THE AIR-JET ULTRASONIC AEROSOL GENERATOR DESTINATED FOR ANTIMICROBIAL TREATMENT OF BIOFILMS FORMED ON SURFACES IN FOOD INDUSTRY

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Abstract: The paper presents the construction of an air-jet ultrasonic aerosol generator that allows adjustment of the dispersing jet. It shows the calculation methodology which includes an air-jet ultrasonic generator and the dosing chamber of the atomized liquid. It is considering using this type of air-jet ultrasonic aerosol generator for cleaning and antimicrobial treatment of surfaces covered with biofilm in the food industry. High antimicrobial resistance of microorganisms in biofilms in the food industry is influenced by the failure of an agent to penetrate inside the biofilm.

Keywords: air-jet ultrasonic aerosol generator, calculation methodology, resonator, frequency, geometrical parameters, *Strouhal* number

1. INTRODUCTION

Applications of ultrasonic propagation are finding increasingly widespread in food industry [1]. Microbiological destructive effect of ultrasonic is a consequence of hydrodynamic forces of surrounding the formation and implosion of ultraacustic cavities. A special role is played by the distance between the location of cavitational phenomena and microbiological entity. As the distance is small, so the cavitation collapses effect is more pronounced [2]. Aerosol production mechanism is explained by the phenomenon of ultrasonic dispersed. Phenomenon occurs when the liquid-gas system is activated in which case the separation of the two environments forms a very dense and soft fog. Ultrasonic fog formed when liquid dispersed in gas contains particles that range in a relatively small field [1].

A biofilm is an aggregate of microorganisms in which cells adhere to each other and/or to a surface [3]. Organization of microorganisms - bacteria or fungal, biofilms form, proved to be the most complex form of resistance of host individuals. This resistance is manifested both to antimicrobial agents (antibiotics and antifungals) and decontaminated agencies to use in sanitation operations [4].The main objective in food industry is safety food production. The biofilms formation can destroy food surfaces that are adhered. That's why in food industry cleaning and antimicrobial treatment programs should be implemented correctly from the beginning of production. In fact, biofilms are important components of food chains [3]. The mechanisms of biofilm resistance to antimicrobial agents are not fully understood. Possible mechanisms include: restricted penetration of drugs through the biofilm matrix, phenotypic changes resulting from a decreased growth rate or nutrient limitation and expression of resistance genes induced by contact with a surface [5].

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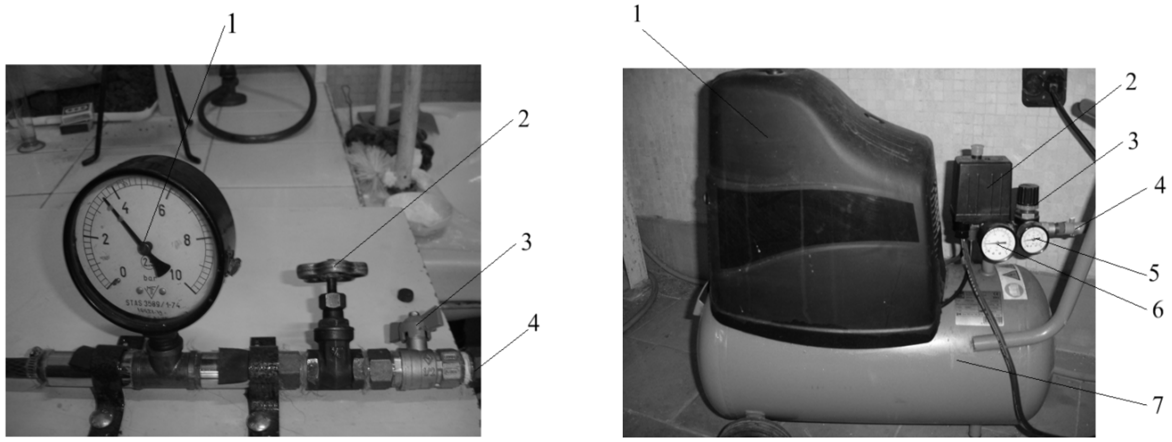
The objective is to achieve an ultrasonic aerosol generator for antimicrobial treatment from food industry and its calculation methodology.

2. THE EXPERIMENTAL INSTALATION FOR AIR-JET ULTRASONIC AEROSOL GENERATOR

Experimental installation includes compressor (Figure 1.b) and generators pressure control system power (Figure 1.a). The experimental installation works as follows.

