Method of Antimicrobial Liquid Processing

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Abstract - A method was proposed for antimicrobial treatment of liquids. A source of high-voltage nanosecond pulses with a semiconductor opening switch and a flow-through chamber outfitted with coaxial electrodes is used in this method.

Microorganisms need be removed from liquids in many spheres of human activities. One of promising methods for the antibacterial treatment of liquids is the use of high-voltage pulses. We shall consider some applications that are most efficient from the commercial viewpoint.

It is important to create compact and efficient systems for preliminary purification of water from natural reservoirs (at least for industrial needs) and treatment of residential waste waters (to the level required for their discharge to natural water reservoirs). These systems are topical and have considerable commercial promise.

One more significant application is pasteurization of food liquids. Heat treatment is nearly the only method today used to reduce the microbiological content of foodstuffs. However, thermal sterilization causes irreversible changes in properties of starting materials. This is not always permissible. Chemical methods [1], such as salting and candying, bring about a similar result. The use of radiation sterilization [2], which is highly efficient, is limited due to radiophobia of the population. Therefore, to prolong the shelf life of foodstuffs, they are pasteurized and then cooled to a temperature preventing the multiplication of microorganisms [3]. But this method requires large power consumption for cooling of foodstuffs and keeping them cooled. Moreover, it is more difficult to transport and process (handle and sell) foodstuffs.

Thus, the development of safe (primarily from the standpoint of consumer psychology) and efficient systems for antimicrobial processing of food liquids (milk, juices, beer, etc.) before they are charged to dispensers should have great commercial promise if it is ensured that properties of the liquids do not change during treatment.

A method is known for processing of liquids and fluid products [4, 5], which serve as the broth for microorganisms (biological fluids), including milk, wine, juices and waste waters, as well as medicines and cosmetics that contain microorganisms. This method uses electromagnetic field pulses less than 10^{-7} s long each. The amplitude of the electric field intensity in the liquid is over 10^7 V/m. The high-rise-rate electric field, which is generated in the liquid during treatment, causes failure (the electrical breakdown) of vital parts (membranes) of microorganisms, leading to their death [2].

Available methods for processing of liquids with high-voltage electromagnetic pulses more than 60 ns long require sufficiently large energy consumption at the level of over 1200 J/l. The energy consumption decreases as the pulse becomes shorter (Table 1).

By the proposed method of the antimicrobial treatment, a flowing liquid is exposed to a series of short high-voltage pulses less than 20 ns long. In this case, the amplitude of the electric field intensity decreases to $6 \cdot 10^6$ V/m. Since the electrodes have the coaxial geometry, the insulator may be removed from the liquid treatment area. As a result, the operating conditions of the insulator are improved and the insulator-to-liquid contact is smaller. Thanks to the use of coaxial electrodes, the chamber insulator may be imparted a shape that is most favorable from the viewpoint of the maximum electric strength.

Cell membranes in microorganisms fail at the pulse front [5]. Therefore, power consumption for the treatment process can be reduced by decreasing the pulse length and, hence, unwanted heating of the liquid diminishes.

A model installation was designed for realization of the method. It included a high-voltage source based on a semiconductor opening switch [6] and a milk treatment chamber (Fig. 1).

The chamber represented coaxial electrodes 1 and 2, which were made of a utensil-grade stainless steel and were separated with the bushing insulator 3. The external electrode 1 was the casing outfitted with the branch pipes 4 for supply and discharge of the liquid to be treated. The internal electrode received a high-voltage pulse from the high-voltage pulse source (Fig. 2).

The ratio between the diameter D1 of the external electrode and D2 of the internal electrode determined the intensity of the electric field in the chamber.

Table 1. Calculated power consumption necessary to reduce the concentration of microorganisms by one order of magnitude [2]

Pulse length, ns	21.5	69	300	2000
Experimental field intensity, kV/cm	36.87	10.65		
Experimental power consumption, J/l	30.88	36.6		
Calculated field intensity, kV/cm	210	143	87.4	46.4
Calculated power consumption, J/l	1120	255	2700	5070

