Acoustic Nebulizer for the Processing of Undersized Fruit Plantations: Parameters and Operating Modes

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Abstract. When protecting undersized fruit plantations from diseases and pests, a large amount of working fluid is consumed, ordinary processing of fruit plantations reduces the productivity of sprayers. To solve this problem, it is proposed to use acoustic sprayers having a low liquid flow rate and a high degree of crushing. Studies have been carried out that have made it possible to optimize the parameters and operating modes of the acoustic sprayer and to establish a scheme for placing the sprayers on a sprayer. The dependence of the radius of the spray pattern on the design parameters of the nebulizer is found out. The average droplet diameter and the degree of coverage of the leaf surface are determined. The parameters of the proposed acoustic sprayer satisfy the agrotechnical requirements. The use of the proposed acoustic sprayer in the technological process of protecting undersized fruit plants allows to reduce the consumption of working fluid and to increase the productivity of the sprayer.

1. Introduction

For the protection of stunted fruit plantations, various types of garden sprayers are used, in which sprayers of hydrodynamic and pneumatic operations are applied that have a high flow rate of the working fluid, which pollutes the environment. When processing fruit plantations, sprayers are forced to pass through each row several dozen times, this leads to a decrease in their productivity and soil fertility due to its compaction.

All this necessitates a reduction in the number of passes of technical between the rows and the flow of working fluid by using new methods of spraying a liquid [1].

2. Relevance, scientific significance of the issue with a brief review of the literature.

Acoustic sputtering of liquids has found wide application in the chemical industry. In acoustic sprayers, the instability of the air jet is used, with which a jet or a liquid film comes into contact. The oscillations of the air jet increase sharply as a result of various wave phenomena that arise in the liquid, especially in the resonance region. Generation of sound oscillations occurs when a supersonic stream flows around the resonator chamber, while the interaction of a constantly existing air jet and a periodically acting return jet causes the air jet to pulsate between the resonator and the shock wave, resulting in a fine liquid crushing (10 ... 100 μm) at low liquid flow rate (0,3 ... 0,8 l/min) in comparison with other methods of liquid spraying [2, 3, 4, 5].

At present, plants and sprayers with acoustic sprayers have been developed and tested in production conditions [6, 7]. However, due to the high degree of crushing of the liquid, these sprayers do not provide a qualitative treatment of the fruit plantations.

3. Formulation of the problem.
The main aim to work out and investigate the new construction of acoustic sprayer which makes possible to process the crown of the fruit plants and provide equal treatment of plans while liquid is educed largely.

4. Theoretical part.

Figure 1 presents a constructive diagram of the proposed acoustic liquid atomizer with an independent resonator drive [8, 9]. The air jet flows through the channel from the outlet 3 of the gas-jet radiator, creating a vacuum in the volume 5 between the resonator 2 and the end 4 of the nozzle. Under the action of this rarefaction, the working fluid flows out of the end of the nozzle 4 by a thin film, falling into the space 5 between the resonator 2 and the nozzle 4, under the influence of alternating sound oscillations, is broken into small droplets, forming a highly disperse aerosol. The elastic element 7 increases the acoustic effect. A sprayed cloud of small droplets of liquid in the air stream, flowing around the rotating resonator, falls on the object being processed.

Figure 1. Acoustic liquid atomizer: 1 - rotating rod radiator with autonomous drive; 2 - resonator; 3 - an exit aperture; 4 - end of the nozzle; 5 is the volume between the resonator and the nozzle; 6 - resonating cavity; 7 - elastic element.

The dispersity of the droplet disintegration, the spray pattern is significantly influenced by the parameters of the acoustic diffuser, and the frequency of the sound waves is determined by the dimensions of the resonator: the depth of the groove, the diameter of the resonator, the distance between the nozzle and the resonator [10].

The state of the theory of the disintegration of liquid droplets sprayed by acoustic sprays does not allow obtaining sufficiently accurate analytical dependences suitable for calculating the average droplet diameter. Therefore, to calculate the median mass diameter of liquid droplets sprayed to acoustic sprays with a rotating resonator, the empirical formula is most suitable [11]:

$$d_k = 0.53 \left( \frac{K_c \rho_a V_a^2}{\rho_l \omega_p^2} \right) ^{1/4} \left( 1 + \frac{0.53 \rho_a \omega_p}{K_c \rho_l V_a} \frac{6 \sigma_w}{\rho_l \omega_p^2} \right)^{1/2} - 1,$$

where $K_c = f \ R_e$ is the coefficient of resistance; $\rho_a$ - density of air, kg / m³; $V_a$ - speed of air flow, m / s; $\rho_l$ - density of the liquid, kg / m³; $r_p$ - the outer radius of the resonator, m; $\omega_p$ - angular velocity of rotation of the resonator, c⁻¹; $\sigma_w$ - the coefficient of the surface tension of the droplet liquid relative to the medium, H / m.

The implementation of expression (1) is shown in Fig. 2.

Figure 2 - Change in the diameter of the droplet of the working fluid, depending on the speed of the resonator of the acoustic sprayer in the presence of air flow

Figure 3 - Trajectory of droplet motion
The speed of the air flow and the speed of the resonator have a significant effect on the diameter of the droplet of the working fluid.

