02TCQ - VORTEX FLOWS - PERSPECTIVE DIRECTION OF HEAT AND MASS TRANSFER PROCESSES INTENSIFICATION

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Abstract

Swirl flow leads to large-scale impact on all the characteristics of the flow field and heat transfer. Due to the presence of transverse velocity components: tangential and radial - enhanced convective transport of momentum, energy and mass changes and the vortex structure of internal swirling flows. The use of vortex flows allows intensifying the processes of heat and mass transfer, aligning local temperature in homogeneities due to convective mixing.

In this work, two types of heat and mass transfer devices are discussed: vortex spray countercurrent mass-transfer apparatuses (VSCMA) and suspended layer vortex granulators (SLVG).

This paper presents a theoretical description of the hydrodynamic flow movements in the working chamber of the vortex apparatus, and the theoretical description on classical hydrodynamic equations and differential equations of motion of a particle in a vortex gas flow.

The results analysis of hydrodynamics theoretical studies of vortex gas and gas-droplet flow in heat and mass transfer processes are given. The hydrodynamic conditions are examined, under which the use of such flows in the heat and mass transfer equipment will be most effective.

Operating experience VSCMA under absorption and rectification showed that the application of the above organization of gas-drop flow in heat exchange technology allows getting from 4 to 7 theoretical stages of concentration change in one stage spray. Industrial prototype testing SLVG the manufacture of porous ammonium nitrate showed that the final product has a degree of monodispersity and 98% humidity up to 0.2%, the strength of the granules is 230-300 g / granule.

1. Introduction

The chemical industry is a major consumer of energy resources and is characterized by low energy coefficients. To the researchers there is a problem of developing new energy-saving and especially energy-efficient technologies associated with the development of devices of high specific productivity. Relevant issue is the development of multi-function devices of combined actions, in which it become possible for simultaneous execution of several processes (Sklabinskyi at al., 2013). In such apparatuses, volume efficiency should be 2-3 times higher than that of existing analogues (Kholin and Sklabinskyi, 1998; Sklabinskyi, 1998).

Currently, the chemical factories, oil refineries, food factories, pharmaceutical and other industries are searching for ways of intensification of mass transfer processes in a unit volume of the workspace. This is due to the need; to reduce materials consumption of mass transfer equipment, reduce energy cost for its operation, maintenance and repair, with high demands on the quality of products. These devices are designed to replace the traditional mass transfer column and granulation tower equipment (Sklabinskyi, 1998; Artyukhov and Sklabinskyi, 2012; Marrone and Scotto, 2011).

2. Aims

1. Theoretical description of the hydrodynamic characteristics of swirling gas flow in the chamber of the vortex apparatus.
2. Determination of the gas flow velocity components in the vortex devices.
3. Results Analysis of mathematical modeling and the determination of the optimal operating conditions of the vortex apparatus.

3, Methodology

An analytical description movement of swirling flow is based on one of these approaches:

1. The flow is represented as a superposition of plane flow and potential rotation. Calculation method is based on the use of empirical coefficients and only involves determining the hydraulic resistance.
2. To describe the motion of the swirling flow, Bernoulli's equation and the extreme principle for one of the flow characteristics while maintaining the radial channel angular momentum are use. The disadvantage of this approach is the rough sketch flow and lack of consideration of the features of motion in the axial zone of the channel.
3. Applying Bernoulli's equation for the liquid motion in the volute. This method requires prior determination of a series of characteristics that depend on the geometric parameters of the channel. This did not provide definitions of all velocity components.

Disadvantages of these methods significantly narrow the scope of their use for the calculation of the swirling flow.

Separately secrete a method in which the description of the axisymmetric motion of the gas with the rotation based on the use of Navier-Stokes differential equations, which are simplified by depending on the task and received physical flow model, and the equations of continuity, energy conservation and the state. This method allows you to conduct fully defining the hydrodynamic characteristics of flow.

