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Substantiation of the device for electro-hydraulic treatment of solutions

A Belov[1], A Vasilev[1], A A Musenko[1], I G Ershova[1] and D A Budnikov[1]

[1]Federal Scientific Agroengineering Center VIM, 1st Institutsky travel house 5, Moscow, 109428, Russia

E-mail: sofronich.bel@mail.ru

Abstract. Relevance of developing the equipment for electro-hydraulic treatment of water and its solutions was substantiated. The device that is one of the electro-hydraulic spark gap installation components has been developed in order to eliminate the drawbacks of similar devices used. The application field of the device for electro-hydraulic treatment of solutions is crop production in agriculture. Electro-hydraulic treatment can be used to produce fertilizers in conditions of irrigation of greenhouse vegetable crops in personal subsidiary and peasant (farmer) farms. The installation, in addition to the cylindrical tank, contains a voltage source, a high-voltage transformer, an autotransformer, energy storage devices, rectifying cells, start-control devices and means of control and measuring. Electrodes are installed in this device, one of which has a technical scientific novelty. The tip of the negative electrode is hemispherical, which allows increasing the stored energy in the capacitor, to increase it in the discharge channel, increasing the length of the spark discharge in the liquid. The model of the device has been developed in order to substantiate the design parameters and operation modes. The developed electric diagram required for installation, runup and control of technological modes of electro-hydraulic impact on liquid media is shown. Actual model of the device is presented in photo content. The perspectivity of studying the electro-hydraulic effect is determined.

1. Introduction
Production technologies of various materials with the required properties using the electro-hydraulic (EH) effect have been developed for a long time [1-3]. The advantages of these technologies are high process efficiency and obtaining an environmentally friendly product with minimal negative impact on the environment. Using cheap raw materials can significantly improve the quality and economic indicators of agricultural enterprises. Currently, there is an embrace of the application of electro-hydraulic technologies in agriculture and national economy. This is due to the fact that in recent years in many countries there has been a tendency for soil fertility decrease. The topsoil is most susceptible to pollution, thereby it loses the ability to restore properties, as well as the fertility regeneration. The applied doses of mineral and organic fertilizers do not compensate for the loss (at harvest) of the nutrient yield in the soil. It can also be used effectively in greenhouses and for electro-hydraulic soil disinfection with simultaneous fertilization [4-6]. Electro-hydraulic processing of peat, including crushing, sequential settling and drying, also has great prospects.

2. Materials and methods
The process of electro-hydraulic tillage is the most theoretically studied, unlike water treatment. During electro-hydraulic processing, most of the soil is ground to particles with a diameter of 0.002 mm. The

size of the resulting surface becomes even larger than size of the most highly dispersed silty fractions of ordinary soil. This contributes to the cost-effective transfer of the nitrogen and phosphorus, trace elements contained in the soil and air, to the solution. It can be easily absorbed by plants. For a sharp increase in the content of nitrogen released from the soil and air after electro-hydraulic treatment, it is advisable to sow the soil with various nitrifying and ammonifying bacteria strains using the so-called bacterial explosion capabilities [7]. It is proposed to apply electro-hydraulic treatment of water and its solutions, using the main advantages of the tillage results. The principle of electro-hydraulic effect is implemented in electro-hydraulic technologies. The electrical energy is transferred into mechanical energy when an electrical discharge appears [8]. In order for a discharge to appear, a current pulse with a sufficient edge steepness of the front up to $2 \cdot 10^{11}$ A/s and an absolute value of current up to 250 kA are required. There are only a few stages of discharge occurrence. First, the occurrence of a conductive channel between the electrodes, then the release of energy in the discharge channel, and the final stage, where all electrical processes end [9]. In the case of electro-hydraulic effect, physical and chemical processes take place. The main problem for watering plants is to obtain a nutrient solution with certain parameters. Water is part of the plant body, mineral salts that enter the plants through the root system are dissolved in it. The demand for water varies depending on the species, variety, phase of plant development. In order to obtain a nutrient solution, it is necessary to take into account the chemical composition of water.

The relevance of modeling the technical means for implementation of the electro-hydraulic method is revealed in the paper in terms of determining the parameters that cannot be measured by existing methods and technical means. The technical device for the implementation of electro-hydraulic technologies is modeled in the graphic editor Kompas-3D. The adherence of the dimensions and technical features of the structure required to withstand the necessary electro-hydraulic processing technological modes of agricultural raw materials is taken into account. Thus, the benefits of using a hemispherical electrode developed by authors is substantiated. The electro-hydraulic device was developed, which relates to crop production in agriculture and can be used to produce fertilizers in irrigation conditions of greenhouse vegetable crops in personal subsidiary and peasant (farmer) farms.

