financial expenses to eliminate accidents. On the other hand, it causes discontent of the population due to the shortfall of water in required amount to meet their needs in a timely manner. No less distrurbing this issue for industrial enterprises when a break in water supply leads to losses due