4. Results and discussion

I Vortex spray countercurrent mass-transfer apparatus (VSCMA)

During 2000 year, chemical technology has developed, which allows create hydrodynamic conditions for the intensification of heat and mass transfer. These apparatuses of spray-type with vortex countercurrent flow motion flows along the radius of the mass transfer chamber (Kovalov and Sklabinskyi, 1998). Factors that lead to the acceleration of mass transfer processes in the vortex spray countercurrent mass-transfer apparatuses (VSCMA) can be explained, using the well-known equation of mass transfer:

$$\mathrm{M} = kF\Delta, \qquad (1)$$

where *M, k, F* and - Amount of substance transferred between the phases, mass transfer coefficient and the surface, the driving force of the process (density difference).

As shown in Fig. 1, a gas or vapor phase is supplied into the swirl mass-transfer chamber via tangential slits, which are arranged on the periphery.

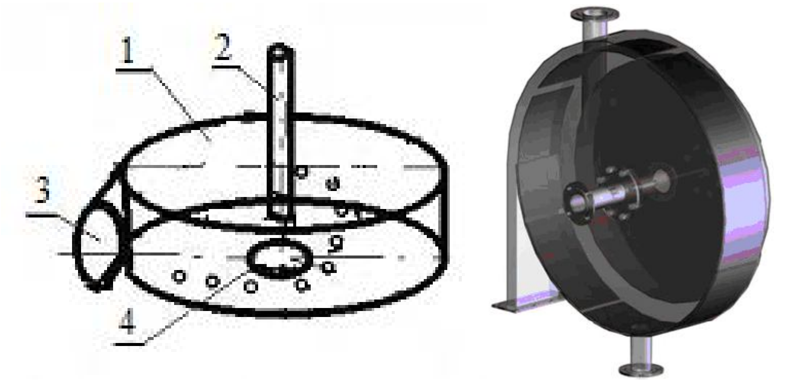

Fig. 1. Vortex spray countercurrent mass-transfer apparatus: 1 - vortex chamber; 2 - spray liquid; 3 - tangential gas inlet; 4 - axial venting.

In its motion to the center of the field, the gas flow increases the tangential component of the total rate (according to the law of conservation of angular rotational motion):

$$m_i \frac{d\left(rV_\varphi\right)}{dt} = 0 . \tag{2}$$

where m_i - weight i-th volume r - current radius, V_φ - tangential component of the total velocity of the gas.

The solution of equation (2) - the dependence of the tangential velocity of the gas flow along the radius of the vortex chamber mass transfer from the periphery to the center (Figure 2).

$$V_\varphi = V_{in}\left(\frac{R_c}{r}\right), \tag{3}$$

where $V_{\varphi\, in}$ - velocity of the gas in the input tangential slots $_c$ - the radius of the vortex mass transfer chamber.

Such countercurrent movement of phase is also important for creating hydrodynamic conditions that lead to accelerate the heat and mass transfer processes. This is due to the motion of the liquid droplets in the gas stream with a transverse gradient of circumferential speed.

Impact of transverse velocity gradient of the gas flow even in very small droplets of liquid leads to the fact that on the opposite side of the droplet along the radius of the vortex chamber, it flows with different gas flow rates (see Fig. 3).

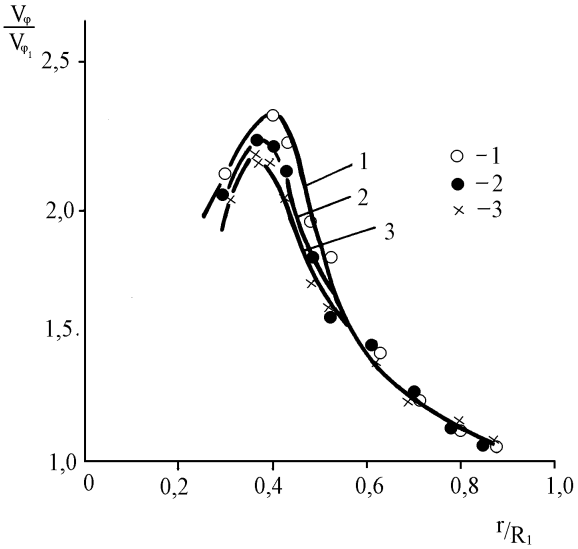

Fig. 2. Changing the tangential gas velocity along the radius VSCMA ($R_2 / R_1 = 0.33$; $V_1 = 32$ m / s) at a height of the device: 1 - near the upper end cover; 2 - in the middle of the height of the vortex chamber; 3 - near the bottom end cover.

