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DEVELOPMENT OF ELECTRICALLY DURABLE WORKING CHAMBERS, EXCLUDING SPARK BREAKDOWN DURING PULSED TREATMENT OF LIQUID MEDIUMS

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Abstract- This article is devoted to energy-efficient and environmentally friendly methods of treatment liquid mediums, including fluid food products, using high-voltage impulse exposure on treated object and elaboration of working chambers with long-term electrical strength to achieve this goal. At the same time, such factors as development of generators of high-voltage pulses of nanosecond duration, corresponding electrode system, excluding spark breakdown in the treated medium, active effect of pulse fields on the membrane of microorganisms, contained in the food product, ensuring long-term storage of products and preserving their biological value are taken into account. All these factors are considered in this article and calculation and coordination of parameters of energy source and treated medium, design of working chamber, excluding spark breakdown of the water gap, is given. This technology can serve as the basis for electro pulse treatment of water-containing mediums with strong electromagnetic fields instead of existing more energy-intensive and environmentally unsafe methods.

Keywords: Energy-efficient method, Pulsed field, High Voltage equipment, Nanosecond Pulse, Pulse Voltage Generator, Pulse Duration, Electrode System, Working Chamber, Liquid Food Products, Electric Pulse Treatment, Environmentally Friendly, Disinfection, Microorganisms, Cell, Biological Value, Thermal pasteurization, Sterilization.

1. INTRODUCTION

Currently, in many technological processes, innovative methods of treatment various mediums with strong electric fields are being introduced with the aim of modifying, activating and cleaning them from various kinds of contaminants, which successfully replace the known energy-intensive and environmentally unsafe technologies [1-8]. In this context, along with existing electric-discharge treatment methods at industrial frequency, elaboration of more energy-efficient high-frequency methods and their further application in industrial production are of great interest to researchers and specialists in this field. Applications range for strong electric pulsed fields is very wide. To achieve this goal and comprehensive solution to the problem, it is necessary to take into account parameters of all connecting elements of installation, from high-voltage part to measuring one, including methods to ensure the uninterrupted operation of all its units. Matching parameters of energy source with load characteristics (treated medium with biological cells contained in them, working chamber, design of electrode system, etc.) are important point in development of high-voltage equipment for specific technological purpose. It should be noted, that the main element of any high-voltage pulse installation is energy source - pulse voltage generator [9-11]. Continuous improvement of designs of its individual units in order to optimize the most efficient operating modes of generator and maximum application of energy to load is necessary requirement, when creating new equipment. Methods for calculating and improving the basic electrical pulse circuits of voltage generators and their individual units. are considered in detail in articles [12-14].

This article is devoted to elaboration of energy-efficient high-voltage installation for electric pulse treatment of fluid food products by environmentally friendly methods (instead of existing technologies of thermal pasteurization, sterilization, etc.) in order to decontaminate them from pathogenic microorganisms, contained in them, prolong terms of their storage and improvement of their organoleptic properties [15, 16].

2. EXPERIMENTS AND DISCUSSIONS

For research, we have developed high pulse voltage generators with alternating electrical parameters, using high-voltage step-up transformer of TVO 140 type of industrial frequency. Generator circuits were assembled, using pulse capacitors of KVI-3 modification of various values and low-inductive resistors - R = 10 kΩ. All connections were made, using strip lines to avoid inductive losses. Main electrical parameters of generator (voltage, charging capacity) varied within 40-100 kV, 0.1 nF - 1 μF, respectively. Pulse parameters (front, duration), depending on parameters of discharge circuit, varied in range of 8 ns - 28.7 μs and 14 ns - 700 μs, respectively. It should be noted, that when choosing parameters of individual elements of generator, one should also take into account geometric dimensions of biological cells, undergoing inactivation.

