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TO CALCULATING THE EQUIVALENT DIAMETER OF A COMBINED REGULAR-SUSPENDED PACKING

Abstract. Based on the analysis of operation of existing heat and mass transfer apparatus with a stationary packing, there are shown the advantages of apparatus with a tubular packing of regular structure, due to which it is possible to regulate the heat exchange process in the tubular packing directly in the contact zone when feeding the heat transfer fluid to the tubes. Here, the contact occurs through the tubes' walls, and the heat transfer fluid's movement in tubes does not affect the gas-liquid layerstructure in the apparatus. Additional advantages are given by introduction into the contact zone of the discrete contact elements (balls, cubes, etc.), which under the operating conditions provide the cleaning of tube space contact zone surfaces, maintain the in-phase operation of vortex interaction and increase the interfacial area.

There has beenstudied the gas motionthrough the stationary packing along thewindingducts, formedbypacking bodies. In respect to the heat and mass transfer apparatus with a combined regular-suspendedpacking, there have been derivedthe equations to determinethe specific surface area of the tubular-ball packing, its volume porosity, and also the equation to calculate its equivalent diameter.

There has been done the analysis of the influence of the tubes arrangementpitchesin the vertical and radial directions, of the tubes and ball packing diameters on the equivalent diameter value.

Key words: regular packing, vertical pitch, radial pitch, tubes, balls, tubular-ball packing, specific surface area, porosity, equivalent diameter.

Introduction. By now there have been developed a great number of heat and mass transfer apparatus, used for carrying out the processes of absorption, rectification, extraction, cooling of gases and liquids[1-5].

In most cases, because of their design features, the developed apparatus can be used for carrying out only one technological process[6-10] or concurrent processes[11-15]. For example, the absorptionof hot gas, containing solid particles. The basic process is absorption, but in parallel to it the heat exchange and the removal of solid particles arecarried out.Here there gulation of parallel running processes is practically impossible.

The particularity of the developed and studied design of the apparatus with a tubular packing of regular structure [16] is that it enables to regulate the heat exchange process directly in the contact zone during the supply of a heat transfer fluid to the tubes. The contact here occurs through the walls of tubes, and the heat transfer fluid's movement does not affect the structure of the gas-liquid layer in theapparatus.

The disadvantage of the known apparatus is that in carrying out some mass transfer processes (for example, in soda ash production by the ammonia method in the processesof ammonia and carbon dioxide absorptionby the sodium chloride solution) there occurs the precipitation of fine solid particles, deposited on the tube bank and walls of the apparatus, resulting in possible clogging of the shell side, causing the disturbances in the in-phase operation and, hence, the considerable reduction in the efficiency of carried out processes[17-19].

To avoid this, it is proposed to introduce into the contact zone the discrete contact elements (balls, cubes, etc.), which under the operating conditions provide the cleaning of tube space contact zone surfaces, maintain the in-phase operation of vortex interaction and increase the interfacial area. [20].

Research methods. To perform the studies, there were used the computer-aided numerical methods.

Researc hresults. The gas moves through the packing along the wind ingducts, formed by packing bodies. The cross-section of these ducts is not constant over the height of the apparatus and, hence, the gas velocity is also a variable value. In the study of packed absorbers the researchers proceed from the average gas velocity, determined by dividing the volumetric gas consumption by the average cross-sectionof ducts [2].

For packed apparatus with a stationary packing[2] the column cross-section area- S(м^2), the packing height- H (m) and its free volume-ε. Then the void volume in the packing, i.e. the volume of ducts, along which the gas is moving, is equal to $SH\varepsilon$ (м^3). The average length of ducts (the gas path length) is equal to Hk (here k – the coefficient, taking into account the sinuosity of ducts). The average value of ducts is:

$$S_{\text{кан}} = \frac{S\cdot H\cdot\varepsilon}{H\cdot k} = \frac{S\cdot\varepsilon}{k} \tag{1}$$

Thevalue $\omega = S_{\text{кан}}/S = \varepsilon/k$, equal to the ratio of the average duct cross-section to the column cross-sectionis called the effective cross-sectionof the packing [2].