3. Results

An electro-hydraulic device is known, which consists of a flat negative electrode immersed in a conductive liquid and a positive rod-like electrode, to which a metal plate is electrically connected. The disadvantage of this design lies in the possibility of regulating the spark discharge length initially only in the decreasing direction of it due to the plate approaching the negative electrode. This entails an increase in losses and, as a result, decreases the length of the spark discharge in the liquid. And only then, due to the plate rotation from a position parallel to the electrode plane to a position perpendicular to the latter, a sharp losses value decrease and, consequently, a spark discharge length increase is achieved. Therefore, the authors have developed a device for electro-hydraulic water treatment with the original negative electrode design, which will be described in more detail later in accordance with the model presented in Figure 1.

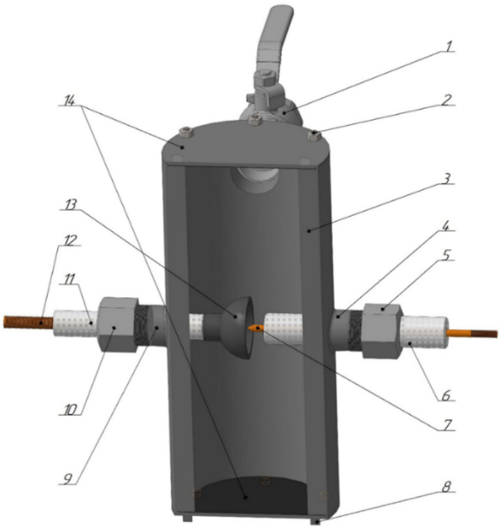

Figure 1. Model of the device for electro-hydraulic processing of solutions. 1 – valve; 2 – bolt clamp of the top cover; 3 – casing; 4 – positive electrode assembly ferrule; 5 – positive electrode nut plug; 6 – positive electrode insulator; 7 – positive electrode peg; 8 – bolt clamp of the bottom cover; 9 – negative electrode assembly ferrule; 10 – negative electrode nut plug; 11 – negative electrode insulator; 12 – negative electrode peg; 13 – hemispherical tip.

The device has a cylindrical shape, the casing 3 serves as a container for the treated liquid drawing, which is an aqueous solution. Positions 2, 8 and the cover 14 are bolted to the top and bottom of the device. The bottom cover is made of metal. The top cover can be made of transparent organic glass for visual assessment and observation of the process. The tank contains inlet and outlet nozzles for supplying and removing the treated liquid using valves 1. Functionally, the device can be used in various technological modes, from periodic to continuous, depending on the conditions of the irrigation process. The device has technological openings, in which ferrules 4 and 9 are installed for fixing high voltage pulse electrodes in accordance with Figure 2.

Figure 2. The actual model of the device for electro-hydraulic treatment of solutions

Positive and negative electrodes are structurally manufactured from a copper core with an insulator, the material of which must be a dielectric. Electrodes are held, embedded and sealed with nut plugs 5 and 10. It is advisable to use fluorine-containing polymers as insulators 6 and 11 in accordance with the voltage level of more than 15 kV. The positive electrode peg 7 has a cross section of 5 mm, the tip has the needle shape with a minimum area. The negative electrode peg 12 has a cross section of 10 mm. The negative electrode has a similar design with some functional and structural distinctive features regarding the positive electrode. This is an adjustment of the air gap between the electrodes, in which a spark occurs, due to the bowl-shaped hemispherical design of the working tip, a hemisphere-shaped disk 13. This allows focusing and compacting the electromagnetic field, collect the antinodes of the modes, which means increasing the electromagnetic field intensity per unit area. Therefore, this allows reducing the dissipated energy in the electrode plane. The plane of the positive electrode tip should be level with the plane of the hemispherical tip edges of the negative electrode to form a maximum power discharge with minimum voltage values in accordance with Figure 3