Before starting process of electronic treatment, entire technological path along which treated medium moves is undergone to thorough disinfection from pathogenic microorganisms by chemically active matters. After that, entire tract is washed with hot water. It should be noted that materials of tract connecting elements are compatible with treated food products. Upon completion of preliminary disinfection of entire technological path, volume of treated food product is entered into system, which is driven by pumping systems. Figure 1 shows process chain of movement of liquid food product throughout the tract, from initial to final link.

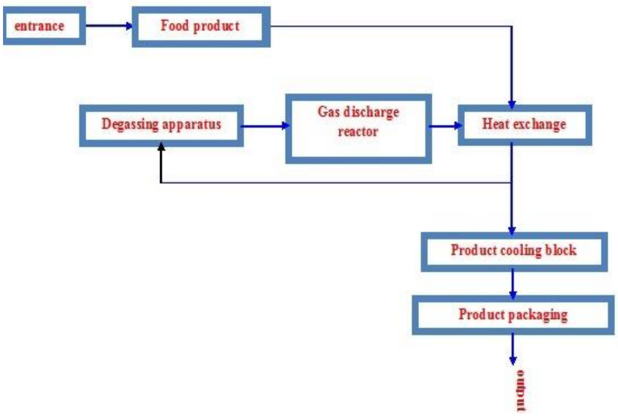

Figure 1. Movement scheme of fluid food products in disinfection technological process from pathogenic microorganisms

As can be seen from diagram, initial food product first enters the heat exchanger for heating. Then it follows to degassing apparatus, in which it is freed from gas inclusions, which significantly reduce breakdown field strength of treated product. After this operation, medium is entered to reactor, where it is electronically treated by strong electric-pulse fields of nanosecond duration. This ensures a high pulse repetition rate (above 100 Hz).

To prevent excessive heating (above critical temperature) of product in reactor, "plane-plane" electrode system [17] with uniform distribution of electric field is used to whole treatment of product without formation of spark channels (Figure 2).

Product in discharge chamber heats up to 10 °Celsius. Then treated product is sent again to heat exchanger. Note, that this process is repeated with certain frequency until medium is heated to temperature slightly higher than critical one, at which life of pathogenic microorganisms is suspended. Critical temperature is in range ~50÷65 °Celsius, depending on type of microorganisms.

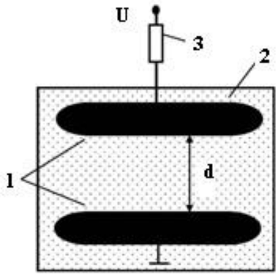

Figure 2. Electrode system "plane - plane": 1 - metal electrodes; 2 - working chamber with fluid food product; 3 - current-limiting resistor; d - interelectrode distance

It should be noted, that with such heating of product its biological value is preserved. Gradual heating of product in reactor promotes transfer of heat to remaining elements of path and to heat exchanger. After heating medium to critical temperature, product is entered the cooling unit. After that, a new portion of food product enters the heat exchanger, which is heated by heat transferred by previous portion. Thus, an energy-efficient heating mode and treated initial food product is achieved with the least energy consumption. After cooling, the treated product is sent for packaging in bags, bottles, etc.

Main feature of this technology is presence of high electric field with strength ~100 kV/cm. It is due to such strong field that temperature of the treated product increases by several degrees, from pre-critical to super-critical. In this case, all pulse energy is converted into heat and contributes to slight heating of product after heat exchanger. In this regard, specific energy consumption is sharply reduced, assessment of which can be estimated by following expressions:

$$W_1 = \frac{Q}{m} = C_t \cdot \Delta t^0 \quad (1)$$

$$W_2 = \frac{Q}{V} = p_m \cdot C_t \cdot \Delta t^0 \quad (2)$$

where, W_1 and W_2 are specific energy consumption per unit mass and unit volume of the treated product respectively; Q is amount of heat received by the body of mass m with increase in its temperature by Δt; C_t, V and ρ_m are specific heat, volume and density of treated product respectively.

Now, let us estimate values of specific energy consumption during electro pulse treatment of liquid food products and power of source of high pulse voltage.

