The design and technological provision of strength and wear resistance of aeroponic installation elements

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Abstract.
The use of modern resource and energy-saving technologies in multifactor technological processes is a promising direction that allows improving the design and technological support of the manufacturing sector in most developed countries. The use of an electrochemical installation - aeroponic installation with automatic control system in industrial processes allows to reduce the consumption of the working solution. It is a more energy efficient process compared to traditional production technologies. The article describes the results of the development and creation of an automatic control system for technological processes in an aeroponic installation. The results of research on ensuring the strength and wear resistance of the elements of the system for supplying the working solution in the form of an aerosol using nozzles are presented.

Keywords: wear resistance, strength, finely dispersed nozzles, titanium nitride, flow turbulization

1. Introduction
At present, the problem of controlling technological processes for processing materials is associated with the need to quickly change the processing modes, which include the electrolyte feed or coolant supply, gap, temperature, strength of electrical impulses, etc.
In the process of removing material from the surface of the workpiece during electrochemical processing, in the case of shape deviations, it becomes necessary to change the magnitude of the current, voltage, and also electrolyte feed [1, 2]. In this regard, the development of special nozzles for turbulization and spraying of a working solution in the form of a fine aerosol into the working area is urgent. And also the development of an automated control program for an aeroponic installation, which will ensure changes in the necessary specified parameters of the technological process, will allow them to achieve their optimal values in terms of strength and wear resistance [3].
The work proposes to use the destructuring of the working solution, which has found wide application in many industrial processes: to improve mixing, initiate the process of turbulence, impart additional internal energy to the solution and better mixing of chemical elements in the working solution during spraying. This process under the conditions of an aeroponic installation will improve the quality characteristics of the aerosol of the working solution, as well as the uniform distribution of substances over the entire volume of the growing tank with fine dispersion and the efficiency of growth processes. An anticorrosive coating, titanium nitride, is proposed to protect against the corrosive effect of the working solution on the nozzle elements.
2. Problem Statement
The research was intended to develop a technological system of a control unit for supplying a working solution using nozzles with a destructor in aeroponic installations for an automated control system with the possibility of preliminary adjustment to specified operating modes.

3. Theory
The basis for the design of an automated control system for an industrial aeroponic installation, which should provide changes to the necessary specified parameters of the technological process, was based on the Arduino UNO board and a solid-state relay control. Proceeding from the necessary operating conditions of the aeroponic installation, the conditions of uninterrupted supply of the working solution during one technological cycle, as well as the quality of the spray within the specified limits were set when changing the processing modes: temperature, flow rate of the working solution, pressure, etc. [4, 5, 6].

Arduino UNO boards for electrochemical processing were chosen due to the convenient implementation of work with the SPI, I2C, UART protocols. When working with these platforms, it is possible to connect power not only through an external power connector, but via USB, while these platforms have a built-in stabilizer and microcontroller. Another advantage of choosing a platform based on Arduino was the presence of a built-in self-healing fuse, convenience and simplicity of programming due to the use of C / C + languages [7, 8]. This programming language has all the necessary tools for developing programs of controlled efficiency for a number of tasks. The software for the automated operation of an industrial aeroponic installation has the ability to display cycles and operating modes in a PC dialog box, and also displays data on switching cycles, which are presented by a pump for supplying a working solution through predetermined cycles, fine nozzles, a control unit for electrical parameters, operating pressure and temperature working solution.

The main feature of the developed software, which will ensure changes in the required specified parameters of the technological process, has sufficient flexibility in managing work cycles and allows you to simulate the conditions of the technological process of processing plant objects (duration of aeration intervals). When developing a schematic diagram of an aeroponic installation and a system for supplying a working solution using nozzles for spraying a solution under the conditions of an aeroponic installation, the possibility of introducing the structural elements of the destructor into the design of the nozzles was considered. Figure 1 shows the technological scheme of the developed industrial aeroponic installation.

![Figure 1. Technological scheme of aeroponic installation:](image)
1 – reservoir with working solution; 2 – check valve; 3 – constant pressure pump; 4 – fine filter; 5 – supporting structure; 6 – valve; 7 – plastic pipe; 8 – nozzles; 9 – growing capacity; 10 – drain collector; 11 – pressure manifold; 12 – current source; 13 – electric generator; 14 – automatic control
unit based on Arduino; 15 – power supply unit for LED strips; 16 – LED strip of blue and red spectra; 17 – fluorescent lamps

