Hydro-aerodynamics of a turbulizer corrector two-phase spray face

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Abstract. This article explores the hydro- and aerodynamic forces acting on a thin layer of fluid that erupts from a turbulent rectifier ring loop developed by the authors. The stages of the decomposition process of a two-phase (air + droplet) torch in which large droplets are formed in this technological process, the physical nature of the Weber number in this process, and the probabilistic nature of highly dispersed droplets are thoroughly covered.

1. Introduction
The issues of agricultural reform and food security are undoubtedly important, and great attention is given to the consistent development of the agro-industrial complex and its engine, i.e., the driving force of diversified farms [1], as well as supporting the farming movement in the agricultural sector-research is underway to phase out cotton and grain production in cluster form.

Cotton has been grown for more than 2,000 years, with 32-34 million hectares in 84 countries. It is one of the leading economies of the United States, India, Brazil, Pakistan, Egypt, and Uzbekistan [2]. Defoliation plays an important role in accelerating the ripening of cotton and its short-term harvesting by machines.

According to the research of leading scientists of the world and Uzbekistan [3,4,5,6,7,8,9], the optimal size is 10-15 microns for disinfection of flying insects living under the leaves of agricultural plants, pests of plants and plants. Drops of 30–150 microns are optimal for decontamination, defoliation and dehydration processes, and for weed control, it is necessary to form droplets of 100–300 microns using spray tools [3,4].

2. Materials and Methods
The highly dispersed droplets formed by the proposed corrector begin to form under the influence of the kinetic energy of local and main aerodynamic air currents flowing through a nozzle (2), symmetrically generated by a fan, in addition to working fluid flowing out of an annular hole Figure 1 [10, 11.12].
Figure 1. Technological process scheme of turbulizer: 1 – sheath; 2 – ring slot; 3 – central tube; 4 - disc adjuster; 5 - sloping ditch; 6 - flow expander; 7 - conical turbulizer; 8 - hole; 9 - adjustment groove; \( q_f \) – transmitted working fluid; \( \alpha, \beta \) – accordingly flow expander, expansion angles of the spray torch; \( h \) – annular slit width; \( \Delta p \) – working fluid pressure.

The mathematical model of the kinetic energy of the local and main turbulent air currents acting on the thin liquid membrane of the liquid flowing out of the above-mentioned rectifier ring hole can be expressed as follows [13]:

\[
E_{ov} = E_f + E_{lo} + E_a = \frac{m_f v_f^2}{2} + \frac{m_{lo} v_{lo}^2}{2} + \frac{m_a v_a^2}{2},
\]

(1)

Here, \( E_f, E_a, E_{lo} \) - the kinetic energy of the hydrodynamic, primary, and local air turbulence flows leading to the disintegration of the thin liquid membrane, \( J \).

The local large air droplets separated from the thin liquid membrane are affected by the gravitational force \( G \) and the aerodynamic drag force \( R \) of the local air flow. The \( R > G \) condition must be met when forming highly dispersed droplets (Figure 2) [14,17].

Figure 2. The multi-stage turbulent decomposition process of the primary drop: 1- primary drop; 2- two-phase liquid membrane; 3- local airflow power lines; 4- highly dispersed droplets; \( P_a, P_f \) - air and fluid pressure, respectively; \( F_a, F_f \) - hydrodynamic and aerodynamic forces, respectively.
We can express the differential equation of motion of droplets of mass \( m_d \) in the air stream as follows [15,16]:

\[
\frac{m_d du}{dt} - R + G = 0.
\]  

(2)

The two-phase spray consists of a fake local airflow and the first large droplets. It serves to form highly dispersed droplets under the influence of aerodynamic forces of the local and main air flow \( (F_h + R) \) (Figure 2).

The local air currents transmitted through the cylindrical holes opened in the turbulizer form a two-phase (drop + air) annular curtain 2 from primary droplet 1 separated from the thin working fluid fragments. The primary droplets are exposed to the gravitational force \( G \), hydrodynamic force \( F_h \), surface tension force \( F_s \), aerodynamic force \( R \), momentum transfer force \( F_m \), resistance \( F_{res} \) and inertia \( F_{inert} \) forces to form highly dispersed droplets whose diameters are close to each other (Figure 2) [17]:

\[
F_h = \pi d_0^2 \Delta p \left( \frac{2 + 3 \cos \varphi - \cos^3 \varphi}{12} \right),
\]  

(3)

Here, \( d_0 \) – diameter of the primary drop, m; \( \varphi \) – angle of change of flow axis, grad.

\[
F_s = \pi \kappa d_{hole}^4;
\]  

(4)

\[
F_m = \left( \frac{\pi}{3} \right) \rho_f w_{lo}^2 \cdot d_{hole}^2;
\]  

(5)

\[
F_{res} = \left( \frac{\pi}{8} \right) d_0^2 \cdot c_d \rho_f w_{lo}^2;
\]  

(6)

\[
F_{inert} = \frac{(\rho_f + 0.5 \rho_a) Q_{lo}}{3\pi (6/\pi)^{2/3} V_{lo}^{2/3}},
\]  

(7)

Here, \( \kappa \) - surface tension coefficient, N/m; \( d_{hole} \) – the diameter of the cylindrical hole in the turbulizer, m; \( \rho_f \) – working fluid density, kg/m³; \( \rho_a \) – air density, kg/m³; \( w_{lo} \) – local air flow rate, m/s; \( c_d \) – the surface of the primary drop, m²; \( V_{lo} \) – the volume of local air flow, m³.