The trajectory of the droplet motion is determined from the expression (Fig. 3) [11]:

\[
Y = \left( \frac{5.25k_o \sqrt{P_o \mu_a}}{d_v^3 \rho_{\infty}} \right) \left( 1 + \frac{V_o \cos\beta}{V_o \sin\beta} \right) V_o \sin\beta/2 - Y \left( V_o \cos\beta/2 - V_e \right).
\]  

(2)

Where \( V_o \) - is the initial velocity of the drop, m/s; \( k_o \) - coefficient of deformation of the drop; \( \mu_a \) - coefficient of dynamic viscosity of air, kg.s/m².

Installation of the sprayer from a number of fruit plantations is determined by the expression:

\[
\ell_\alpha = 0.3...0.4B.
\]  

(3)

Where \( B \) is the row spacing, m.

The average height of the trees that the sprayer will handle is determined from the relation:

\[
h_\alpha = h_p + \ell_\alpha \tan \beta/2,
\]  

(4)

where \( h_p \) - is the average height of fruit trees, m; \( \ell_\alpha \) - Spreading of the spray gun to the side, m; \( \beta \) - angle of spray, deg.

Machining area \( S_{\alpha p} \) is calculated by the expression:

\[
S_{\alpha p} = \pi \ell_\alpha^2 \tan^2 \beta/2.
\]  

(5)

5. Practical significance, proposals and results of implementation, the results of experimental studies.

To investigate the parameters and operating modes of the acoustic sprayer, a laboratory-bench installation was installed.

The effect of the rotational speed of the resonator (0; 500 and 1000 rpm), air pressure (0.08, 0.13 and 0.18 MPa), distance between the nozzle and the resonator (6, 10 and 14 mm) on the radius of the spray using the method of mathematical experiment planning [12, 13].

At the same time, the dispersity of the liquid droplet disintegration and the density of the crown cover of the fruit tree were determined by the drops of the working fluid. The thickness of the coating was determined using cards 50x70 mm in size, hung on the crown of the fruit tree according to the standard scheme [14, 15].

The liquid droplets were collected by a flow trap. To calculate the number and measurement of droplets, a microscope with an inclined tube was used with simultaneous microphotography of liquid droplets. The results of the experiments were processed using Microsoft Excel 2010 software, Mathcad Prime 3.0.

Having analyzed the obtained results made it possible to obtain the regression model of the response surface in the form of a second-order polynomial [16]:

\[
R = 0.969 - 0.00055n + 1.155P - 0.038\ell_p + 0.0032nP + 0.000032n\ell_p + 0.562P\ell_p - 0.00000003n^2 - 31.25P^2 - 0.002\ell_p^2
\]  

(6)

where \( n \) - is the number of revolutions of the resonator, rpm; \( P \) - air pressure, MPa; \( \ell_p \) - distance from the nozzle to the resonator, mm.
Optimum values of the number of rotations of the resonator (613 rpm), air pressure (0.09 MPa), distance from the nozzle to the resonator (8.6 mm) are established. The distance between the nozzle and the resonator of the acoustic sprayer exerts the greatest influence on the radius of the spray nozzle [16].

Studies have shown that by varying the distance between the nozzle and the resonator, it is possible to adjust the spraying angle of the liquid within 25-1600. It should be noted that the direction of the sprayed jet changes in the opposite direction when the cavity of a larger diameter is in close proximity to the diameter of the nozzle. Therefore, the ratio of the diameter of the nozzle to the diameter of the resonator should be taken equal to 1.

After processing the results of microscopy, the performance of the acoustic sprayer is determined (Table 1).

| Quality indicators                        | Meaning of indicators |
|-------------------------------------------|-----------------------|
| Median-mass index, mkm                    | 130                   |
| Average arithmetic diameter, micron       | 115                   |
| Sprayer width, m                         | 1.6                   |
| The number of droplets with a size of 100 ... 150 μm,% | 70                   |
| The degree of surface coating,%          | 27.0                  |
| Coating density, pcs / cm²               | 30–120                |
| Uneven coverage, %                       | 29.4                  |

Table 1 - Performance of the acoustic sprayer

The density of coating the drops of the leaf surface is an important indicator characterizing the quality of processing the inner volume of the crown. This figure when twisting the spray of the spray is 42 pcs. / cm², and without twisting - 15 pcs. / cm². When the fruit tree is treated on both sides with the proposed acoustic sprayer, this indicator doubles simultaneously (Figures 4, 5) [17, 18, 19, 20]. The technical characteristics of the acoustic sprayer are given in Table 2.

| Parameter name                        | Value       |
|---------------------------------------|-------------|
| Working fluid consumption, 1 / min   | 0.3–0.8     |
| Air consumption, m³ / h               | 4.8         |
| Pressure in the air supply network, MPa | 0.1–0.15   |
| Liquid pressure, MPa                  | 0.03–0.08   |
| Revolutions of the resonator, rpm     | 500–1000    |
| Cavity drive                          | electric    |
| Weight, kg                           | 0.3         |

Table 2 - Technical characteristics of acoustic sprayer

Figure 4 - General view of the acoustic sprayer

Figure 5 - Acoustic sprayer in operation
Conclusion

The conducted researches have shown that the indicators of the work of the proposed acoustic liquid atomizer meet the agrotechnical requirements imposed on plants for the processing of fruit plantations.

Application of the developed acoustic liquid atomizer in the technological process of protection of undersized fruit plantations allows to reduce the consumption of working fluid by 10 times; increase the sprayer's productivity by 2 times; get a pure discounted income, equal to 16415 rubles. / ha.

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