Research on the disinfection of livestock wastes by ultrasound

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Abstract: Issues of using existing systems for the disposal, treatment and disposal of livestock wastes, taking into account environmental protection and improving the sanitary condition of livestock farms, need to be addressed immediately. The proposed technology for disinfection of livestock waste is cost-effective only under certain conditions of processing of feedstock. Providing these conditions leads to higher cost of processing. The most advanced methods of disinfecting wastewater are physical methods of exposure. The use of ultrasound is effective in disinfecting livestock waste from aerobic and anaerobic bacteria. Destruction of pathogenic microflora occurs under the influence of alternating loads, the range of which is established by the proposed method. Theoretical studies have established the scope of wave processes corresponding to ultrasonic disinfection of livestock waste. Under certain modes of radiation intensity and frequency, ultrasound results in a decrease in the coli titer of E. coli and staphylococci.

1. Introduction
To protect the environment from pollution by runoff from livestock farms, a system of measures is required to protect nature. Since livestock wastes contain valuable organic substances, the main direction of existing technologies for wastewater treatment is associated with their processing into organic fertilizers [1].

Currently the use of certain methods and livestock disinfection technological schemes due to different volumes of effluents and local conditions for the location of livestock enterprises. The feasibility of constant disinfection of all effluents obtained at enterprises, regardless of the veterinary well-being of the farm, is confirmed by research on sanitary hygiene. Traditional methods of storage and use of effluents are unacceptable in conditions of environmental degradation due to the threat of environmental pollution and the spread of infectious diseases among people and animals [2], [3].

2. Materials and methods
When using ultrasonic processing, the issue of the number of emitters providing high-quality processing of the disinfected mass. In the present invention, emitters are installed around the perimeter of the working chamber of the installation for disinfecting wastewater evenly, at the same distance from each other [4], [5], [6]. This arrangement is dictated by the need to ensure uniform irradiation of livestock stocks with ultrasound in the pipe section of the working chamber. The optimal solution is to determine the number of emitters, the increase of which will lead to higher construction costs without improving the quality of disinfection [7], [8].
As a criterion for the quality of disinfection, we take such an installation of emitters, in which the
distribution of the amplitudes of ultrasonic pressure on concentric circles inside the contour of the cross
section of the working chamber will be uniform. The distribution of minima (zeros) and maxima
(beams) of amplitudes along the radius depends on the location of the frequency converters. If you
select a circle on which pressure has a maximum and plot a diagram of the distribution of pressure
amplitudes on it, then the maximum amplitudes will be under the emitters, and the minimums on the
radii between the emitters (figure 1).

![Figure 1. Ultrasound pressure amplitude distribution diagram:](image)

1 – emitter working chamber;
2 – emitter;
3 – pressure amplitude maximum;
4 – amplitude minimum.

By increasing the number of emitters, one can achieve a plot that is close to a uniform distribution.
The initial data for the calculation of the proposed program are:

- \( t \) - number of converters;
- \( \alpha \) - nondimensional radius (in fractions of the radius of the body of the working part of the
  installation for ultrasonic treatment);
- \( P \) - total installation power.

3. Results and discussion

We divide the circumference of the working chamber into \( i \) parts in length and denote by \( a_u \) the length
of the arc of the maximum radiation of one of the transducers (figure 2).

![Figure 2. Diagram of the distribution of pressure amplitudes with increasing number of emitters:](image)

\( R \) – working chamber radius;
\( a_u \) – arc maximum radiation length.
In order to maintain the comparability of the results of solving a number of problems with an increase in the number of converters, it is necessary that their total radiated power is preserved. Therefore

\[ N_i = \frac{I}{i}, \]  

(1)

where \( I \) – total emitter power (accepted per unit); \( i \) – number of converters; \( N_i \) – power of one converter.

We formulate the boundary conditions for the placement of emitters, taking into account the design features of the working chamber of the installation for disinfection of livestock waste.

With the number of transducers \( i \) the circle length remaining without exposure to radiation is equal to

\[ 2\pi R \cdot a_i. \]  

(2)

For complete disinfection of the mass passed through the working chamber, it is necessary that the radiation be provided both on the arcs of the maximum pressure amplitudes of each transducer and on the arcs adjacent to them. This condition can be satisfied if

\[ \frac{2\pi R}{i} \leq a_u \]  

(3)

Therefore, each converter must act on an arc of length equal to

\[ L_i = \frac{2\pi R - i \cdot a_u}{i}. \]  

(4)

Since the directivity characteristic of the emitters is represented in the Cartesian and in the polar coordinate systems, therefore, the boundary conditions can be specified by the polar angle \( \varphi \).