Air compressor develops compressed air at 8 bar pressure that accumulates in the compressor tank. To reduce pressure until required value of 1.5- 4 bar it’s using a pneumatic gear then the hose 4 goes to control installation. Selected air pressure has access to installation by valve 3. To obtain more accurate adjustment of working pressure, installation has accurate valve adjustment. Air pressure at the generator input, measured with manometer pressure monitor and works of maximum precision. Airflow is controlled by manometer and output section of nozzles controlled by the work method.



a) b)

Fig. 1. The experimental installation for air supply of air-jet ultrasonic aerosol generator:
a) generators pressure control system power: 1— manometer pressure monitor work; 2— air control valve; 3— valve opening; 4— air supply with hose;
b) compressor: 1—piston cylinder; 2— electrical system power off; 3— valve;4— air supply with hose; 5— tank pressure at the exit of manometer; 6— manometer tank pressure; 7— tank.

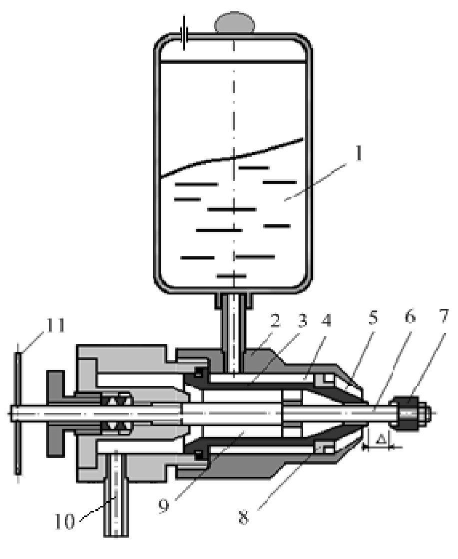


Fig. 2. The air-jet ultrasonic aerosol generator scheme:
1— liquid room; 2— injector body; 3, 5 — nozzle;4— liquid channel; 6—rod; 7— resonator; 8— swirl; 9— air duct; 10— air supply; 11— handle adjustment spacers.

Ultrasonic aerosol generator (Figure 2) has a centrifugal injector where is installed the axial type of air-jet ultrasonic generator. The liquid solution enters the room 4 and in swirl 8 where obtains rotations and create a vortex in the nozzle 5. The compressed air reaches the nozzle 3 in resonator 7, fixed on the rod 6, installed inside the generator nozzles with the possibility of moving. Supersonic air jet nozzle after interaction with the resonator cavity, loses stability and gives high-frequency shock waves. Varying the distance between the nozzle 5 and resonator 7 by rotating the rod we obtain dispersed liquid jet angle adjustment. Figure 3 shows the air-jet ultrasonic aerosol generator in operation. It can be seen the dispersing jet.

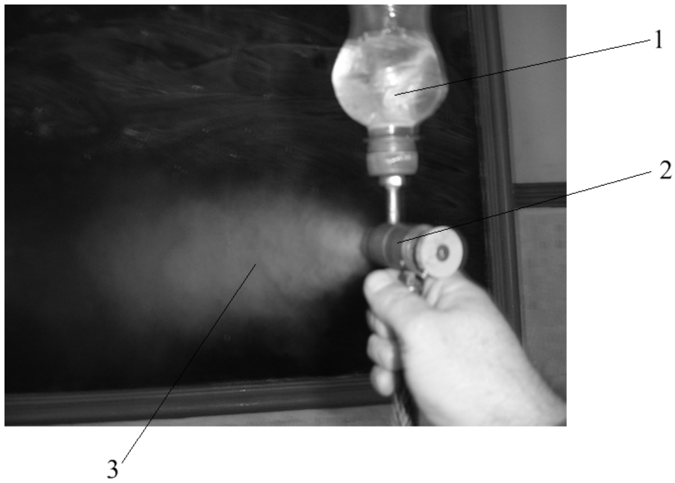


Fig. 3.The air-jet ultrasonic aerosol generator:
1— liquid room; 2—air-jet ultrasonic aerosol generator; 3— dispersing jet.

The effectiveness of disinfectants is limited and much dependent on application conditions. The factors which control the efficiency of disinfectants are microbial type and growth condition, interfering substances, acidity-pH, temperature, contact time and concentration. The relationship between time and efficiency is dependent upon the type of microorganism [6].