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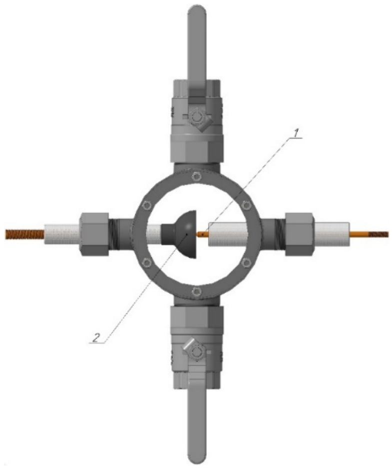

Figure 3. Model of the device for electro-hydraulic treatment of solutions (top view): 1 – positive electrode; 2 – negative electrode

The authors are developing an electrical circuit diagram of electro-hydraulic processing. The effect on water from various sources is used as an example in accordance with Figure 4. Distilled, tap, river, lake and sea water is used as raw materials.

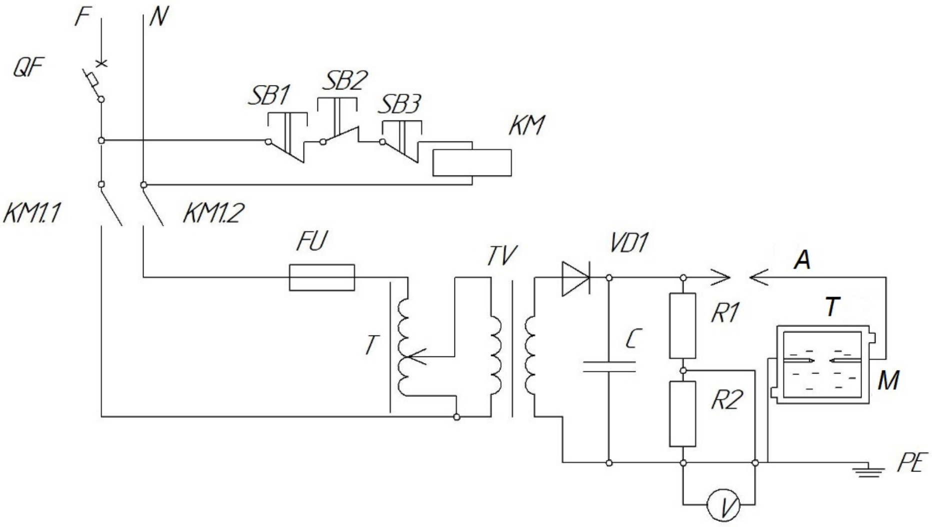

Figure 4. Electrical block schematic diagram of installation for electro-hydraulic treatment of solutions.

Power is supplied to the circuit using a KM magnetic starter, which closes KM1.1 and KM1.2 contacts. In order to close the contacts KM1.1 and KM1.2, it is necessary to use a control system, which consists of a QF automatic circuit breaker acting as a limiting device for opening the circuit when the fault current passes. There is a start button SB1in the control system, which sends a signal to the magnetic starter. It closes the contacts KM 1.1 and KM 1.2. In turn, the stop button SB2 serves as a control element that opens the contacts KM1.1 and KM1.2, if necessary. Also, the control system includes a lock SB3, locking the contacts KM1.1 and KM1.2 in a certain position.

The installation of the electro-hydraulic discharge device includes following components:

- single-phase transformer TV;
- rectifying diode VD1;
- high voltage capacitor C;
- voltage divisor assembled on resistive impedances R1, R2;
- voltmeter V;
- grounding PE;
- the main spark gap M;

- device (tank) with liquid T;
- additional spark gap A.

TV – single phase step-up transformer for converting electrical energy. The transformer has two windings of low 220 V and high voltage 50 kV.

VD1 – rectifying diode is needed to convert AC to DC and to discharge/charge a capacitor.

C – high-voltage capacitor storing energy that is released in the spark gap.

R1, R2 – resistive divisor lowers the voltage in order to connect a voltmeter.

V – voltmeter for measuring the voltage in the electrical circuit.

PE – device protecting a person from electric shock.

M – a spark discharge is formed in the spark gap, due to which a water hammer occurs.

T – the device (tank) is necessary for the formation of electro-hydraulic hammer, the copper electrodes are located there.

A – the forming gap is needed to measure the voltage on the secondary winding.