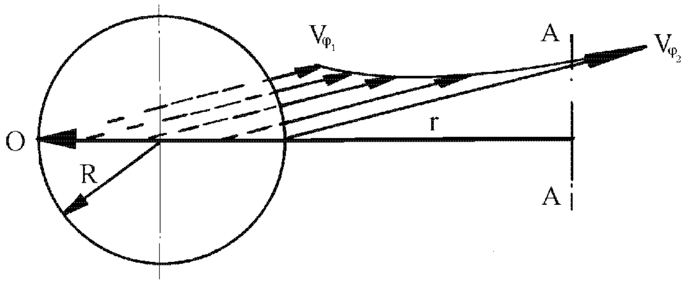

Fig. 3. Diagram of action of the gas flow on the drop in the vortex chamber VSCMA.

The presence of transverse velocity gradient of gas leads to an intensification of internal circulating currents that increase the intensity of mass transfer and the number of transfer units.

II Vortex granulator (SLVG)

A significant amount of chemical industries use heterogeneous processes occurring in the "gas-liquid-solid" and occupy a special place among other processes, because their rate of flow is determined by the law of mass and heat transfer in the interacting phases that interact. These processes include various granulation methods.

Analysis of the current market producers of granular products for the chemical, mining, pharmaceutical and food industries has shown that these methods of granulation to the latest (advanced) applies in fluidized bed granulation. Preparation of granular product in fluidized bed is used by world-famous producers of fertilizers and pharmaceutical products - Urea Casale SA, Kahl Group, Stamicarbon, Toyo Engineering Corporation, Changzhou Xianfeng Drying Equipment Company Ltd, Glatt, Uhde Fertilizer Technology, Rottendorf Pharma and others.

In the Suspended layer vortex granulators (SLVG) (Figure 4) spin of the gas stream is achieved by using swirl devices (swirlers) (Artyukhov, 2013).

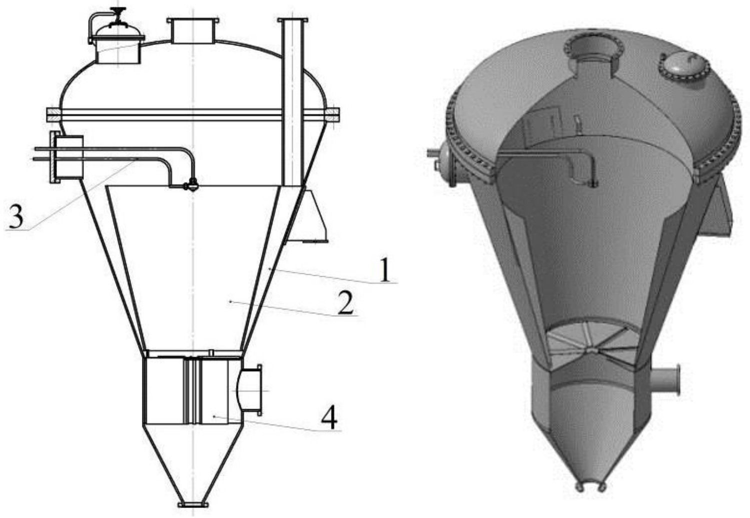

Fig. 4. - Suspended layer vortex granulator with a variable cross-sectional area of the working space: 1 - workspace; 2 - inter-ring space for internal circulation of small granules; 3 - the dispenser; 4 - swirl.

This method of directional movement phase is a passive stimulation technique that does not require an additional supply of external energy, unlike active methods (vibration, impact and the electrostatic, acoustic or magnetic field, mixing, blowing or extracting fluid through a porous surface). Swirl stream using swirl leads to large-scale effects on heat and mass transfer characteristics of the flow field.