The average gas velocity:

$$w = \frac{V_{\text{г}}}{S_{\text{кан}}} = \frac{V_{\text{г}}}{S\cdot\omega} = \frac{w_0\cdot k}{\varepsilon}, \tag{2}$$

where $w_0 = V_{\text{г}}/S$ - the gas velocity, referred to the whole cross-section of the column.

Usually it is assumed that $k=1$,then$\omega=\varepsilon$and equation (2) takes the form:

$$w = \frac{w_0}{\varepsilon} \tag{3}$$

The equivalent packing diameter will be defined as the equivalent diameter of ducts,along which the gas is moving[2]:

$$d_{\text{экв}} = \frac{4\varepsilon}{a_{\text{н}}}, \tag{4}$$

whereε- the volume tric packing porosity; $a_{\text{н}}$– the specific packing surface area per volume unit of the apparatus.

To derive the equation for equivalent packing diameter with respect to the heat and mass transfer apparatus with a combined regular-suspended packing [17], we will define the components of formula (4).

The specific surface area of a tubular packing is calculated under the formula:

$$a_{\text{тр}} = \frac{\pi d_{\text{тр}}}{2\cdot t_{\text{р}}\cdot t_{\text{в}}}, \tag{5}$$

where$t_{\text{р}}$ - the value of tube spacing in the radial direction; $t_{\text{в}}$ - the value of tube spacingin the vertical direction.

The specific surface area of a ball packing will be defined under the formula:

$$a_{\text{ш}} = \frac{\pi d_{\text{ш}}^2}{2\cdot t_{\text{р}}\cdot t_{\text{в}}\cdot l} \tag{6}$$

Here$l$– the size, equivalent to the length of tubes, m. For a ball packing it can be:

$$l = m\cdot d_{\text{ш}} \tag{7}$$

Then

$$a_{ш} = \frac{\pi d_{ш}}{2 \cdot m \cdot t_{р} \cdot t_{в}} \tag{8}$$

The specific surface area of a tubular-ball packing will be:

$$a_{общ} = a_{тр} + a_{ш} = \frac{\pi(\mathrm{m} \cdot d_{тр} + d_{ш})}{2 \cdot m \cdot t_{р} \cdot t_{в}} \tag{9}$$

The volumetric porosity of a tubular packing can be defined under the formula:

$$\varepsilon_{тр} = 1 - \frac{\pi d_{тр}^{2}}{2 \cdot t_{р} \cdot t_{в}} \tag{10}$$

To define the volume tric porosityof the ball packing layer, we'll determine the layer volume:

$$V_{сл} = h \cdot в \cdot l\,, \tag{11}$$

In this equation:
The relative height - $h = n_1 \cdot d_{ш}$. The number of balls $h/d_{ш} = n_1$;
the relative width - $в = (t_{р} + d_{тр}) = n_2 \cdot d_{ш}$. The number of balls $(t_{р} + d_{тр})/d_{ш} = n_2$;
the relative layer length$l$.
Substituting the obtained values into equation (11), we'll find:

$$V_{сл} = \frac{n_1 \cdot n_2 \cdot l \cdot \pi \cdot d_{ш}}{6} \tag{12}$$

The volume unit of the apparatus:

$$V_{ап} = 2 \cdot t_{р} \cdot t_{в} \cdot l \tag{13}$$

Then the ball packing porosity:

$$\varepsilon_{ш} = 1 - \frac{V_{сл}}{V_{ап}} = 1 - \frac{n_1 \cdot n_2 \cdot \pi \cdot d_{ш}}{12 \cdot t_{р} \cdot t_{в}} \tag{14}$$

The volumetric porosityof a tubular-ball packing:

$$\varepsilon_{общ} = 1 - \left[\frac{\pi \cdot (6 \cdot d_{тр}^{2} + n_1 \cdot n_2 \cdot \pi \cdot d_{ш}^{2})}{12 \cdot t_{р} \cdot t_{в}} \right] \tag{15}$$

The equivalent diameterof a tubular-ball packing:

$$d_{экв} = \frac{2 \cdot m \cdot \left[12 \cdot t_{р} \cdot t_{в} - \pi \cdot (6 \cdot d_{тр}^{2} + n_1 \cdot n_2 \cdot d_{ш}^{2}) \right]}{3 \cdot \pi \left(m \cdot d_{тр} + d_{ш} \right)} \tag{16}$$

Figures 1 and 2 give the results of calculation under the equations derived.

