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The model of crossed movement and gas-liquid flow interaction with captured liquid film in the inertial-filtering separation channels

Oleksandr Liaposchenko, Ivan Pavlenko, Olha Nastenko *

Sumy State University, Faculty of Technical Systems and Energy Efficient Technologies, 2 Rymskii-Korsakov, Sumy 40007, Ukraine

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ABSTRACT

This article represents the results of study dedicated to the development of mathematical model of captured liquid film and gas-liquid flow interaction in the process of inertial-filtering separation. For this purpose one has worked out the physical model and obtained the equations for determination of the main parameters of captured liquid film and gas-liquid flow interaction. The presented mathematical model is thoroughly analyzed and one has estimated its adequacy. One has also determined basic ways and tasks of the further studies.

1. Introduction

One of the most prospective methods of gas-liquid mixtures depuration is the method of inertial-filtering separation [3–5], fulfilled in the high-efficient gas separators, which combine advantages of the inertial and filtering mechanisms of aero-dispersed systems separation.

When gas-liquid mixture passes through channels of the inertial-filtering separator, liquid droplets sediment all over the surface of the curvilinear channel walls and these droplets form the liquid film. Thus under influence of the forces of gas flow inter-phase friction on the film surface there takes place liquid capturing and it flows off along the channel not vertically down but under the angle β, and flowing off liquid film, in its turn, influences gas flow in such a way that it moves at some angle α to the axes X. The pattern of flows movement and angles α and β are shown in Fig. 1.

As known, there are some regimes of liquid film movement on the flat surface [2,6]: laminar liquid movement without waves formation ($Re_f = 4–25$); laminar liquid movement with waves formation ($Re_f = 25–2000$); turbulent movement ($Re_f \geqslant 2000$). When waves are formed on the film surface the velocity of some layers becomes negative in the hollows between waves. It provides a conclusion that there are whirls at these places which are repeated along the whole length of the surface and provide the flow mixing.

If there are formed waves on the flowing off film and if the gas-liquid flow velocity becomes higher than the critical value it results in the intensive liquid droplets separation from the top points of waves, in other words secondary drop entrainment will take place. Thus maximal intensity of the drop entrainment is observed on the straight sections of the curvilinear channel and at their output.

So, the main target of the research is to determine the interaction and mutual influence of gas and liquid flows at each other in the inertial-filtering separator volume.

2. Results of modelling basic interaction mechanisms of the captured liquid film and gas-liquid flow

Gas-liquid mixture, on the straight sections of the curvilinear channel and at their output, has two velocity components: tangential $w_{mix\ x}$ and axial $w_{mix\ y}$. The formed liquid film which is flowing off along the channel walls, under the influence of gravity force and inter-phase friction with gas flow gets axial $w_{l\ y}$ and tangential $w_{l\ x}$ velocities.

To make a mathematical model of captured liquid film and gas-liquid flow interaction one takes the following simplifying assumptions: process is isothermal; liquid film movement is stationary; liquid film is formed on both channel walls and its thickness is constant; in determining film velocity one considers the middle cross-section area; droplets of the smallest size; τ = const, τ_w = const, α = const and β = const go into the film on the straight sections of the gas-liquid flow channel.

* Corresponding author.
E-mail address: o.nastenko@pohnp.sumdu.edu.ua (O. Nastenko).

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Nomenclature

x, y, z axes names
$w_{mix\ x}$, $w_{mix\ y}$ velocity components of mixture movement, m/s
$w_{l\ x}$ $w_{l\ x}$ velocity components of liquid movement, m/s
t channel width, m
t_p distance from film to film at different channel walls, m
L and H length and height of the rectilinear channel section, m
g acceleration of gravity, m/s^2

Greek symbols
α, β angles of flow movement, °
φ concentration of continuous phase
τ friction force on the inter-phase surface, N/m^2
τ_w friction force on the channel wall, N/m^2
ζ friction coefficient
ρ_{mix}, ρ_g, ρ_l density in mixture, gas and liquid, kg/m^3
μ_l the coefficient of liquid dynamic viscosity, Pa·s
ν_l kinematic coefficient of the liquid viscosity, m^2/s

2.1. Determination of the liquid film velocity

Using the concentration determination we can find its value for liquid:

$$1-\varphi=\frac{L\cdot(t-t_p)}{L\cdot t} \quad (1)$$

where we find

$$t_p=t\cdot\varphi \quad (2)$$

For laminar liquid flow gravity force exceeds greatly friction force at the interface surface, so one gets approximate formula [1] $\frac{dP_{mix}}{dy}=\frac{dP_l}{dy}=\rho_{mix}\cdot g$ and so mathematical formulation of the task for the flowing off film in the Cartesian coordinate system can be written as:

$$\begin{cases}\mu_l\frac{d^2w_l}{dz^2}=g(\rho_{mix}-\rho_l)=-g\varphi(\rho_l-\rho_g);\\ \tau|_{z=\frac{t_p}{2}}=\mu_l\left(\frac{dw_l}{dz}\right)\Big|_{z=\frac{t_p}{2}};\\ w_p|_{z=\frac{t}{2}}=0.\end{cases} \quad (3)$$

where the boundary conditions determine friction on the film surface, obtained from the solution of the exterior task, and the condition of liquid sticking to the channel wall.

