






Theoretical Foundations of Forming Working Fluids into Highly Dispersed Droplets Using Aerial Vehicles

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Abstract. *The article discusses the possibility of applying precision and smart agriculture while reducing the environmental impact of chemical treatments, associated with drones that form highly dispersed droplets. This allows for the protection of agricultural, medicinal, and other plants from pests and diseases, as well as targeted fertilization with liquid mineral fertilizers during the growing season, ensuring uniformity of nutrient concentration. The targeted use of drones in various agricultural operations can reduce labor requirements and also decrease working time. The hydraulic systems of UAVs and their working elements are aimed at improvement and are relevant issues of today. In addition, with the help of a special camera installed on the UAVs, image processing over the internet and machine learning algorithms assists in studying the precise results of agricultural activity, future achievements, shortcomings, and challenges. The article also examines the hydro-and aerodynamic forces acting on a thin curtain of liquid ejected from the annular slot of a turbulent tedder developed by the authors. This technological process investigates the stages of destruction of a two-phase (air-droplet) jet, resulting in the formation of large droplets, the physical essence of the Weber number, and elaborates on the likelihood that small droplets have probabilistic characteristics. The ability of the working medium to break down under the influence of modifiers is assessed by the increase in the Weber number. ($10 \leq We_{\text{кр}} \leq 10^5$). Using the UAVs, it was found that for fan spray nozzles the Weber number $We=42$, while for the proposed turbulator spray nozzles during the spraying of two-phase flow $We=85$, which confirmed the validity of the working hypothesis.*

Keywords: *UAV, tedder, turbulence, droplets, hydrodynamics, aerodynamics, dispersity*

1 Introduction

Today, with the increase in the world's population, the demand for food is also rising. This, in turn, increases the demand for naturally grown food products. In this context, there is a need for the efficient use of land, water, and labor resources, as well as the sustainable development of agriculture.

Agriculture is one of the promising sources of strengthening the country's export potential, along with meeting the population's demand for food, and the processing industry for high-quality raw materials.

In world practice, various sprayers and spraying methods have been developed to increase the efficiency of the decomposition of working fluids using sprayers used in the chemical treatment of crops.

Traditional farming methods are insufficient to meet the existing requirements, which leads to a decrease in the share of the agricultural sector, as well as to the adaptation of used land to other industries. Most agricultural activities are heavily dependent on manual and mechanized labor, which leads to increased costs and working hours. Even the rapid development of mechanization of all agricultural activities cannot completely minimize human involvement. Consequently, alongside mechanization, automation in agriculture has become critically important. This project focuses on automating agricultural machinery, particularly through the use of UAVs (Unmanned Aerial Vehicles), which enable precise and smart farming management while reducing the environmental impact of chemical treatments.

Agricultural UAVs equipped with high-dispersion spraying systems can be effectively utilized for:

- Crop protection against pests and diseases in agricultural, medicinal, and other plants,
- Targeted liquid fertilizer application during the vegetation period, ensuring uniform nutrient concentration and optimized feeding.
- "The targeted application of UAVs (Unmanned Aerial Vehicles) for various agricultural operations enables significant reductions in labor requirements and operational time.
- The aforementioned factors necessitate comprehensive scientific-theoretical and practical research to implement intelligent spraying systems in Uzbekistan's agricultural production. These systems would allow for precise, measured, and environmentally-conscious chemical treatment of crops using agricultural drones, minimizing ecological impact while maintaining targeted application efficiency.

The development of innovative scientific-technical solutions focused on generating highly dispersed droplets is of critical importance for creating resource-efficient technologies and sprayers used in plant nutrition, pest/disease control, and weed management. In this regard, priority research tasks include:

1. Developing a structural design for a dispersion device capable of forming highly dispersed droplets, specifically adapted for low-volume fan sprayers;
2. Substantiating its technological operational process;
3. Determining optimal parameters and operating modes for the device;
4. Producing an experimental prototype of the dispersion device;
5. Conducting field tests and implementing the practical application.

These targeted scientific investigations represent crucial objectives in advancing precision agricultural technologies.

