The Effluent Disinfection Based on the Cavitation Effect in a Venturi

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Abstract. This paper deals with the problems of effluent disinfection due to hydrodynamic cavitation caused by using the biogas technology. Effluent disinfection due to the acting hydrodynamic field makes it possible to destroy pathogenic microorganisms without using chemical reagents. The effect of the hydrodynamic field on microorganisms can be studied experimentally. Therefore, for experimental studies, a laboratory unit to create a cavitation field is developed. The paper presents the methods and results of experimental studies on the effluent disinfection in Venturi tube with the help of the cavitation field. The results of the experiment showed that for the E. coli bacteria group there is a threshold of sensitivity to cavitation action. The liquid flow rate at which the intensity of cavitation can destroy the microbial cell is shown. The dependence of effluent disinfection degree on cavitation regime parameters is established. The results of experimental research prove the efficiency of effluent disinfection in the cavitation field.

1. Introduction
The purpose of the experimental studies was to determine the effectiveness of disinfection of effluent in a cavitation field, depending on the regime and design parameters of the cavitation generator.

Experimental studies included two stages: carrying out laboratory studies on the disinfection of effluent in a cavitation field and the analysis of the results obtained by regression analysis. A diagram of a cavitation unit with a Venturi is shown in Figure 1.

2. Methods of experimental research and instrumentation
Before starting the experiment a program of experimental studies was drawn up on the basis of the theoretical studies, (Figure 2)
The assembly of the laboratory bench had been done after a choosing of measuring equipment capable to work with effluent. Manometers with a membrane separator of TM5 media (measurement range 0 ÷ 1.6 MPa, accuracy class 1.5) and a vacuum meter TB5 with a membrane separator media (measurement range 0 ÷ 1.6 MPa, accuracy class 1.5) were chosen.

The general view of the laboratory hydrodynamic installation of cavitation disinfection is presented in Figure 3.

The laboratory unit (Figure 4) includes: the high-pressure gasoline motor pump Zongshen HG30 with a capacity of 7.6 kW (maximum flow rate 750 l / min, maximum head height 75 m); source and receiving tanks; a suction pipe and an injection pipe. The injection pipe contains: a flow meter; a venturi tube type cavitation generator; ball valves; a manometer with a membrane divider of TM5 environments (No. 1) installed at the entrance to the venturi tube; vacuum meter TB5 with a membrane separator for media installed in a narrow section of the venturi tube. There is also a pressure gauge with a membrane separator of TM5 media next to the venturi tube (No. 2). Sampling was performed from the tank with the source material and the tank with the waste material, respectively, before and after the work of the cavitation generator.

The principle of operation of the installation looked like the effluent from the source tank was fed into the discharge pipeline, from where it was pumped through the discharge pipeline into the cavitation generator. After that the effluent passed through the venturi tube, the processed raw material entered the receiving tank.

At the end of the process, the pump was turned off and the receiving tank was emptied. The cavitation reactor is made of plexiglass, that allowed to do some visual observation and take some photos. Sampling was carried out directly from the injection pipeline.

Testing the performance of the laboratory unit in pure water showed the possibility of creating cavitation, while the readings of the manometer No. 1 were 0.4 MPa, the vacuum meter was 0.05 MPa, and the manometer No. 2 was 0.38 MPa. The pressure in front of the venturi ranged from 0.2 to 0.4 MPa.
Making an experiment for disinfection of effluent in a cavitation field

An effluent (from animal waste) from LLC Avangard, Safonovo town, Smolensk Region, was taken as the source material for experimental laboratory studies.

The geometrical dimensions of the Venturi tube were selected on the basis of theoretical studies of a cavitation generator. The working chamber of the Venturi tube with the opening angle of the diffuser 200 is shown in Figure 5.

Figure 5. Working chamber of a cavitation reactor.

The chosen research methodology was based on the analysis of known theories and experiments with hydrodynamic cavitation [1].