Before starting, it is necessary to verify the absence of voltage across the installation and inspect the installation for defects and faults. After performing pre-launch maintenance, it is necessary to adhere a following number of measures and requirements for safe operation of the installation for electro-hydraulic treatment of solutions:

1) the QF automatic circuit breaker is turned to the ON position;

2) start is performed by pressing the button SB2, which tunes on the magnetic starter KM, closing the contacts KM1.1 and KM1.2;

3) the SB3 lock is moved to the operating position;

4) as a result of the voltage supply, the TV transformer starts to convert energy;

5) VD1 alternating current is converted to direct current while passing through the rectifying diode;

6) the charge accumulates when a constant voltage is applied to the plates;

7) the capacitor is the source of the accumulation and release of discharge energy in this circuit. After the capacitor C is fully charged, it will begin to discharge into a circuit. When a certain potential is reached, an air gap A is punched; the energy stored in the capacitor transfers to a spark gap concentrated in the operating device (tank) fluid P, thereby creating an electrical pulse having a sufficient discharge power [10];

8) the discharge occurs in the operating device (tank) between the electrodes, accompanied by the occurrence of a voltaic arc;

9) pops appear, accompanied by a splash and movement of water.

The energy losses spent on the discharge channel formation negatively affect the result of the process. It is acceptable to add pulse energy to eliminate these losses, but it affects the service life of the electrode elements, the insulation of the electrodes in particular. This process of chosen capacitance and voltage is resumed at a frequency that depends on the selected power of the transformer.

4. Discussion

The technological process of electrohydraulic treatment of the solutions occurs in the following manner. It is substantiated by the example of tap water. The device is filled with tap water to a level that should be higher than the electrodes by more than 50 mm, depending on the processing conditions. Receiving an electrical discharge at a voltage of 30 kV at a forming gap of 10 mm is detected. It has been stated that the use of a flat disk or the tip edge of a negative electrode does not generate a spark using the same modes of voltage and a forming gap. It is necessary either to increase the voltage or to increase the gap. An electro-hydraulic effect is observed, that is, there are oscillations and movement of water, which is accelerated as a result of the formation of cavitation pockets when ultrahigh hydraulic pressures occur in the discharge zone.

Periodically, a water portion supplied to the device is processed by electro-hydraulic action. For 1 minute, 5 liters of tap water are processed in order to achieve the following desired results:

- as a result of electro-hydraulic exposure to fluids with ionic conductivity, the pathogenic microflora in it decreases, the nutrient digestibility of the aquatic environment increases, the nitrogen content

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increases, thus the technology is universal, that is, it is possible to perform several operations with a single device.

The surface area of the negative electrode hemispherical tip is 1700 mm^2. The maximum intervals of the operating and the forming gaps are 5-20 mm, and the operating voltage is up to 15-50 kV in tap water with a discharge capacity of 0.05-0.2 μF. Plant capacity reaches 300 l/h.

There are only two types of ions in the water where the discharge occurs. Negative ions play a major role in the development and existence of the discharge. The greater their concentration, the further the streamer grows. Along with this, the length of the discharge channel and, accordingly, its surface and the mechanical efficiency of the discharge increase.

Positive ions do not participate in the growth of streamers and are useless for the discharge development process. Therefore, in order to increase the discharge efficiency, it is necessary to create conditions under which mainly negative ions would form in the operating gap and impede the formation of positive ions. Such conditions can be created by changing the areas in contact with the water of the electrodes.

The significant field asymmetry between the electrodes is created. The surface of the positive electrode that comes into contact with water is reduced as much as possible to a point with a diameter of 2-3 mm. The active surface of the negative electrode increases substantially to dimensions limited by the size of the working chamber. The diameter of the negative electrode of the working body in the device equals 20-60 mm. As a result, the number of negative ions sharply increases and a negative space charge arises between the electrodes from these ions, which give up their electrons to the streamer channel, which grows over considerable distances.

The electro-hydraulic hammer process is divided into 5 stages corresponding to the pressure zones according to the generalized and averaged data of physico-chemical phenomena:

Stage 1. Spark discharge.

Stage 2. The material breaks down into dispersed parts. The fluid acquires the properties of a solid elastic body.

Stage 3. The clinging of metals occurs. The fluid is in a solid elastic state.

Stage 4. There is an emission of particles due to a powerful pushing action. The fluid is in an elastic body state.

Stage 5. The pressure decreases with distance from the discharge center. Large volumes of fluid move.

EH technologies use high-voltage pulsed power sources with capacitive storage. The discharge circuit of an RC generator includes consistently connected capacitance C, inductance L, which consists of load inductance, connecting wires and internal drive inductance, and resistance R, which includes the load resistance, connecting wires and internal resistance of the drive.