2 Materials and methods

Elongation The development of atomizers as key components of spraying equipment, along with research on substantiating and improving their technological parameters and operating regimes, has been studied by V.N. Stelmakh, F.Sh. Khafizov, A.N. Ishmatov, Mireia Altimira, Gary J. Dorr, B. Utepov, B. Yusupov, and others [1-17]. V.N. Stelmakh proposed the following expression for determining the mass-median diameter of droplets produced by a liquid atomizer:[5]:

$$d = 1,48 \left(\frac{q \cdot \kappa}{\rho_j \Omega^3 R_o^{\frac{5}{2}}} \right)^{\frac{2}{7}}, \quad (1)$$

where:

- q – liquid flow rate, l/min;
- γ – surface tension of the liquid, N/m;
- Ω – air flow rate, Pa;
- R_o – disk radius, m;
- ρ_j – liquid density, kg/m³.

The working fluid atomization device developed by F.Sh. Khafizov, V.G. Afanasenko, and Ye.V. Boevlar was specifically designed for fuel oil atomization, making it unsuitable for chemical spraying applications in agro-industrial complexes. The authors recommend using the following expression to determine the diameter of fine droplets produced by this device [6]:

$$d_\kappa = \frac{2\kappa}{\xi \cdot \rho \cdot u^2}, \quad (2)$$

where:

- γ – surface tension of the liquid, N/m;
- ξ – droplet drag coefficient;
- ρ – density of the sprayed liquid, kg/m³;
- u – velocity difference between the liquid droplet and the incoming gas stream, m/s.

The research conducted by B.B. Utepov and B.Yu. Yusupov focused on substantiating the key parameters and operating regimes of pneumatic-disc and disc-type rotary tedder for low-volume spraying of working fluids on cotton plants. Their work investigated the droplet breakup process under the influence of a perpendicularly directed aerodynamic flow acting on individual capillaries (Figure 1).

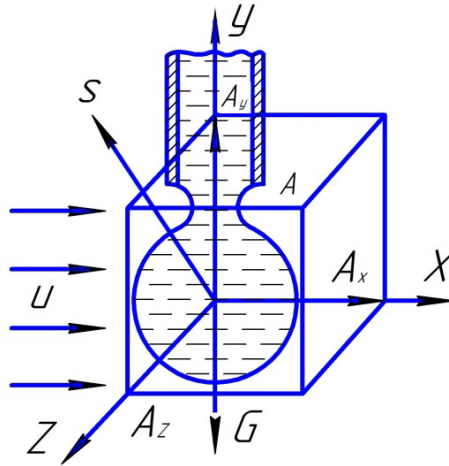


Figure 1. Schematic diagram of capillary envelopment by aerodynamic force vectors.

The core theoretical approach of this work proposes that the force acting on a droplet during its envelopment by a perpendicularly directed aerodynamic flow around a capillary can be determined using the following expression:

$$R_A = C_A \frac{\pi d_T^2}{4} \cdot \frac{\rho_x U^2}{2} \tag{3}$$

or

$$R_A = A_X = C_X \frac{\pi d_T^2}{4} \cdot \frac{\rho_x U^2}{2}, \tag{4}$$

Where:

- S_A -Aerodynamic force coefficient;
- d_T - Theoretical droplet diameter, mkm;
- ρ_x - Air density, kg/m³;
- U - Aerodynamic airflow velocity, m/s.

The coefficient of surface resistance force $S_x=f(Re)$, (where Re is the Reynolds number) is determined as follows:

$$Re = \frac{Ud_t}{\nu},$$

where:

ν – kinematic viscosity of the liquid, m²/s

Figure 2 shows the variation graph of the surface drag coefficient $S_x = f(Re)$ versus airflow velocity U .