3. Experiment realization on effluent disinfection in the cavitation field

The experiments with the hydrodynamic installation were made according to the following general scheme:

- An effluent sample was taken from the tank with the source material having the initial concentration of microorganisms.
- Hydrodynamic installation was filled with effluent (volume is about 250 dm3 (liters)).
- The cavitation reactor was set up to the specified mode of operation (in terms of fluid flow).
- The installation was adjusted at the studied speed.
- Effluent was processed once, twice and triple, after each cycle, samples were taken out from the tank with the source material and the tank with the used material and put into a sterile container for analysis. The container was tightly closed with a stopper and the label with the number of experience was pasted.
- After the experiments had been done, the installation was disinfected.

After each experiment the internal surface of the apparatus used was washed out with detergent, rinsed and dried. In these experiments, the start of cavitation was determined visually according to the leakage of certain bubbles. During the transition from the non-cavitation regime of the flow of pathogens to cavitation, back pressure wasn’t created in the discharge line.

During the work the flow rate and the stage of cavitation were constant. The required length of the cavitation zone was created by changing the backpressure at a constant flow rate.

To carry out the study of the biocidal action of hydrodynamic cavitation, it is necessary to assess the degree of its effect on microorganisms by testing [2, 3]. Testing was done with Escherichia coli, which is an indicator of fecal contamination and biological pollution, and it is widely used as a test object in the evaluation of disinfection methods, the activity of disinfectants and biologically active substances.

4. Experimental results

The preliminary experiments have shown there is a certain threshold of sensitivity to cavitation for Escherichia coli bacteria group. So, at a flow rate in the channel of a cavitation generator equal to 25 m/s, regardless of the stage of cavitation, the change in the concentration of microorganisms after a single treatment was practically not observed, where at a speed of 26 m/s the result was obvious. Therefore, there is a value of speed at which the intensity of cavitation reaches a level capable to destroy a microbial cell in one cycle of exposure [4].
The purpose of further work was to find the threshold value of the velocity in the reactor channel, followed by the bactericidal action. In the course of the experiments, the change in the concentration of the bacterium group of Escherichia coli depending on the velocity V was studied, with the constant water temperature (16 °C).

The degree of biocidal action of the studied factors was judged with the number of colony-forming BGKP units, using "Petritest substrate" (BGKP test) that is manufactured by the company "Alternative", Saratov city. "Petritest substrate" was placed in a thermostat at 37 ± 1 °C and the result was taken into account a day later.

The results of the microorganisms growth (the number of grown colonies) were taken into account after 24 hours incubating the plates in a thermostat. At least three cups with a dense nutrient medium were used at the sowing of each dilution.

The initial culture of microorganisms that were not exposed to cavitation was sown as a control in each experiment. The results of the experiments were calculated in absolute values and in percentage relatively to the number of grown in the control sample microorganisms.

All grown in the cups colonies in the cups were counted, observed with increasing in 2 times. The number of colonies in each plate was summed and multiplied by four according to the method [5, 6]. The result was expressed with the number of colonies in 1 g of the test effluent.

The same experiment with the same values of the influencing factors, was carried out three times. Three seedings from each obtained sample were done according to the standard procedure [7].

The quality of disinfection was determined by sowing the sample that was processed in the cavitation field on a nutrient medium and was expressed in the number of colonies of microorganisms that were in the effluent after treatment in the cavitation generator [8, 9].

The best from the obtained results was chosen, and the combination of influencing factors for that it was obtained was taken as optimal one.

The concentration of microorganisms was monitored after each processing cycle. It was done with sequential single-step sampling of three samples from the tank with the source material and the tank with the waste material, each experiment was made three times (Figure 6).

![Figure 6. Colonies of grown microorganisms in a nutrient medium.](image1)

![Figure 7. Dependence of the disinfection degree on the rate of effluent in a narrow part of the venturi tube, during different cycles.](image2)

The sequence of decontamination of effluent samples in the cavitation installation and the examination of samples that were processed in the cavitation installation on the EGCC was written down in the test report. The obtained data were processed with the least squares method [11, 12].