Solution of the boundary Eq. (3) enables to determine fluid velocity in the film:

$$w_l(z)=\frac{\tau}{\mu_l}\left(z-\frac{t}{2}\right)-\frac{g\varphi(\rho_l-\rho_g)}{2\mu_l}\left(z-\frac{t}{2}\right)\left(z-t_p+\frac{t}{2}\right), \quad (4)$$

than liquid velocity on the film surface can be written as following:

$$w_{l1}=\frac{\tau}{\mu_l}\left(\frac{t_p}{2}-\frac{t}{2}\right)-\frac{g\varphi(\rho_l-\rho_g)}{2\mu_l}\left(\frac{t_p\cdot t}{2}-\frac{t_p^2}{4}-\frac{t^2}{4}\right) \quad (5)$$

and average liquid velocity is determined by the expression:

$$w_l^{avg}=\frac{2}{t-t_p}\int_{p/2}^{t/2}w_l dz \quad (6)$$

So, we obtain:

$$w_l^{avg}=\frac{\tau}{4\mu_l}(t-t_p)+\frac{g\varphi(\rho_l-\rho_g)}{12\mu_l}(t-t_p)^2 \quad (7)$$

Thus velocity distribution along the film thickness is as follows (Fig. 2):

Determination of the value Re for the liquid film can be made using the formula:

$$Re_l=\frac{w_l^{avg}d_{eq}^l}{H\cdot\upsilon_l} \quad (8)$$

We can find the hydraulic diameter of the flowing off liquid film:

$$d_{eq}^l=\frac{4(t-t_p)}{4+2(t-t_p)}=\frac{t-t_p}{1+\frac{t-t_p}{2}}\approx t-t_p \quad (9)$$

thus we obtain:

$$Re_l=\frac{w_l^{avg}(t-t_p)}{H\cdot\upsilon_l} \quad (10)$$

so, we can write:

$$Re_l=\frac{\tau}{4\mu_l\cdot\upsilon_l\cdot H}(t-t_p)^2+\frac{g\varphi(\rho_l-\rho_g)}{12\mu_l\cdot\upsilon_l\cdot H}(t-t_p)^3 \quad (11)$$

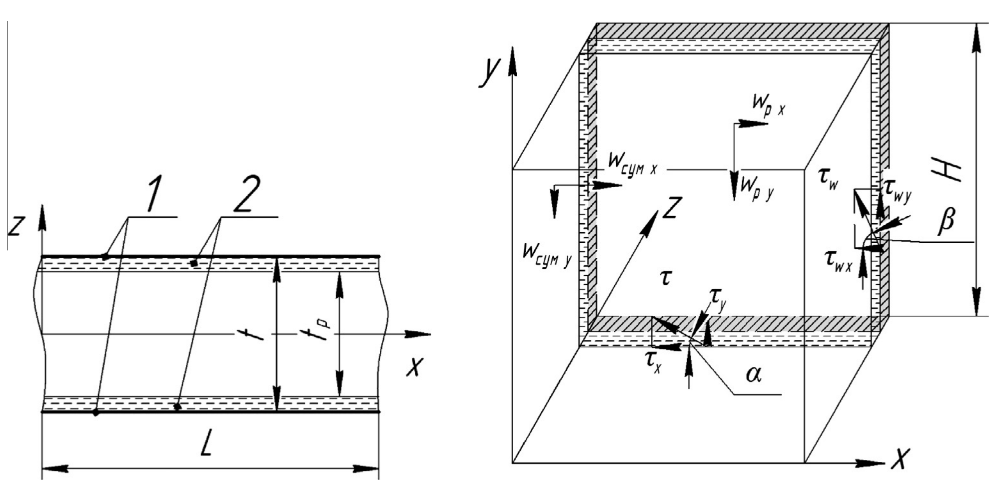

Fig. 1. Gas-liquid flow and liquid film interaction patterns and the basic dimensions: 1- channel walls, 2 – liquid film.