# ANNOTATION

dissertations for the degree of Doctor of Philosophy PhD in the specialty
8D07180 – Technological machines and equipment (on branch)

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## Hydrodynamics, heat and mass transfer and dust collection in single-zone and two-zone combined gas-cleaning apparatus

**The purpose of the dissertation research:** development of the scientific foundations of hydrodynamics, dust collection and heat and mass transfer processes in single-stage and two-stage (single-zone and two-zone) apparatuses, with two-way gas flow supply, shock-vortex and cyclone-vortex action, creation of scientifically based calculation methods, recommendations for operation and design, verification of the results obtained in experimental industrial conditions and implementation in industry.

**The task of research:**

- classification of single-stage and two-stage heat and mass transfer and dust collecting devices;
- experimental study of hydrodynamic characteristics, mass transfer and dust collection of a shock-vortex device with a two-way gas flow supply and obtaining calculated dependences of hydraulic resistance, the amount of liquid retained, the gas content of the layer, the coefficients of mass transfer in the gas phase and the efficiency of dust collection;
- experimental study of hydrodynamic characteristics, mass transfer and dust collection of a shock-vortex apparatus with a tubular nozzle and obtaining the calculated dependences of hydraulic resistance, amount of retained liquid, gas content of the layer, mass transfer coefficients in the gas phase and heat transfer, dust collection efficiency;
- experimental study of hydrodynamic characteristics, mass transfer and dust collection of a cyclone-vortex device and obtaining calculated dependences of hydraulic resistance, the amount of liquid retained, the gas content of the layer, the coefficients of mass transfer in the gas phase and the efficiency of dust collection;
- development of scientifically based engineering methods for calculating the developed devices and recommendations for design and operation;
- verification of the results obtained in experimental industrial conditions and implementation in industry.

**Research methods:** methods of physical research for obtaining experimental data on hydrodynamics (hydraulic resistance, amount of retained fluid), coefficients of mass transfer in the gas phase and heat transfer, dust extraction efficiency, methods of mathematical modeling.

**The main provisions (proven scientific hypotheses and other conclusions that are new knowledge) submitted for defense:**

- based on the analysis of the mechanisms of interaction of gas and liquid flows, a classification of single-stage and two-stage heat and mass transfer and dust collecting devices is proposed;

- with two-way gas supply, based on the revealed hydrodynamic regularities of the shock interaction of the gas flow with the liquid, fluid ejection and vortex interaction of gas and liquid flows in the volume of a regularly placed nozzle, equations are obtained for calculating the hydraulic resistance of the ejection zone and the vortex contact zone, their total resistance, the amount of liquid retained and the gas content of the layer of the nozzle zone;

- based on the revealed regularities of the shock interaction of the gas flow with the liquid, the vortex interaction of gas and liquid flows in the volume of a regularly placed nozzle of a two-stage shock-vortex device with a tubular nozzle, equations are obtained for calculating the hydraulic resistance of the shock and vortex contact stages, their total resistance, the amount of liquid retained and the gas content of the layer of the nozzle zone;

- based on the conditions of movement of the coolant in the pipes, taking into account local resistances and friction resistances, an equation for calculating hydraulic resistance is obtained;

- based on the revealed patterns of the gas flow movement in a spiral, the vortex interaction of gas and liquid flows in the volume of a regularly placed nozzle of a two-stage cyclone-vortex apparatus, equations are obtained for calculating the hydraulic resistance of the cyclone and vortex contact stages, their total resistance, the amount of liquid retained and the gas content of the layer of the nozzle zone;

- on the basis of the turbulent-diffusion mechanism of capturing solid particles on liquid droplets, a mathematical description of the turbulent and diffusive deposition of solid particles in the impact zone and a regularly placed nozzle is given, and using a dissipative approach, calculated dependences are obtained for determining the coefficients of mass transfer in the gas phase and heat transfer;

- a mathematical model of centrifugal and inertial particle deposition in a cyclone stage of a two-stage cyclone-vortex apparatus has been developed on the basis of a centrifugal-inertial mechanism for capturing solid particles.

**Description of the main results of the study.**

When carrying out laboratory studies of the developed designs of apparatuses: a single-stage two-zone apparatus with a regularly placed nozzle and a two-way gas flow supply (ATWGFS), two-stage shock-vortex action apparatus with a regular tubular nozzle (ASVA with TN) and cyclone-vortex action (ACVA), graphic dependences were obtained and calculation equations of hydrodynamic characteristics, parameters of heat and mass transfer and dust collection.

