ANNOTATION

of the dissertation for the degree of Doctor of Philosophy (PhD) in the educational programme 8D07180 – Technological Machines and Equipment (by industry)

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Hydrodynamics and mass transfer in an apparatus with vortex interaction of flows under conditions of rotational motion of packing elements

The aim of the dissertation research: to develop the design of an apparatus with a regular rotating nozzle with rectangular blades and a ring rim, to obtain equations for calculating the rotation frequency, hydrodynamic characteristics and mass transfer parameters, to create scientifically based calculation methods, recommendations for operation and design, and to implement technical documentation in industry.

Research objectives:

- to study the patterns of interaction between the gas and liquid phases in the contact zone of a regular rotating nozzle with rectangular blades and a ring rim and to obtain calculated dependencies of the structural components of the liquid phase;
- experimental study of the parameters of the movement of packing elements (rotation frequency), hydrodynamic characteristics (hydraulic resistance, amount of retained liquid, gas content of the layer) of a regular rotating nozzle with rectangular blades and a ring rim when changing operating and design parameters and obtaining calculated dependencies;
- experimental study of mass transfer characteristics (mass transfer coefficients in the gas and liquid phases) when changing operating parameters and obtaining calculated dependencies;
- development of a scientifically based engineering methodology for calculating the developed apparatus and recommendations for design and operation;
- implementation of technical documentation in industry.

Research methods: physical research methods for obtaining experimental data on hydrodynamics (hydraulic resistance, amount of retained liquid, structural components of the liquid phase), rotation frequency of packing elements, mass transfer coefficients in the gas and liquid phases.

Main provisions (proven scientific hypotheses and other conclusions that constitute new knowledge) put forward for defence:

- assuming that the gas movement in the volume of the rotating nozzle is carried out through winding channels, the calculated dependencies were obtained to determine the specific surface area, its volumetric porosity, and the equivalent diameter;
- based on the balance of forces acting on the rectangular blades of the rotating nozzle, equations were obtained to determine its rotation frequency;

- Based on the identified patterns of interaction of vortices in the volume of rotating nozzle elements with rectangular blades and a ring rim equations were obtained for calculating the coefficients of resistance, hydraulic resistance, and the amount of retained liquid ;

- a mechanism has been proposed for breaking up the liquid film moving along rectangular blades and a rim in a rotating packing element into streams and droplets, taking into account the vortex mechanism of phase interaction, and based on the analysis of forces acting on the structural elements of the liquid phase, equations are obtained for determining the average values of film thickness, jet diameter and droplet size ;

- based on the use of a dissipative approach, equations were obtained for determining mass transfer coefficients in the gas and liquid phases.

Description of the main research results.

During laboratory studies of the developed apparatus design with a regular rotating nozzle with rectangular blades and a ring rim, graphical dependencies and calculation equations were obtained for the design parameters of the nozzle , the rotation frequency of the nozzle elements , and the hydrodynamic and mass transfer characteristics.

Design parameters of the nozzle.

Porosity of the rotating nozzle in the apparatus cross-section :

$$\varepsilon_0 = 1 - \frac{0{,}785 \cdot d_{\text{тр}}^2 + 8 \cdot b \cdot cos\propto \cdot l + \pi \cdot d_{\text{об}} \cdot \delta}{t_{\text{р}}^2} \tag{1}$$

Volumetric porosity of a regular rotating nozzle:

$$\varepsilon = 1 - \frac{0{,}785 \cdot d_{\text{тр}}^2 \cdot t_{\text{в}} + 8 \cdot cos\alpha \cdot l \cdot \delta_{\text{лоп}} + 3{,}14 \cdot d_{\text{об}} \cdot h_{\text{об}} \cdot \delta_{\text{об}}}{t_{\text{тр}}^2 \cdot t_{\text{в}}} \tag{2}$$

Equivalent diameter of a regular rotating nozzle:

$$d_{\text{экв}} = \frac{4 \cdot \left[t_{\text{тр}}^2 \cdot t_{\text{в}} - \left(0{,}785 \cdot d_{\text{тр}}^2 \cdot t_{\text{в}} + 8 \cdot cos\alpha \cdot l \cdot \delta_{\text{лоп}} + 3{,}14 \cdot d_{\text{об}} \cdot h_{\text{об}} \cdot \delta_{\text{об}}\right)\right]}{3{,}14 \cdot d_{\text{тр}} \cdot t_{\text{в}} + 16 \cdot b \cdot l + 6{,}28 \cdot d_{\text{об}} \cdot h_{\text{об}}} \tag{3}$$

Rotation frequency of nozzle elements.

$$\omega_{вр} = \frac{1{,}7}{\varepsilon} \cdot \sqrt{\frac{(\rho_г \cdot W_{\text{г}}^2 - \rho_{\text{ж}} W_{\text{ж}}^2) \cdot S \cdot \sin\alpha \cdot K}{2mR + \rho_{\text{г}} R^2 \cdot S \cdot \sin\alpha \cdot tg\alpha}} \tag{4}$$