In the first stage, the balance of forces acting on the fluid flow is determined by the following expression:

\[
F_h + F_m = F_s + F_{res} + F_{inert}.
\]  

(8)

We describe the concentration of air in the coefficient

\[
\chi = \frac{m_s}{Q_{lo}},
\]  

(9)

where \( m_s \) is the mass of highly dispersed droplets released per second and \( Q_{lo} \) is the mass of local air transmitted to the turbulizer condensing chamber per second.

The number of holes drilled in the turbulizer is large, which creates a strong turbulization effect in the condensing chamber around points A and C, allowing the formation of highly dispersed droplets in a short spray torch (Fig. 3).
Figure 3. Scheme for determining the turbulence effect: 1- current expander; 2- speakers; 3-turbulizer; 4- cylindrical holes; 5- turbulization effect, 6- two-phase flare; 7- highly dispersed drops.

3. Results and Discussion

The number of holes in the turbulizer is determined by the following expression:

\[ z_T = \frac{\pi D_T}{\ell_0} = \frac{3.14 \cdot 40}{8} = 15.7 \approx 16 \text{(count)} \]  

(10)

Here, \( D_T \) – turbulizer diameter, mm; \( \ell_0 \) - range of cylindrical holes, mm.

The local air flow rate \( (m^3/s) \) transmitted through the cylindrical bores of the turbulizer is determined by the following expression:

\[ Q_{ho} = \mu_a z \frac{\pi \Delta l_{hole}^2}{4} \sqrt{2 \frac{\Delta \rho}{\rho_a} \cdot \cos \gamma} = \mu_a z \frac{\pi \Delta l_{hole}^2}{4} \nu_a \cos \gamma, \]  

(11)

Here, \( \mu_a \) – air consumption coefficient, \( \mu_a=1 \); \( z_T \) – number of cylindrical holes in the turbulizer, pcs; \( \gamma \) – the angle of inclination of the holes in the conical turbulizer relative to the axis of the turbulizer, degrees; \( \Delta \rho \) – air pressure, Pa; \( \rho_a \) – density of air, kg/m\(^3\); \( \nu_a \) – the velocity of the air flow along the axis coming out of the spray speaker, \( \nu_a = 52...54 \text{ m/s} \) equivalent.

In the calculations, the coefficient \( \mu_a \) is assumed to be 1 because the air density is small relative to the working fluid density.

Figure 4 shows a graph of the change in the local air flow transmitted through the cylindrical holes of the turbulizer according to expression (14) depending on the parameters \( \gamma \) and \( z \).
Figure 4. Graph of the dependence of the local air flow through the cylindrical bores of the turbulizer on the parameters $\gamma$ and $z$: 1 - $\gamma=10^\circ$; 2 - $\gamma=15^\circ$; 3 - $\gamma=20^\circ$.

The disintegration capacity of the working fluid turbulizer inside the condensing chamber is assessed by increasing the Weber number ($10 \leq We_{cr} \leq 10^5$).

Suppose that the local air pressure acting on the surface of a large primary droplet is equal to $P_a = \rho_d \nu_d^2 / 2$. According to Laplace's expression, the force of surface tension on a liquid sphere $P_f = 4\kappa/d_0$. The value of this pressure ratio is called the Weber number, which is defined by the following expression [14]:

$$P_a / P_f \approx We = \rho_d \nu_d^2 d_0 / 8 \kappa = 1.45 \cdot 75.5^3 \cdot 0.006 / 8 \cdot 0.073 = 85$$

Here, $\rho_d$ – working fluid density, kg/m$^3$; $\nu_d$ – drop velocity, m/s; $\kappa$ – surface tension coefficient (for water $\kappa=0.073$ N/m).

The Weber number is $We=42$ for conventional OBX-600 fan spray nozzles, $We=85$ for the proposed two-phase spray torch breaker for the proposed turbulizer nozzles, and the accepted basic working hypothesis proved correct.

We see that the sizes of highly dispersed droplets formed by two-stage accelerated decay around points A and C under the influence of a strong turbulization effect have the property of randomness. The main parameters of such drops and the laws of distribution obey the laws of probability theory.

4. Conclusion

Based on theoretical developments, the strong local air flow rate around the point A to achieve a stable turbulization effect $Q_{lo}$ involves the number of cylindrical holes in a conical turbulizer $z = 16$, and the angle of inclination of the cylindrical holes relative to the turbulizer axis $\gamma=15^\circ$ allowed us to obtain the expected turbulization effect through the centre. In this case, the local air flow consumption, which allows us to obtain a turbulization effect, is equal to $Q_{lo} = 0.01$ m$^3$/s.

We see that the size of the highly dispersed droplets formed by the two-stage accelerated disintegration around points A and C under the effect of a strong turbulization effect has the property of randomness. This shows that the basic parameters of such drops and the laws of distribution obey the laws of probability theory.
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