If

\[ \varphi \leq \frac{2\pi}{i} + \frac{a_u}{R}, \]  

then

\[ N_i = \frac{1}{i \cdot a_u}. \]  

(5)

If

\[ \varphi \leq \frac{2\pi}{i} - \frac{a_u}{R}, \]  

then

\[ N_i = 0. \]  

(6)

Thus, when the boundary conditions are satisfied, the amplitudes are uniformly distributed on the arcs of the radiation beams and are equal to zero between the transducers. The boundary of the radiation field is the envelope of the pressure amplitude and is determined by the number of transducers (figure 3).

The mathematical model for the distribution of the envelope of pressure amplitudes is the Laplace equation. In an analytical review of existing theories and models of acoustics in this dissertation it is shown that the wave equation is

\[ \frac{d^2 p}{dt^2} = C^2 (\frac{d^2 p}{dx^2} + \frac{d^2 p}{dy^2}), \]  

(7)

in the case of a steady ultrasonic field \( \frac{d^2 p}{dt^2} \rightarrow 0 \), which leads to the Helmholtz equation.
\[
\frac{d^2 p}{dx^2} + \frac{d^2 p}{dy^2} + k^2 P = 0, \quad (8)
\]

\[
\Delta \rho = \frac{1}{r} \frac{d}{dr} \left( r \frac{dP}{dr} \right) + \frac{1}{r^2} \frac{d^2 P}{d\varphi^2} = 0
\]

The boundary conditions for the problem of interest to us are determined by the values

\[
r = R, \quad P_i = \frac{1}{i \cdot a_\nu}
\]

when

\[
\frac{2\pi}{i} a_\nu \leq \varphi \leq \frac{2\pi}{i} a_\nu.
\]

The solution of the problem possible in presenting it in the form of a Poisson integral

\[
P(r, \varphi) = \frac{1}{2\pi} \frac{\pi}{\int_{-\pi}^{\pi} f(t) \left| \frac{1 - N^2}{1 - 2r \cos(t - \varphi)tr^2} \right| dt}
\]

where \( f(t) = P_i(R) \) amplitude distribution on the generatrix of the flange;

\( t \) - variable integration angle.

When using this formula, the radius of the working chamber of the installation is assumed to be equal to unity.

When concretizing the values of the function \( f(t) \), the Poisson integral is not applicable for a practical solution, since it belongs to the class of non-moving integrals. The specific numerical value of the Poisson integral can be obtained by writing the solution in the form of a Fourier series.

If the boundary condition \( P(\varphi) \) decomposes uniformly in a Fourier series by for 0,2 \( \pi \), then...
\[ P(\varphi) = a_0 + \sum_{k=1}^{\infty} (a_k \cos k \varphi + b_k \sin k \varphi) \] (13)

and therefore

\[ P(r) = a_0 + \sum_{k=1}^{\infty} \left( \frac{r}{R} \right)^k (a_k \cos k \varphi + b_k \sin k \varphi) \] (14)

In this work we used the Laplace operator to determine the optimal number of emitters

\[ \Delta \varepsilon (r) = \delta (r-r_o), \] (15)

where

\[ \Delta \varepsilon = 0 \quad \text{as} \quad r \neq r_o; \]

\[ \delta \rightarrow \infty \quad \text{as} \quad r \rightarrow r_o. \]

For plane problems, the Laplace equation

\[ \varepsilon = \frac{1}{2\pi} \ln(r). \] (16)

4. Conclusions

The existence of the function \( \delta (r-r_o) \) at the point \( r_o \) physically means the presence of a single power source in it. Therefore, the distribution of amplitudes on the radius in polar coordinates of interest to us is found by the formula (figure 4).

\[ P(R_o, \varphi) = \sum_i (R_c - R_i) \] (17)

or in a quadratic coordinate system (figure 5)
Figure 5. Estimated distribution pattern of the generator in Cartesian coordinates.

\[ P(x,y) = \sum_{i} \frac{1}{i} \alpha(x-x_i, y-y_i), \quad (18) \]

where

\[ x_i = R \cos \left( \frac{2\pi}{i} \right), \quad y_i = R \sin \left( \frac{2\pi}{i} \right). \quad (19) \]

The performed calculations allow us to obtain:
- Diagrams of the distribution of pressure amplitudes \( P \) on a circle of radius \( \alpha R \);
- Arrangement of converters in the working chamber of the installation for disinfecting wastewater with ultrasound.

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