If the parameters of the discharge circuit are linear, then the transition process can be described by known equations. The type of discharge depends on the coefficient γ, which depends on the active, reactive resistance and capacitance. If ($\gamma < 1$), then the discharge will be oscillatory, in the case with ($\gamma > 1$) the discharge will be aperiodic and it will be critical at ($\gamma = 1$). Aperiodic discharge is typical mainly for electro-hydraulic technologies.

Energy release during the electro-hydraulic effect occurs on the active resistance of the circuit, which is close to critical. The main factors affecting the occurrence of electro-hydraulic effect are the amplitude, steepness of the pulse edge, the shape and duration of the electrical impulse.

The electrical parameters required for EH processing of various organic structures were established experimentally.

It was established experimentally that the following operating modes of installations are possible when processing the peat pulp:

- hard – $U > 50$ kV; $C < 0.1$ μF;
- medium – 20 kV $< U < 50$ kV; 0.1 μF $< C < 1$ μF;
- soft – $U < 20$ kV; $C > 1.0$ μF.

The discharge duration at different stages for different processing modes has been established:

1. Predischarge stage; hard 0.000003-0.3 μs; medium 0.03-30.0 μs; soft 3.0-300.0 μs.
2. Forward edge; hard 0.000005-0.05 μs; medium 0.005-5.0 μs; soft 0.5-50.0 μs.
3. Back edge; hard 0.000015-0.15 μs; medium 0.015–15.0 μs; soft 1.5-150.0 μs.
4. The subsequent half-waves; hard 0.00005-0.5 μs; medium 0.05-50.0 μs; soft 5.0-500.0 μs.
5. Waning; from few seconds to many hours, days.

Electro-hydraulic water treatment requires little energy and the necessary electrical parameters are within the following limits: U = 15-50 kV; C = 0.05-0.2 μF;

There are following requirements when crushing organic materials and processing plant and animal feed: U = 20-70 kV and C = 0.1-0.6 μF.

The efficiency of EH processing is influenced not only by the absolute values of the electrical parameters, but also by their interrelation. The magnitude of the voltage determines the length of the discharge channel, the capacitance determines the diameter of the channel. The capacitance increase leads to the increase of pulse energy and the amplitude of the current at a constant voltage. The discharge is shorter in the case when voltage increases, an increase in the capacitance leads to an increase in the duration of the discharge. The efficiency of the discharge increases by reducing the active and inductive resistance of the circuit.

EH effect is the more effective, the greater is voltage level of the pulsed currents generator and the energy introduced into the operating gap. It is also more effective if the pulse edge is steeper and the pulse duration is shorter. Therefore, the main principles of creating a laboratory installation will be as following:

– the optimal type of a high-voltage pulsed current source, providing all the necessary EH processing modes;
– resistant (to erosion) electrode design;
– independent adjustment of output parameters.

The forecast for the relevance of the proposed project.

In Russia, the greenhouse vegetable complex of year-round use in the 3rd (middle) light zone in block or hangar greenhouses requires 20 l/m^2 of irrigation in average indicators of winter-spring, autumn and transitional revolutions per sprinkling. The sprinkling intensity is no more than 1 l per 1 m^2/min at the rate of 5 l/m^2 for cucumber and 15 l/m2 for tomato. The 2 times a week average irrigation frequency is adopted. Overall, 2080000 l of nutrient solution per year are required for every 1000 m^2 of area. For a greenhouse plant with small production capacity and 3000 m^2 greenhouse area, 6240000 l of nutrient solution per year is required. Thus, the required number of electro-hydraulic units with a design capacity is three. Considering the approximate total area of greenhouses in greenhouse complexes, which is more than 2000 hectares, the forecast for the demand of serial batch production of the electro-hydraulic unit is 10 pcs.

5. Conclusions

The developed device for the realization of electro-hydraulic effects on solutions in order to activate water and its solutions is substantiated. The arguments in favor of using a hemispherical tip of the negative electrode are the required lower voltages during discharge formation of the same length. The design parameters of the device are shown as a model in a graphic editor for testing modes. The actual model of the device is presented in the form of photographic materials. Along with this, the promising application areas for electro-hydraulic technology, such as electro-hydraulic tillage in stationary and field conditions in order to obtain digestible forms of fertilizers are determined.

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