3. CALCULATION METHODOLOGY OF THE AIR-JET ULTRASONIC AEROSOL GENERATOR

The calculation methodology of the air-jet ultrasonic aerosol generator design with swirl chamber and the axial air-jet generator leaves from the following considerations:
- the operation of the air-jet ultrasonic aerosol generator, portion of the jet nozzle and the resonator oscillates, generating high frequency shock waves which due to dissipative processes, lose intensity transforming into sound waves;
- maximum effectiveness of dispersal processes will occur when the geometric parameters of the resonator will ensure maximum intensity oscillations. The calculation methodology is done in two phases: initially axial air-jet ultrasonic aerosol generator parameters are determined followed by the size of the swirl chamber.

3.1. The calculation of axial air-jet ultrasonic aerosol generator

The calculation methodology is based on the determination of pressure ratio parameter [7]:

$$n = \frac{P_0 + P_{ca}}{P_{ca}} \cdot \pi \cdot \left(M_a\right) \tag{1}$$

where P_0 is manometric working pressure of the air-jet aerosol generator, P_{ca} is the pressure atmosphere in the swirl chamber, $\pi\left(M_a\right)$ is the is air-jet function and M_a is the Mach number nozzle exit section.

Starting from the calculated value of *n*, dimensionless geometric parameters are determined [7]:

$$\bar{\Delta}_R = \frac{\Delta_R}{2\delta} = 0.74 \cdot n + 0.20 \tag{2}$$

$$\bar{l}_R = 1.1 \cdot \bar{\Delta}_R \cdot \left(f_{or} \cdot \varphi_a = \varphi_R = 30^0 - 45^0 \right) \tag{3}$$

$$\bar{D}_R = \frac{\delta_R}{\delta} = 0.34 \cdot n + 0.56 \tag{4}$$

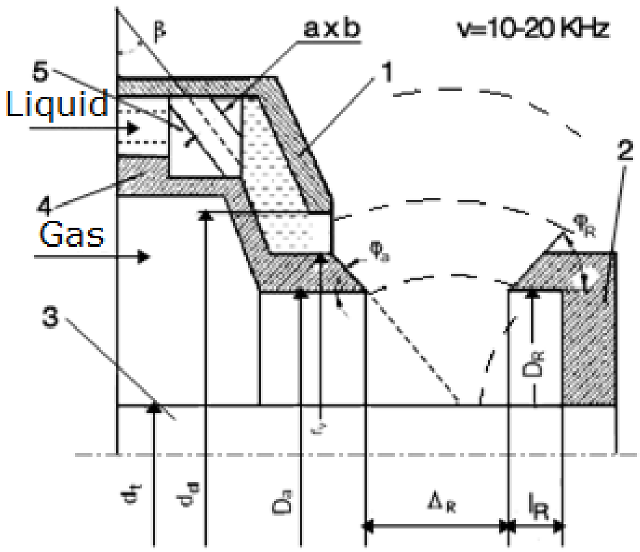


Fig. 4. Dimensional diagram of the air-jet ultrasonic aerosol generator:
1—injector body; 2— resonator; 3, 4—nozzle; 4—swirl.

Using the parameter values, $\bar{l}_R, \bar{\Delta}_R, \bar{D}_R$ and *n* we calculate the *Strouhal* number value [7]:

$$S_h = \frac{0.5 \cdot n^{0.35}}{\bar{l}_R^{\,0.23} \cdot \bar{\Delta}_R^{\,0.17} \cdot \bar{D}_R^{\,0.69}} \tag{5}$$

where: $S_h = \frac{\nu}{M_a \cdot a_0}$ is the *Strouhal* number, $\nu = 20 - 26$ kHz is the generator frequency, $M_a = 1$ nozzle *Mach* number and a_0-sound velocity.