The degree of effluent disinfection is determined with the formula:

$$\eta = \frac{C_0 - C_n}{C_0} \cdot 100$$

where $C_0$ is the initial concentration of microorganisms, CFU / g; $C_n$ is the concentration of microorganisms after the n – cycle of exposure, CFU / g. The results of the effluent disinfection degree assessment are given in the graph of its dependence on the speed of the analysed material movement.
5. Discussion
The analysis of the data shows that the degree of disinfection increases in the process of disinfection when speed and number of cycles rise. In the process of disinfection at increasing speed and number of cycles, the degree of disinfection increases. To increase the degree of disinfection, for example, up to 30% one should increase the speed from 26 to 38 m/s, or at 26 m/s for 2 cycles of effluent treatment through the Venturi tubes.

The established dependence of the disinfection degree on the fluid flow rate and the number of effluent treatment cycles have allowed us to determine the threshold value of the fluid flow rate (V=26 m/s) at which the bactericidal effect of hydrodynamic cavitation can be achieved. There is a disinfection regime (an effluent speed and a number of cycles) when energy costs will be minimal.

The need for multiple cavitation treatment is explained by the fact that when bacteria are in the cavitation zone with low intensity, the surface protective layers of the microbial cell are disturbed, while saving its viability, but if exposure is repeated, the cell dies [13, 14].

According to the analysis of the obtained data, hydrodynamic cavitation has an antibacterial effect, and eukaryotic microorganisms are more susceptible to cavitation, that is explained by the size of the microbial cell, and for a given mode of action in the area of collapse of cavitation bubbles. The bubbles of comparable to microorganisms size dominate [15, 16]. So the shock wave, which is formed during the collapse of the bubble, affects only part of the cell, causing the mechanical damage of a different nature [17, 18].

The least-squares method was used to process the experimental dependence [19], the analysis of the results of the relative errors calculations indicates a sufficient accuracy of the obtained values and the experiment’s correctness.

The practice of conducting experiments indicates the need in each particular case, creating a specific design of an experimental test bench, that takes into account the particularities of the final product, the conditions of external influences and the physical characteristics of the impact.

The analysis of the relationships characteristic that are typical for studied processes and phenomena with a complex structure and diversity of their inherent connections is complex [20]. First of all, it is necessary to establish the existence of relationships and their nature, after that it is necessary to establish the closeness of relationships and the degree of influence of various factors (causes) on the result of interest. If the studied objects can be measured and expressed quantitatively, then the analysis of interconnections can be carried out using mathematical methods, they will make it possible to determine the presence or absence of interconnections between these or other features. Further, by means of mathematical methods, it is possible to establish the closeness and nature of interrelations or to reveal the degree of the influence of various factors on the result. Multiple regression procedures are widely used in the similar works [19, 20].

In the regression analysis, a one-side dependence of a random dependent variable on one or several independent variables is considered [23, 24]. Independent variables are called factors, or predictors, and the dependent variable is a resultant attribute, or a response.

The experimental studies carried out by modeling the processing process allowed us to obtain the regression equation:

\[ \eta = 0.066 \cdot (n^{1.128}) \cdot (V^{1.64}) \]  

where n is the number of cycles; V is the velocity in the narrow part of the Venturi tube, m/s.

The regression equation (2) allows you to determine the optimal parameters of the cavitation disinfecting effect: the values of the fluid flow rate of and the number of processing cycles.

6. Conclusions
1. The methodology for conducting experiments on the hydrodynamic installation was worked out and the main parameters for the study of various cavitation regimes were determined.
2. The regression equation was obtained, it shows the general contamination of the effluent that was treated in the cavitation generator, depending on the effluent rate in the working area and the number of processing cycles.

3. The dependence of the disinfection degree of effluent on the regime and design parameters of the cavitation generator were studied and established. The threshold value of the fluid flow rate is determined, it’s \( V_{\text{min}} = 26 \text{ m/s} \), when the bactericidal effect of hydrodynamic cavitation is achieved.

4. Hydrodynamic cavitation, under certain conditions, has a bactericidal effect Escherichia coli bacteria, which have different resistance to unfavorable environmental factors. Moreover, the eukaryotic cells used in the experiments are more susceptible to its influence.

5. The sterilizing action of hydrodynamic cavitation is proportional to the change in its intensity, that depends on the stage of cavitation and the flow rate.

6. It is necessary to try to use the maximum possible number of cycles to use of the supplied energy completely, provided that the flow rate in the channel of the working chamber reactor should be close to its threshold value.

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