The effect of destructuring the working solution, which was taken as the basis for introducing the nozzles into the operating principle, was turbulization - (swirling) of the nutrient working solution flow [9, 10]. The process of turbulization of a fluid flow is a complex movement of a liquid or gas, which consists in the formation of a large number of vortices with different thermodynamic characteristics. Currently, many devices and inventions are known for obtaining flow turbulization in a liquid medium. For example, to swirl the fluid flow, artificial barriers, profiled channels, rotating structural elements in the form of rotors, blades, discs, etc. are used. The created turbulent flows with the help of artificial barriers (protrusions, wire, conical, spherical walls, etc.) are chaotic and do not have a clear direction of flow. Artificial barriers can be used for better mixing of liquid flow layers and increasing the characteristics of heat and mass transfer of the flow, however, they are not suitable for use in an aeroponic installation for growing regenerant plants and obtaining minitubers using a complex working solution composition. In contrast to artificial barriers, profiled channels create a turbulent flow in the fluid flow, while the currents have strictly profiled trajectories, which leads not only to an increase in the characteristics of heat and mass transfer of the flow, but also sets the direction of its movement, and in most cases imparts centrifugal acceleration to this flow. To create turbulent flows, various rotating structural elements are used, which impart centrifugal acceleration to the fluid flow and set a certain trajectory of motion.

Based on the characteristics presented to the flow of the working solution under the conditions of an aeroponic installation for cultivating and obtaining minitubers of potatoes, the selection of a destructor element was carried out, which made it possible to turbulize the flow of the nutrient working solution at the outlet of the nozzles. As a result of the analysis, it was decided to use profiled channels in the design of the nozzles to turbulize the flow of the working nutrient solution. Figure 2 shows a schematic diagram of a one-component nozzle with swirling working solution flow.

![Figure 2](image_url)

**Figure 2.** Schematic diagram of a one-component nozzle with swirling of the working solution flow:
1 – a needle with a bore; 2 – rubber seal; 3 – outer case; 4 – twisting flow sections

The use of nozzles with swirling the flow of the working solution in an aeroponic installation allows obtaining the necessary spray characteristics, while the overall dimensions of the nozzles are not increased and their design is not complicated. The presented characteristics for operation such as the conditions of simplicity and high reliability of the developed nozzles are taken into account.

The titanium nitride (TiN) was chosen as an anticorrosive coating to reduce the corrosive effect of the working solution containing salts and iron chelate. Titanium nitride provides a coating with an even thin protective film of a thinner application for coating nozzles, which practically does not change the size of the flow sections of the finished product and does not wear off during friction. This coating is also distinguished by excellent resistance to aggressive effects of physical and chemical environmental factors, to corrosion and oxidation [11, 12]. However, the anticorrosive coating has the most significant advantages, the key ones of which are: high adhesion to the substrate; high wearing resistance, erosion and corrosion; good conductivity; hardness.
The application of an anticorrosive coating to the manufactured structural elements of the nozzles with an anticorrosive component, titanium nitride, increases the service life and provides an opportunity for cleaning and servicing the nozzles.

4. Experimental results
As a result of the research a technological system for the control unit for supplying a working solution using nozzles with a destructor in aeroponic installations for an automated control system with the possibility of preliminary adjustment to specified operating modes was developed. Analysis of monitored parameters and their number, range (humidity, temperature, pressure, duration of the working solution supply) allows the use of these automation systems in a wide range, and in particular, in industrial aeroponic installations. The developed system for programming the technological process was adapted for plant objects in an aeroponic installation.

As a result of the experiments, a technological scheme of an industrial aeroponic installation with an automatic control unit was designed, that was equipped with an uninterruptible power supply, which made it possible to carry out work in specified operating modes in closed systems. The working solution from the reservoir was supplied using a pump through a pipeline, and then supplied to the growing tank in the form of a fine aerosol using nozzles.

On the basis of the developed design diagram of a sample of fine atomization nozzles with a built-in destructor, a laboratory sample of nozzles was manufactured. The laboratory sample was made according to the stated quantitative parameters: fine atomization from 0.1 to 0.7 mm, maintaining the set temperature from 22 °C to 25 °C with stable irrigation, cyclic spraying of the working solution aerosol, fine aerosol spraying cycle - 2 min, nozzle closing cycle and the aeration process - 8 minutes, maintaining the specified level of hydrogen indicators within (pH 5.6–5.8) when the working solution passes through the nozzles.

In addition, in the inner surface of the nozzles, there was a destructor element in the form of profiled channels for finely dispersed spraying of the working solution in the growing tank of the aeroponic installation. This made it possible to obtain smaller aerosol particles at the same energy consumption as compared to the use of similar nozzles without profiled channels (without flow swirl) for supplying the working solution. Structural elements of the nozzle have the following structural division: body, atomizer, adjusting element (needle), destructor, as well as weight and size characteristics: weight no more than 50 g, size no more than 20 × 20 × 20 mm. The manufactured laboratory sample of nozzles is a metal body with a spray inside.

The sprayer forms the required spray of the working nutrient solution and, together with the adjustable element (needle), will provide the desired aerosol particle diameter for effective mineral nutrition of the root system of potato plants.

When carrying out work in the conditions of an aeroponic installation and the process of corrosion during the operation of nozzles with a working solution, three variants of anticorrosion coatings were chosen that most satisfy the specified operating parameters.