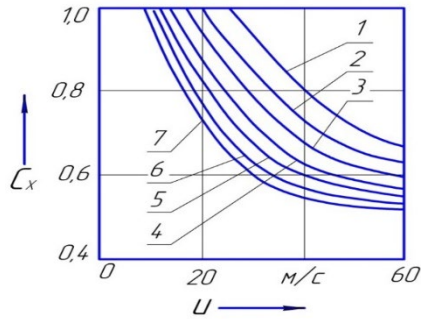


Figure 2. Graph of the change in the coefficient of surface resistance $S_x = f(\text{Re})$ relative to the air flow velocity U

According to the above graph, the surface resistance coefficient $S_x = f(\text{Re})$, whose air flow rate varies with respect to U $d_t = 80$ to 200 μm under normal condition ($v = 1.45$ m^2/s , $t = 15^\circ$, $P = 760$ mm Hg).

The diameters of the primary large droplet released outside the capillary column under the action of aerodynamic force A are determined under the following conditions.

$$S^2 = A^2 + G^2, \quad (5)$$

Where:

$G = \pi d_t^2 \rho_j g / 6$ – gravitational force, N;

$S = 2\pi r k$ – surface tension force, N.

Based on the results of the analysis, a working hypothesis was adopted that the formation of highly dispersed droplets can be achieved by exposing the kinetic energy of local and main air flows generated by a spray fan to a thin liquid curtain ejected from the rectification slot.

3 Results

The highly dispersed droplets formed in the proposed rectifier begin to form under the influence of the kinetic energy of the local and main aerodynamic airflow flowing through the spray pipe, symmetrically forming an axis on the fan side, in addition to the flow rate of the working fluid ejected from the slot. We can express a mathematical model of the kinetic energy of the liquid ejected from the above-mentioned straightening slit, local and main turbulent air flows acting on a thin liquid curtain, as [18-20]:

$$E_{y,m} = E_c + E_{to} + E_x = \frac{m_c v_c^2}{2} + \frac{m_{to} v_{to}^2}{2} + \frac{m_x v_x^2}{2}, \quad (6)$$

E_c, E_x, E_{30} -in this case, respectively, the kinetic energy of hydrodynamic, basic and local turbulence air flows, leading to the destruction of a thin liquid curtain, J.

The Weber number for aerosol spray rectifiers using UV radiation was $We=42$, for the proposed rectifier- $We=85$ during the decomposition of a two-phase spray burner, and it was shown that the accepted basic working hypothesis is correct.

We see that the sizes of highly dispersed droplets formed by a strong turbulizing effect have the property of randomness. Weber's rule for aerosol spray rectifiers using UV radiation was $we=4$ th

4 Conclusion

1. Due to the expansion of the cylindrical part of the rectifier speaker at an angle β and the action of a local turbulent air flow from the turbulator openings, the formation of highly dispersed droplets in a short jet burner from a thin liquid curtain was achieved.
2. Due to the expansion of the cylindrical part of the rectifier speaker at an angle β and the action of a local turbulent air flow from the turbulator openings, the formation of highly dispersed droplets in a short jet burner from a thin liquid curtain was achieved.
3. Savings in working fluid consumption are provided with the internal and external radii of the proposed rectifying annular gap $r_1 = 3.4$ mm, $r_2 = 4$ mm, respectively, the expansion angles of the flow expander and spray burner $\alpha = 45^\circ$, $\beta = 15^\circ$, the flow coefficient of the working fluid $m = 0.47$.
4. The air flow coefficient $m_x = 1$, the number of holes in the turbulator $z = 16$ pieces, the angle of inclination of the holes of the conical turbulator relative to its axis $\gamma = 15^\circ$, the velocity of the air flow exiting the spray speaker $v_x = 52-54$ m/s, the turbulence flow rate at the local flow rate of air coming from the holes of the turbulator $Q_l=0,01\text{m}^3/\text{s}$ obtaining the effect becomes possible.
5. The ability of the turbulator of the working fluid to decompose inside the condensation chamber, estimated by the increasing Weber number ($10 \leq We_{kr} \leq 10^5$), turned out to be equal to $We=42$ for rectifiers of sprayers with a fan using UV radiation and $We=85$ for the proposed rectifiers with turbulators during the decomposition of a two-phase spray burner. The ability of the turbulator of the working fluid to decompose inside the vessel.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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