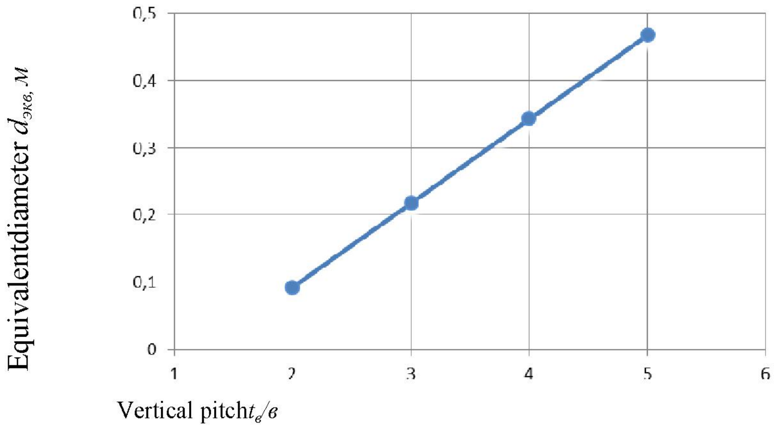

Figure 1 – Dependence of the regular-suspended packing equivalent diameter $d_{экв}$ on the pitches of tube arrangement in the vertical direction $t_в / в$

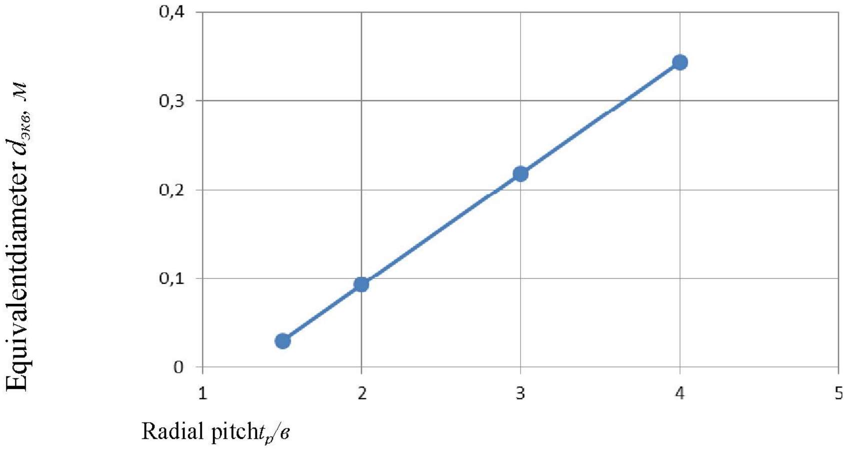

Figure 2 – Dependenceof theregular-suspended packingequivalentdiameter $d_{экв}$ onthe pitches of tube arrangement in the radialdirection $t_р / в$

As it can be seen from Figure 1, when changing the pitches of tube arrangement in the vertical direction$t_в$/d from 2 to 5, as well as when changing the pitches of tube arrangement in the radial direction$t_р$/d from 1.5 to 2 (Figure 2), the values of variables $d_{экв}$ increase. It is obvious, since the dependence of the equivalent diameter on the pitches of tube arrangement is directly proportional.

The calculation under equation (16) shows that with the increase in tubes diameter, the equivalent diameter values increase, whereas with the increase in balls diameter, the equivalent diameter values decrease.

Conclusions. There has been studied the gas motion through the stationary packing along the winding ducts, formed by packing bodies. In respect to the heat and mass transfer apparatus with a combined regular-suspended packing, there have been derived the equations to determine the specific surface area of the tubular-ball packing, its volume porosity, and also the equation to calculate its equivalent diameter.

There has been done the analysis of the influence of the tubes arrangement pitches in the vertical and radial directions, of the tubes and ball packing diameters on the equivalent diameter value.

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