The possibility of using an anticorrosive coating of nozzles with tungsten carbide has a significant disadvantage for use in an aeroponic installation due to the possibility of penetration of tungsten carbide nanopowder into the solution, and then into the cells of plant organisms and minitubers, which will become toxic to living organisms, as well as the higher cost of tungsten carbides and a decrease in economic efficiency.

Titanium carbide is mainly used for spraying metal cutting tools to improve their strength characteristics. This anticorrosive coating has higher strength characteristics, however, according to the main necessary anticorrosive characteristics it corresponds to titanium nitride, but the final application of this coating is more expensive than spraying titanium nitride on the working surfaces [12].

The processes of chrome plating and nickel plating, as a rule, are carried out by electrochemical deposition methods with a sufficiently high thickness of the applied coating from 1 to 50 microns, which has low adhesion to the substrate materials, which leads to deformation, the appearance of microcracks and the destruction of the protective layer during operation. A significant disadvantage of applying chromium coatings is the presence of tensile stresses in the deposited layer, which increase in
proportion to the thickness of the chromium layer. The presence of tensile stresses in the applied chromium coating leads to chrome flaking during operation, and also leads to a decrease in the fatigue strength of parts.

The process of plating by nickel plating has significant drawbacks for using as an anticorrosive coating of nozzle elements interacting with a nutrient working solution - a high susceptibility to sulfur and ammonia compounds, as well as the likelihood of peeling and washing off of the deposited coating over time under the influence of liquids.

According to the conducted analytical review on the properties of anticorrosive coatings for use in the operating conditions of an aeroponic installation, the titanation process was chosen. On the surface of the nozzles interacting with the working raster containing corrosive substances, an anticorrosive coating - titanium nitride was applied using an ion-plasma spraying device NNV-6.6-I1 (Fig.3). This coating will eliminate the corrosive effect of the working solution and increase the operating time and labor costs for replacing the nozzles during the technological cycle.

5. Discussion

The technological system of the control unit for supplying the working solution using nozzles with a built-in destructor is industrially applicable for an automated control system. A prototype of the installation was made, copyrights are protected by Russian Federation patent [13].

Providing the required specified sizes of aerosol particles of the working solution in the aeroponic installation corresponding to the phases of plant growth (during the growth period, the formation of stolons, microtubulation) leads to a more efficient assimilation of nutrients by the root system of plants in comparison with hydroponic installations of various types. The ability to regulate the particle size of the working solution using the developed nozzles allows for the acceleration of metabolic processes, plant growth and development, as well as stimulation of the formation of environmentally friendly minitubers all year round under the conditions of an aeroponic installation. The advantage of using nozzles with a built-in destructor for swirling the working solution flow in an aeroponic installation eliminates the need to replace nozzles at different stages of plant growth, due to the possibility of adjusting the size of aerosol particles. This leads to a decrease in labor costs and an increase in economic feasibility, and also simplifies the operation of an aeroponic installation in comparison with existing analogues. The choice of anticorrosive coating of titanium nitride was the most satisfactory to all requirements as it is the most effective and resistant to aggressive effects of the alkaline medium of the working solution when it is exposed to the working solution under the conditions of an aeroponic installation. The anticorrosive coating with titanium nitride allows to increase the service life of the developed nozzles, reduces the likelihood of clogging of the nozzles as a result of corrosion from the action of macro- and micro-salts of the working solution.

The use of non-metallic (polypropylene, polyurethane) materials for the manufacture of nozzles in an aeroponic installation has a significant drawback, which consists in chemical interaction with the working solution and the possibility of destruction during operation. The disadvantages of non-metallic materials are structural weakness for cheaper plastics and high cost performance for more expensive plastics. The use of stainless steel for the manufacture of nozzles has the following disadvantages: high cost of raw materials for manufacture, the need for more expensive tools.
The designed control unit can be used in industrial installations and cultivation of potato micro-tubers in large areas. Creating microclimate for plants, which includes feeding and aeration of the root system will have a positive impact on the growth of potato plants, as well as obtaining mini tubers.

6. Conclusion
The use of the developed control unit for the parameters of the working solution supply in an industrial aeroponic installation and fine atomization nozzles makes it possible to simplify the technological process. Due to the absence of the need to replace the nozzles in the cycle of work, the labor intensity of the technological process is reduced. By the use of the automated work, the productivity of the structure is increased compared to traditional technological processes.

The use of the developed fine atomization nozzles with a built-in destructor and anti-corrosion coating of elements interacting with the working solution in aeroponic installations will allow: more economical use of the nutrient working solution per unit area; to simplify the technological process for the production of potato mini-tubers; increase the service life and operation of the injectors; to produce virus-free mini-tubers of potatoes with a lower cost compared to the use of similar nozzles from other manufacturers.

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