For example, in case when liquid product is water or with high water content with specific heat C_t = 4.19 kJ/(kg.deg), specific density $\rho_m = 10^3$ kg/m^3 and Δt= 5 °C, W_1 = 5.8 kW.h/t, W_2 = 5.8 kW.h/m^3, which is 2 times lower than during thermal pasteurization or sterilization.

As for source power for conducting experiments, it is necessary to take into account performance of installation, i.e. movement speed of liquid product along production line, ensuring its heating in reactor within Δt = 5 °C. For example, suppose that performance of high-voltage installation is P_V = (1000-2000) l/h. Then, power of high-voltage source can be determined by following formula:

$$N_{average} - W_2 \cdot P_V \quad (3)$$

As can be seen from formula, to increase performance of high-voltage installation, an increase in source power is required.

And now (according to following formulas) we can calculate necessary number of pulses n_i for electronic treatment of liquid products in reactor at known installation parameters, such as: treatment time in reactor - t_{tr}, installation’s productivity P_V, reactor volume V_r and electrical parameters of energy source: average power N_{av}, voltage U, current I, pulse duration t_i and pulse repetition rate f_i:

$$n_i = t_{tr} \cdot f_i \quad (4)$$

$$t_{tr} = \frac{V_r}{P_V} \quad (5)$$

$$f_i = \frac{N_{av}}{U \cdot I \cdot t_i} \quad (6)$$

With the following calculated installation parameters: N_{av}=5.8 kW, U=100 kV, I=1 kA, t_i=350 ns, V_r=10^{-2} l, P_V=2000 l/h (~0.55 l/s) we get: f_i=140 s^{-1}, t_{tr}= 1.8×10^{-2} s, t_i=2.5. Thus, during product treatment in reactor, from 2 to 3 nanosecond pulses are affected on it, which increase temperature on Δt=5 °C and cause its completely disinfection from pathogenic microorganisms. It should also be noted that with decrease in pulse duration, their repetition rate and number of pulses are increased too.

Specific energy consumption is associated mainly with heating of treated liquid product in reactor. Lower the heating temperature in working chamber, the less product is exposed to strong electric pulsed fields. Preliminary heating of product (to reactor) occurs due to heat exchange of new product batch with the last electronic treatment. How effective is heat transfer process, less will be specific energy consumption for heating product to critical temperature. Studies show that specific energy consumption is approximately ~5 kW.h/m^3. On the other hand, excessive heating of product in process path before it enters reactor can contribute to deterioration of its polyphenol properties and loss of its biological value. Therefore, in order to maintain useful properties of treated product, it is advisable to slightly increase specific energy consumption for electric pulse treatment in working chamber in order to obtain biologically valuable product at the output.

When electro pulse treatment of liquid food products, magnitude of electric field strength, as well as its energy released in product is important. Moreover, as noted earlier, final temperature of the liquid product, which ensures its complete inactivation from pathogenic microorganisms, plays an important role. It should be noted, that this temperature is in any case lower than temperature of thermal pasteurization. Typically, electric field during electro pulse treatment reaches 100 kV/cm and above at pulse repetition rate above 100 Hz.

When developing electro-pulse technology, sizes of inactivated microorganisms and their concentration per unit volume in product should also be taken into account. As known, in structure of microorganism there is outer shell - membrane with very low electrical conductivity (~10^{-7} Ohm.m). Depending on concentration of microorganisms and their density, electrical conductivity of entire product and energy power released in it will change. For example, in case of disordered (loose) arrangement of microorganism cells in liquid product volume, allocated power is inefficiently distributed throughout product, goes to its heating and is quite large (tens of kW).

Situation is different with ordered (tight) arrangement of microorganisms in volume of liquid product. In this case, resistivity of entire product will be determined by electrical conductivity of membranes of microorganisms, which is several times less than product’s one. In this case, heating of product itself will be significantly reduced. So, when high pulse voltage is applied to liquid food product, biological structures (microorganisms) located in its volume will be polarized in direction of electric field with formation of bias currents and electrical conductivity. In this case, energy of strong electric pulse field will be released in liquid product itself.