Using the parameter values, $\bar{\Delta}_R, \bar{l}_R, \bar{D}_R, n$ and the frequency ν we determine the size of the nozzle exit slit [7]:

$$\delta = 0.075 \cdot \frac{M_a \cdot a_0 \cdot n^{0.35}}{\nu \cdot \bar{l}_R^{\,0.23} \cdot \bar{\Delta}_R^{\,0.17} \cdot \bar{D}_R^{\,0.69}} \tag{6}$$

The determination of critical section area [7]:

$$F_c = \frac{P_0 \cdot \dot{m}_a}{\sqrt{T_0}} \cdot \left(\frac{k+1}{2}\right)^{\frac{k-1}{2\cdot(k-1)}} \cdot \left(\frac{R}{k}\right)^{\frac{1}{2}} \cdot 10^4,\ [mm^2] \tag{7}$$

From the system of equations [7]:

$$\begin{cases} F_c = \dfrac{\pi}{4} \cdot \left(D_a^2 - d_t^2\right) \\ \delta = \dfrac{D_a - d_t}{2} \end{cases} \tag{8}$$

We determine D_a and d_t.

The generator calculating completes with the determination of the resonator geometric parameters [7] .

$$D_R = \bar{\Delta}_R \cdot \left(D_a - d_t\right) + d_t ,[mm] \tag{9}$$

$$\Delta_R = \bar{\Delta}_R \left(D_a - d_t\right),[mm] \tag{10}$$

$$l_R = \bar{l}_R \cdot \left(D_a - d_t\right),\ [mm] \tag{11}$$

3.2. Calculation of vortex chamber

Nozzles diameter (Figure 4):

$$d_d = 2 \cdot r_v + 0.64 \cdot \left(D_a - d_t\right),\ [mm] \tag{12}$$

in wich the radius of the central gas swirl r_v is determined from formula [7]:

$$r_v = {d_t}/{2} + 1.42 \cdot \left(D_a - d_t\right) \cdot \left(0.2 \cdot n + 0.43\right) \tag{13}$$

Determine the coefficient of filling nozzle [7]:

$$\varphi = 1 - \left(\frac{2 \cdot r_v}{d_d}\right)^2 \tag{14}$$

The main geometrical parameter A, the flow coefficient μ and dispersing jet angle are determined by centrifugal injector ideal theory formula [7]:

$$A = \frac{(1-\varphi) \cdot \sqrt{2}}{\varphi \cdot \sqrt{\varphi}} \tag{15}$$

$$\mu = \sqrt{\frac{\varphi^2}{2-\varphi}} \tag{16}$$

$$2\alpha = 2 \cdot \left(arctg \frac{\sqrt{8} \cdot (1-\varphi)}{\left(1+\sqrt{1-\varphi}\right) \cdot \sqrt{\varphi}} \right) \tag{17}$$

Supply pressure liquid flow is determined from the formula [7]:

$$P_l = \frac{8 \cdot \dot{m}(2-\varphi)}{\pi^2 \cdot d_d^4 \cdot \varphi^2 \cdot \rho} \; , [Pa] \tag{18}$$

Geometric dimensions of the swirl chamber (Figure 4.) results from formula [7]:

$$A = \frac{(1-\varphi) \cdot \sqrt{2}}{\varphi \cdot \sqrt{\varphi}} = \frac{R_t \cdot \frac{a_d}{2} \cdot \pi}{i \cdot S \cdot \sin \beta} \tag{19}$$

where β is the channel pitch angle (Figure 4), $S = a \times b$ is the cross-sectional area of the channel width a and depth b, i is the number of input channels and R_t is the arm rotating swirl flow.

Average diameter *Sauter* of droplets [7] can be appreciated based on the empirical formula:

$$d_{32} = 0.2602 \cdot Sh^2 \cdot 10^4 \; , [\mu m] \tag{20}$$

4. CONCLUSIONS

Calculation methodology has been developed for ultrasonic aerosol generators including air-jet sonic nozzles design. Aerosol generator was made allowing the jet dispersion angle variation from 70 to 180°C and ensures spraying smoothness of 10-15 µm. Because parallel with aerosols sound waves are produced, the biofilms destruction (cleaning) will be more effective. Due to acoustic pressure waves, aerosols chemical disinfection can penetrate any small crack from biofilm surface and accelerates automatic cleaning of technological vessels. The experimental test was performed for ultrasonic aerosol generator, was designed and realized a dispersed flow generator angle adjustment, with disinfecting fluid supply system installed directly on the generator and were made functional testing of the generator. Using this generator in food industry can be beneficial for the removal of biofilms. Calculation method consists of calculating from 2 parts: calculation methodology of the air-jet ultrasonic aerosol generator and calculation of vortex chamber. The method ends with average diameter *Sauter* depending on dimensionless frequency, allowing dispersion appreciation depending on the generator frequency.

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