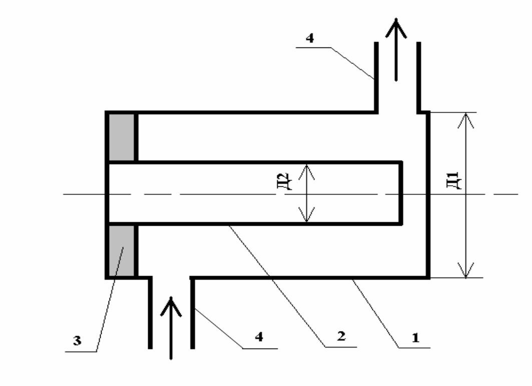

Fig.1. Treatment chamber

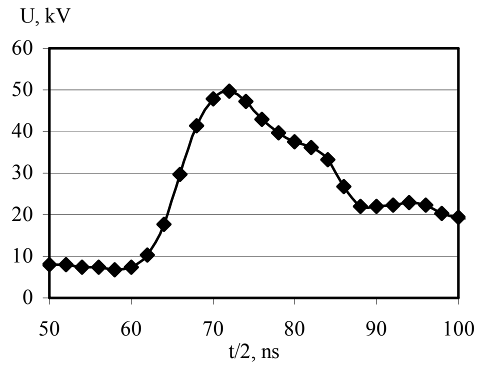

Fig.2. Voltage pulse oscillogram

In the experiments the diameter D1 was equal to 55 mm, while D2 was chosen from the series of 7, 20, 32 and 40 mm. The upper limit of D2 was chosen considering the electric strength of the liquid. The other diameters ensured that the electric field intensity at the internal electrode increased 8, 2.7, 1.7 and 1.4 times.

Also, the diameter ratio and the electrode length determined the chamber impedance. This feature was essential for matching to the impedance of the high-voltage pulse source. The chamber was 220 mm long.

The liquid, which is processed in the treatment chamber, may contain dissolved gases. As a result, gas bubbles are formed both in the treatment chamber cavity and in the pipelines feeding the liquid to the treatment chamber. The probability of the formation of gas bubbles grows higher as the pipeline speed and the temperature of the liquid increase. Since the electric strength of the gas in the bubbles is much lower than the electric strength of the treated liquid, spurious discharges can occur in the bubbles. To eliminate these discharges, the liquid passed through the treatment chamber at a high pressure. The pressure was adjusted at 0.2-3 atm. The speed of the treated liquid was limited by the appropriate choice of the high pressure so as to exclude switching from the laminar to turbulent flow conditions. The speed could be preset at 3-11 ml/s.

A model liquid infected with *Eschericia coli* in the concentration of 10^4 1/ml was used in the majority of the experiments. The pulse generator was adjusted to a frequency of 75-200 Hz and the liquid speed was preset at 3-10 ml/s during processing of the model liquid.

The experiments demonstrated (Table 2) that the death of the microorganisms depended not on the maximum field intensity (84.6 kV/cm) in the gap between the coaxial electrodes, which was achieved with the minimum diameter of the internal electrode (D2 = 7 mm), but on a high average intensity of the field in the gap or near the external electrode surface (15.86 kV/cm). The latter was produced at D2 = 40 mm.

The concentration of the microorganisms decreased as the liquid treatment rate was accelerated (Fig. 3).

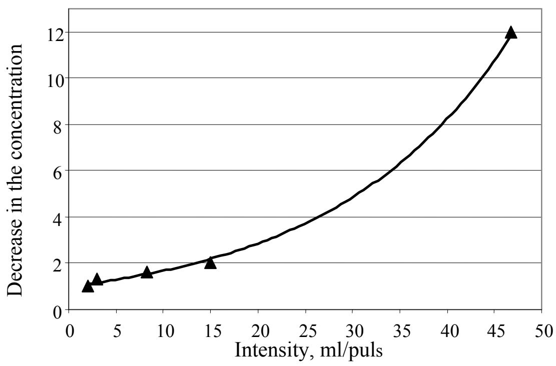

Fig.3. Concentration vs. treatment rate

The concentration decreased exponentially: $N0/N1 = 0.98 \cdot \exp(0.05 \cdot I_{pulse})$. Here N0 and N1 denote the initial and final concentrations of the microorganisms.

Experiments with milk pasteurization were performed for evaluation of the method usefulness.

Table 2. Field intensity and the treatment rate calculated as a function of D2

Internal diameter of the electrode, mm	7	20	32	40
Maximum field intensity, kV/cm	84.6	28	27	21.2
Minimum field intensity, kV/cm	10.77	10.22*	15.72*	15.42
Treatment rate, ml/pulse	48	-	-	48
Decrease in the concentration	11.1	-	-	72.2

Design values

Eschericia coli, which are the most characteristic microorganisms in milk, were introduced in the concentration of 10^4 l/ml [3].

These experiments were analogous to those with the model liquid. The analysis showed that the treated milk satisfied the corresponding standards (GOST P 52054-2003 "Natural cow's milk – Primary product" and the Sanitary Standard SanPiN 2.3.2 (078-6)).

Power consumption for milk pasteurization (the concentration of the microorganisms decreased by 2 orders of magnitude) was 30.9 J/l. The liquid treated by this method was heated to not more than 10 degrees and, therefore, its properties remained unchanged.

References

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