In any case, and with dense and loose arrangement of microorganisms in product volume, magnitude of electrical field strength induced on the cell membrane will depend on its size. With increase in size of biological structures, potential induced on cell’s membrane will increase accordingly.

Design of reactor with symmetrical “plane-plane” electrode system for electro pulse treatment of liquid food products is shown in Figure 2. Reactor vessel is made of Plexiglas, and flat electrodes are made of food grade stainless steel. Location of electrodes in reactor (vertical or horizontal) is of particular importance. To prevent current shunting in warmer part of treated product with vertical arrangement of electrodes, it is advisable to arrange electrodes in horizontal plane, shown in Figure 3.

Inner surface of reactor is oval to increase electric strength of working chamber and prevent formation of spark channels during product treatment. As can be seen from figure, reactor consists of two volumes in which movement direction of treated medium is constantly changing. This, in turn, improves process of microorganism’s inactivation, since when movement direction of product changes, microorganisms change their orientation in accordance with electric field vector. Reactor for electronic treatment of liquid food products in technological scheme of high-voltage equipment is load of high pulse voltage generator. Output voltage of generator and parameters of pulse can vary in accordance with task.

As conducting experiments show, to ensure uniform treatment of liquid food products throughout whole volume, impact pulses must be in nanosecond range. We have chosen following generator parameters: output voltage - 80 kV, front and duration of generated pulse - 20 ns and 350 ns, respectively, pulse repetition rate - above 100 Hz. With such parameters of pulsed electric field, maximum inactivation of microorganisms in reactor volume, maximum release of electric field energy in structure of biological cells, and minimum heating of entire product are achieved. Use of symmetrical flat electrode system entails prevention of formation of spark channels in treated medium while increasing electric strength of working chamber.

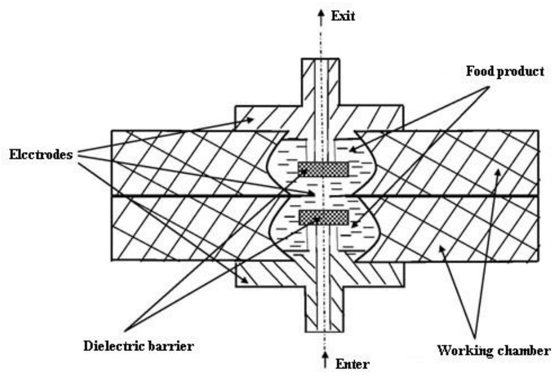

Figure 3. Reactor for electric pulse treatment of liquid food products

To further increase productivity of reactor, it is necessary to increase an average power of pulse generator. To do this, we propose to increase range of output pulse voltage while maintaining invariability of current values. To achieve such regime, it is proposed to increase an interelectrode distance in reactor and, accordingly, increase its resistance with product. Such reactor, as load of high-voltage pulse generator, allows generating shorter pulses of nanosecond range at output, which is very important for electronic treatment of food products.

3. CONCLUSIONS

Thus, researches carried out indicate effectiveness of high-voltage electrical impulse effects on microbiological indicators (for bacteria of E. coli group, mesophilic aerobic and facultative anaerobic microorganisms), toxic elements and organoleptic properties of fluid food products in compliance with physico-chemical parameters, nutritional and biological value.

There are proposed mechanisms for developing the most energy-efficient reactors for electronic treatment of liquid food products. It is shown, that in order to achieve the most uniform treatment of entire volume of food in order to disinfect it from pathogenic microorganisms, it is necessary to create the most favorable conditions for concentration and release of electric field energy directly on these biological structures. This is achieved due to dense packing of microorganisms and generation of strong electric field of nanosecond duration, which acts directly on membrane of microorganism and leads to its destruction.