The analytical solution results of hydromechanics classical equation (Sklabinskyi and Artyukhov, 2008) with the adopted simplifications and assumptions (Sklabinskyi and Artyukhov 2010) allowed obtaining velocity components of the gas flow:

- Longitudinal/perpendicular:

$$V_z(z) = \frac{Q}{\pi R^2} = \frac{Q}{\pi \cdot tg\alpha^2 \cdot z^2}, \tag{4}$$

- Radial $$V_{r1}(z,r) = \frac{-\dfrac{Q \cdot r^2}{\pi \cdot tg\alpha^2 \cdot z^3} + \dfrac{Q}{z \cdot \pi}}{r}, \tag{5}$$

- Circumferential (decision not given due to its bulkiness):

$$V_\varphi(z,r) = f(z,r,\alpha,Q,V_{\varphi 1}), \tag{6}$$

where Q - gas flow rate; R - the maximum radius of the workspace granulator; r - the current maximum workspace radius of granulator; α - half angle of workspace cone of granulator; z - the current height of the working space of the granulator; V_1 - spin rate of the initial gas stream (output of gas distributor).

The calculation results by formulas (4) - (6) for individual cases are shown in Fig. 5-7.

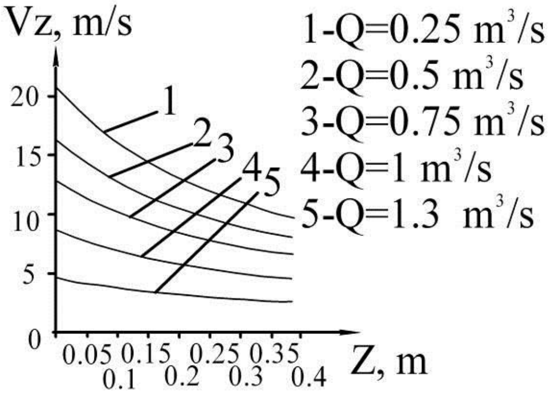

Fig. 5. Calculated change of the longitudinal velocity of the gas flow throughout the height depending on the gas flow rate (at α = 13°).

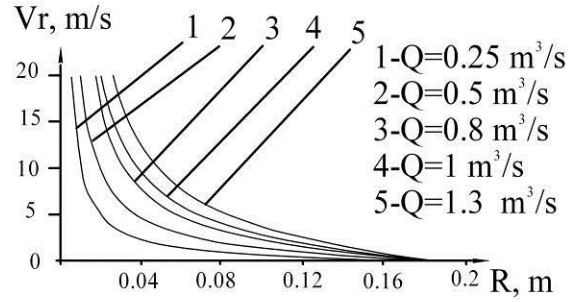

Fig. 6. Calculated change of the radial velocity of the gas flow depending on the gas flow rate (at α = 13°, z = 0.8m).

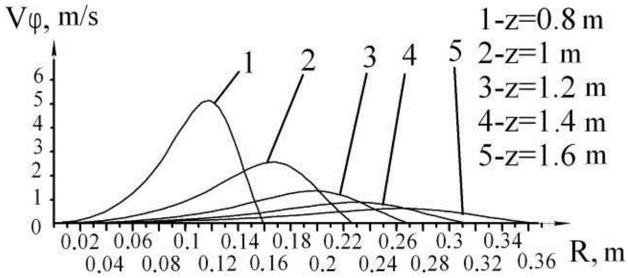

Fig. 7. The calculated change of the circumferential velocity of the gas flow depending = 0.63 m^3 / S) at different heights of the device.

5. Conclusions

Operating experience VSCMA under absorption and rectification showed that the application of the above organization of gas-drop flow in heat exchange technology allows getting from 4 to 7 theoretical stages of concentration change in one stage spray.

This approach makes it possible to reduce material heat and mass transfer equipment due to a sharp decrease in the size of devices. It is very important at this time to reduce the cost of newly established production lines and reconstruction of existing technological systems.

Industrial prototype testing SLVG the manufacture of porous ammonium nitrate showed that the final product has a degree of monodispersity and 98% humidity up to 0.2%, the strength of the granules is 230-300 g / granule.

The basic of further research - the study of the influence of the hydrodynamic vortex flows on the intensity of heat and mass transfer processes in systems of "gas-liquid", "gas-solid", "gas-liquid-solid".

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