**Hydrodynamic characteristics.** The nozzle zone of the ATWGFS and ACVA devices contain a plate nozzle; a tubular nozzle is placed in the ASVA device with TN. ***The hydraulic resistance*** of the packing zone is determined by the well-known Darcy-Weisbach dependence. The resistance coefficient included in it for the plate nozzle has the form:

$$\xi_L = 0{,}43 \cdot \theta_{\text{в}} \cdot \theta_{\text{р}} \cdot \frac{\mathrm{Re}_{ж}^{0,25}}{\mathrm{Re}_{г}^{0,1}}, \quad (1)$$

tubular

$$\xi_L = 0{,}195 \cdot \theta_{в} \cdot \theta_{р} \cdot \mathrm{Re}_{ж}^{0,1}, \quad (2)$$

where $\theta_b$ - the coefficient characterizing the degree of interaction of vortices in the vertical direction; $\theta_p$ - the coefficient characterizing the degree of interaction of vortices in the radial direction; $\mathrm{Re}_ж$ and $\mathrm{Re}_г$ – Reynolds criteria for gas and liquid related to the equivalent diameter of the nozzle.

The amount of liquid retained (ALR) of the ATWGFS and ASVA devices with TN:

$$h_o = A \cdot \xi_L \cdot \frac{H}{t_в} \cdot \frac{\rho_г W_г^2}{2 \cdot \rho_{ж} \cdot g \cdot \varepsilon_0^2}, \quad (3)$$

where is the experimental coefficient A: for ATWGFS - 0,506; for ASVA с TN - 0,65.

ALR apparatus ACVA:

$$h_0 = (h_{\text{пл}} + h_k) \cdot \frac{H}{t_b}, \quad (4)$$

in which the film component $h_{пл} = \delta_{пл}\,(1-\varepsilon_o)$. The droplet component of $h_к$ is determined on the basis of the energy conservation balance equation:

$$h_k = 0{,}88 \cdot \xi_L \frac{\rho_г W_г^2}{2g\rho_ж} \cdot \frac{(2-\varepsilon_0)(1-\varepsilon_0^2)}{\varepsilon_0^2}. \quad (5)$$

To determine the hydraulic resistance of the ejectionzone of the ATWGFS and ASVA devices with TN, the following equation was obtained::

$$\Delta P_э = \lambda \frac{\rho_г \cdot W_{\text{пат}}^2}{2} + \rho_ж g[(1-\varphi_э)h_д]. \quad (6)$$

where $\varphi_э$ – gas content in the ejection zone; $h_д$ - the dynamic liquid level (m) for the ATWGFS is determined through the diameter and depth of the resulting funnel; for an ATWGFS with a TN , it is determined by the amount of liquid displaced into the nozzle zone.

***The hydraulic resistance of the cyclone stage is determined based on the additivity of the resistances***. At the same time, for: the input section ($\xi_{\text{вх}} = 3{,}32$); ring zone ($\xi_{\text{кольц}} = 4{,}1$); output section ($\xi_{\text{вых}} = 5{,}7$).

**Heat and mass transfer parameters.** To calculate the mass transfer coefficient in the gas phase, the equations are received:

for ATWGFS:

$$\beta_{гs} = 5{,}53\left(\frac{\varphi}{1-\varphi}\right)^{1/4} \cdot \left[\frac{D_г^2 \cdot C_k \cdot U_г^3 \cdot (h_0 - h_{пл})}{\varphi_{яч}(t_b - h_{пл}) \cdot d_k \cdot \nu_г}\right]^{1/4} \quad (7)$$

for ASVA с TN:

$$\beta_{гs} = 10{,}4\left(\frac{\varphi}{1-\varphi}\right)^{1/4} \cdot \left[\xi_L \cdot \frac{D_г^2 \cdot U_г^3}{\varphi_{яч} \cdot t_в \cdot \nu_г}\right]^{1/4} \quad (8)$$

for ACVA:

$$\beta_{гs} = 6{,}22/(1-\varepsilon)^{1/4} \cdot \left[ D_г^2 \cdot \frac{\xi_L (1-\varepsilon)\cdot U_г^3}{\delta_{пл}\cdot \varphi_{яч}\cdot \nu_г} \right]^{1/4} . \quad (9)$$

***The heat transfer coefficients are calculated according to the formulas***:

for ASVA с TN:

$$\alpha = 7{,}28 \cdot \left(\frac{\varphi}{1-\varphi}\right)^{1/4} \cdot c_p \cdot \left[\xi_L \cdot \frac{D_г^2 \cdot U_г^3}{\varphi_{яч}\cdot t_в \cdot \nu_г}\right]^{1/4} \quad (10)$$

for ACVA:

$$\alpha = 4{,}35/(1-\varepsilon)^{1/4} \cdot c_p \cdot \left[ D_г^2 \cdot \frac{\xi_L (1-\varepsilon)\cdot U_г^3}{\delta_{пл}\cdot \varphi_{яч}\cdot \nu_г} \right]^{1/4} \quad (11)$$