Hydrodynamic characteristics. The hydraulic resistance of the packing zone is determined by the well-known Darcy-Weisbach relationship. The resistance coefficient included in it for a regular rotating nozzle with rectangular blades and a ring rim is as follows:

$$\xi_L = 0{,}212 \cdot \theta_{\text{в}} \cdot \theta_p \cdot \sqrt{\frac{\mathrm{Re}_ц \cdot \mathrm{Re}_ж}{\mathrm{Re}_Г}} \tag{5}$$

Amount of retained fluid:

$$h_o = 0,476 \cdot \xi_L \cdot \frac{H}{d_{экв}} \cdot \frac{\rho_г W_г^2}{2 \cdot \rho_{ж} \cdot g \cdot \varepsilon_0^2} \tag{6}$$

Gas content of the layer:

$$\varphi = \varepsilon - \frac{h_о}{H} \tag{7}$$

Structural components of the liquid phase.

Thickness of the liquid film on the inner surface of the rim:

$$\delta_{пл}^{об} = \left(\frac{3 \cdot \nu_ж \cdot U_ж \cdot B_s}{2 \cdot \omega_{вр}^2 \cdot \sin\alpha} \right)^{1/3} \tag{8}$$

Diameter of liquid jets:

$$d_{стр} = 1,6 \cdot \left(\frac{\sigma}{\rho_{ж} \cdot \left(d_{об} / 2 \right) \cdot \omega_{вр}^2} \right)^{0,5} \tag{9}$$

Diameter of droplets:

$$d_k = 0,925 \cdot \xi_L^{1/3} \cdot \frac{\rho_ж^{1/6} \cdot d_{стр}^{2/3} \cdot \sigma^{1/3} \cdot U_Г}{U_{стр}^{5/3} \cdot \rho_Г^{1.2}} \tag{10}$$

Mass transfer characteristics.

The mass transfer coefficient in the gas phase is calculated using the formula:

$$\beta_{ГS} = 2,25 \cdot \left(\frac{\varphi}{1-\varphi} \right)^{1/2} \cdot \xi_L \cdot \frac{U_к^{1/2} \cdot \nu_Г^{5/6} \cdot \Phi^2}{d_к^{1/2} \cdot D_Г^{1/3}} \tag{11}$$

The mass transfer coefficient in the liquid phase is calculated using the formula:

$$\beta_{жs} = 30,94 \cdot \left[\frac{(1-\varphi)}{\varphi} \right]^{1/4} \cdot \left[\xi_L \cdot \frac{(1-\varepsilon_0)}{(1-\varphi_{яч})} \cdot \frac{K_\rho \cdot D_{ж}^2 \cdot U_Г^3}{t_в \cdot \nu_{ж}} \right]^{1/4} \tag{12}$$

***Legend*:** $d_{тр}$ – pipe diameter, m; b and l – blade width and length, m; $\propto$ – blade angle; $d_{об}$ – rim diameter, m; δ – rim thickness, m; $t_в$ – vertical pitch; $t_р$ – radial pitch; K – number of blades; θ_b and θ_p – coefficients characterising the degree of interaction of vortices in the vertical and radial directions; Re_c , Re_d , Re_e – modified Reynolds numbers for the gas and liquid phases; H – height of the packing zone, m.

Justification of the novelty and importance of the results obtained.

The novelty of the calculated dependencies for determining the specific surface area of the rotating nozzle, its volumetric porosity, equivalent diameter, and rotation frequency is that they were obtained for a newly created nozzle protected by a Kazakhstani patent.

The novelty of the equations for calculating the coefficients of resistance, hydraulic resistance and the amount of retained liquid lies in the consideration of the identified patterns of interaction of vortices in the volume of rotating packing elements with rectangular blades and a ring rim.

The equations for determining the average values of film thickness, jet diameter and droplet size are new, as they are based on the proposed mechanism of breaking up the liquid film moving along rectangular blades and a rim in a rotating packing element into jets and droplets, taking into account the vortex mechanism of phase interaction.

The novelty of the equations for determining mass transfer coefficients in the gas and liquid phases is that they take into account the vortex interaction of flows in the volume of rotating packing elements, as well as the dissipation of energy of the main flow by the cascade energy transfer mechanism.

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

Compliance with scientific development trends or state programmes. The work was carried out in accordance with the priority research area of the Ministry of Natural Resources and Environmental Protection of the Republic of Kazakhstan for 2022-2024, "Rational use of water resources, flora and fauna, ecology," in the specialised scientific area of "Water purification, gas purification, soil and dust collection systems."

Description of the doctoral student's contribution to the preparation of each publication. Eleven articles have been published on the topic of the dissertation. The total contribution of the doctoral student is ~70%. The contribution to the articles includes such components as conducting experimental research, processing the results in the form of tabular values and graphical dependencies, and the obtained calculation equations.