Technique of selecting power of pulse voltage source in accordance with performance high-voltage technological installation is presented. Technique for calculating efficiency of electric pulse treatment in accordance with electrical parameters of pulse voltage generator is presented.

Shown are ways to further increase performance of high-voltage equipment by changing geometric parameters of reactor in electronic food treatment line.

Article proposes an energy-efficient and environmentally friendly electrical technology based on high pulsed voltage of nanosecond duration for disinfection of liquid food products, which can be actively implemented in technological lines for production of environmentally friendly food products.

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BIOGRAPHIES

Havar Amir Mammadov was born in Azerbaijan on July 1, 1945. He graduated from Automation and Telemechanics Faculty, Azerbaijan Polytechnic University, Baku, Azerbaijan in 1968. He worked as a Senior Lecturer at Department of Automation of Production Processes and Calculating Techniques of the same university, Baku, Azerbaijan during 1975-1984. He defended dissertation on the topic of "Transition processes in electric circuits with successive switching parameters" and was awarded scientific degree Candidate of Technical Sciences in 1983. By defending his doctoral dissertation in the topic of "Investigation methods of switching processes in complex electrical circuits with distributed parameters" in 1998 and was awarded scientific degree of Doctor of Technical Sciences in 2003 entitled with status of Professor. He worked as the Rector of Azerbaijan Technical University, Baku, Azerbaijan in 2000-2016 and as a Rector of Qafqaz University, Baku, Azerbaijan during 2016-2017. He is the Rector of Baku Engineering University, Baku, Azerbaijan from 2017 till present. He has been a full member of International Academy of Sciences since 2001, full member and Vice President of Azerbaijan Engineering Academy, Baku, Azerbaijan, and a corresponding member of International Oil Academy, Baku, Azerbaijan. He is author of 250 papers, 4 monographs, 22 textbooks and 10 patents.

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Elchin Jalal Gurbanov was born in 1963. In 1986, he graduated from the Moscow Power Engineering Institute, Electronics Faculty. In 1986-2006 he worked at the Institute of Physics of Azerbaijan National Academy of Sciences as a leading scientific officer at the Laboratory of "Physics and technique of high voltage". In 1995, he defended thesis on "Interaction of High Voltage Low Temperature Electric Gas Discharges with Components of Composite Materials" and awarded degree of PhD in Physics. In 2006-2010, he studied at "High Voltage Techniques and Electrophysics" chair of the "Moscow Power Engineering Institute" National Research University and worked as a senior researcher. In 2018 he defended doctoral thesis on "Development of scientific and technological bases of effects of short-term high-electric pulses and gas discharges on different dielectric mediums" and awarded degree of Doctor in technological sciences. He is the author of more than 100 scientific articles, have 2 patents and 1 certificate of Authorship. At present he is working at the Baku Engineering University as a Technopark Director.

Manafeddin Bashir Namazov was born in 1963. In 1986 he graduated from the "Automation and Telemechanic" specialty of Automation and Computing Techniques of Leningrad Electronics Institute, Russia. In 1988-1991 he completed his postgraduate education in Information and Automation Institute of USSR National Academy of Sciences and defended candidate dissertation on "Development of algorithmic and software for processing and identification of Mossbauer spectrum". In 1994-1995, he worked as an Associate Professor of Programming Department and Dean of Engineering Faculty National Progress Institute. In 1995-2008, he worked as senior lecturer and Associate Professor in Azerbaijan Technical University. In 2006-2011 he taught at various subjects as Associate Professor at Department of Electrical and Electronics at Engineering Faculty of Cumhuriyet University, Sivas, Turkey. In 2012-2018 he worked as Associate Professor and head of Department in Information and Communication Technologies Faculty of Baku Higher Oil School, Azerbaijan. Since 2019 he is working as vice-rector for International Relations at the Baku Engineering University, Azerbaijan and as Associate Professor teaching various subjects on Computer and Information Technologies Department. He is author of 62 scientific articles.

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