**Dust collection parameters.** A mathematical model of inertial diffusion deposition of solid particles was used to calculate the efficiency of dust collection**.** Using the theory of locally isotropic Kolmogorov-Obukhov turbulence, equations for calculating the coefficients of turbulent diffusion are obtained:

for the ejection zone in ATWGFS and ASVA devices with TN:

$$D'_т = B_1 \cdot (\xi_{пат})^{1/3} \cdot \left(\frac{\rho_г}{\rho_ж}\right)^{1/3} \cdot \left(\frac{1}{\Delta h}\right)^{1/3} \cdot d_{k_1}^{4/3} \cdot W_{пат} \cdot Stk, \quad (12)$$

where $B_1 = 4{,}5\cdot 10^{-2}$ – for ATWGFS; $B_1 = 2\cdot 10^{-2}$ – for ASVA с TN;

for the nozzle area of the devices ATWGFS, ASVA с TN, ACVA:

$$D''_т = B_2 \cdot (\xi_L)^{1/3} \cdot (1-\varepsilon_0)^{1/3} \cdot \left(\frac{H}{t_в}\right)^{1/3} \cdot \left(\frac{\rho_г}{\rho_ж}\right)^{1/3} \cdot \left(\frac{1}{h_0}\right)^{1/3} \cdot d_k^{4/3} \cdot u_г \cdot Stk\ , \quad (13)$$

where $B_2 = 8{,}85\cdot 10^{-2}$ – for ATWGFS; $B_2 = 4\cdot 10^{-2}$ – for ASVA с TN; $B_2 = 8{,}38\cdot(1-\varphi)$ – for ACVA.

A mathematical model of centrifugal and inertial particle deposition in the cyclone stage of the ACVA apparatus has been developed on the basis of the centrifugal-inertial mechanism for capturing solid particles. The coefficient included in it, depending on the design ratios of the dry stage of the apparatus, is calculated by the equation:

$$C_к = \frac{\pi \cdot D_ц^2}{a \cdot в_1} \cdot \left[1 - \left(\frac{d}{D_ц}\right)^2\right] \cdot \left(\frac{2\cdot h_T}{D_ц} - \frac{h_в}{D_ц}\right) + \left[\left(\frac{d}{D_ц}\right)^2 - \left(\frac{d_1}{D_ц}\right)^2\right] \cdot \left(\frac{4\cdot H_ц}{D_ц} + \frac{4\cdot H_к}{D_ц}\right) \quad (14)$$

The constructive relations in the equation have the form: $a = 0{,}66 \cdot D_ц$; $в_1 = 0{,}26 \cdot D_ц$; $d = 0{,}59 \cdot D_ц$; $d_1 = 0{,}4 \cdot D_ц$; $h_T = 1{,}74 \cdot D_ц$; $h_в = 0{,}3 \cdot D_ц$; $H_ц = 2{,}26 \cdot D_ц$; $H_к = 2 \cdot D_ц$.

**Substantiation of the novelty and importance of the results obtained.**

The importance of classifying single-stage and two-stage heat and mass transfer and dust collecting devices is to take into account the traditional mechanisms of interaction of flows, as well as determining the path of their possible combination.

The novelty of the equations for calculating the hydraulic resistance of the shock and vortex contact steps, the amount of fluid retained, the calculated dependencies for determining the coefficients of mass transfer in the gas phase and heat transfer, the mathematical description of the turbulent and diffusive deposition of solid particles in the impact zone and the regularly placed nozzle is that they are based on the revealed patterns of shock and vortex interaction of the gas flow with the liquid.

The novelty of the equations for calculating the hydraulic resistance of the cyclone and vortex contact stages, the amount of liquid retained, the calculated dependencies for determining the coefficients of mass transfer in the gas phase and heat transfer, the mathematical description of turbulent and diffusive deposition of solid particles in the area of a regularly placed nozzle, as well as the model of centrifugal and inertial particle deposition in the cyclone stage is that they take into account the regularities spiral motion of the gas flow and vortex interaction of the gas flow with the liquid.

The importance of the obtained equations lies in the fact that they form the basis of engineering calculation methods and, along with recommendations for design and operation, allow calculating industrial designs.

**Compliance with the directions of science development or state programs.** The work was carried out in accordance with the research direction of the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan on priority «Rational use of water resources, flora and fauna, ecology» in a specialized scientific direction «Wastewater treatment, gas purification and dust collection systems».

**Description of the doctoral student's contribution to the preparation of each publication.** 30 articles have been published on the topic of the dissertation. The total contribution of a doctoral student is 55-60%. The contribution to the articles is represented by such components as conducting experimental studies, processing the results in the form of tabular values and graphical dependencies, and the calculated equations obtained.