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COMMON APPROACH TO THE CALCULATION OF HYDRAULIC RESISTANCE OF A TUBE BANK OF CONTACT AND SURFACE HEAT EXCHANGERS

Abstract. Heat and mass transfer processes and apparatus are widely used at the enterprises of chemical, oil refining, petrochemical, gas processing, metallurgical, food, chemical-pharmaceutical and energy industries in Kazakhstan, as well as in the agro-industrial complex, building materialsproduction, dust and gas collection systems.

The existing designs are being constantly modernized, withthe new ones being created. The known methods of heat and mass transfer intensification are the operating and the design ones. As the research has shown, the most promising method of design intensification is the method, using the laws of vortex interaction of flows.Due to the scientifically substantiated choice of distances between the turbulence creating elements, depending on their shape and size, it is possible to change the phase interaction modes at a constant flow rate or to improve the mass and heat transfer characteristics due to the vortex mixing within a single phase.

There has been done the analysis of the known data on streamlining around the packing elements,arranged along and across the flow,with thecalculated dependences given for determination of the vortex interaction degree in the vertical and radial directions. On the basis of the laws of interaction of vortices, being formed during streamlining around regularly arranged packing elements, there has been created a class of apparatus with different types of regular packing.

The established regularities and calculated dependencies have been used in thecommon approach to the calculation of hydraulic resistance of contact heat and mass transfer and surface heat exchangeapparatus.

Key words: regular packing, vortices, vertical pitch, radial pitch, in-phase operation, vortex interaction degree, hydraulic resistance, contact apparatus, surface apparatus.

Introduction. Heat and mass transfer processes and apparatus are widely used at the enterprises of chemical, oil refining, petrochemical, gas processing, metallurgical, food, chemical-pharmaceutical and energy industries in Kazakhstan, as well as in the agro-industrial complex, building materials production, dust and gas collection systems. However, a large variety of applied designs does not always meet the production requirements. One of the main reasons of the iridle and unprofitable work is that the technology and technique applied have high material and energy indices. The latter index is of great importance under modern conditions of market economy.

According to [1], when creating the new technique and technology, it is necessary to proceed from the promising directions of scientific and design work in the specific field of knowledge with taking into account the real conditions and requirements to the operation and manufacturing of the design. Besides, when predicting the appearance of the designed object, it is necessary to proceed from the assessment of positive and negative features of the known analogues.

There are two approaches to the heat and mass transfer intensification: the operating and the design ones.

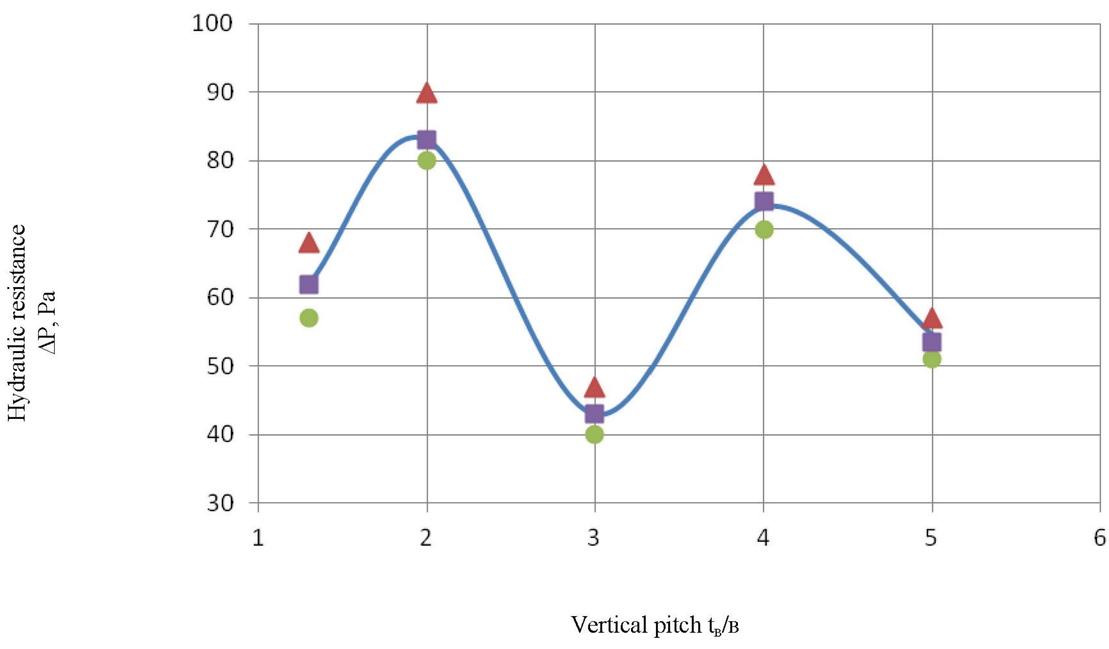
In the first one the key parameter is the flow rate increase.This direction promoted the creation of co-current flow motion apparatus, which has caused the sharp and unjustified increase in energy costs. In recent years in Kazakhstan there are being carried out the studies [2,3] for purposive control of physical and chemical properties of interacting phases to increase the efficiency of heat and mass transfer processes.

Thekey parameters of the design approach are the contact device's size, shape and arrangement of elements. This direction has been first developed in the scientific school of the South-Kazakhstan State University named after M.O.Auezov. It is based on the scientific discoveries[4,5]. It is a promising method of intensifying the heat and mass transferand gas-cleaning apparatuses. Thus, it appeared that due to the scientifically substantiated choice of distances between the turbulence creating elements, depending on their shape and size, it is possible to change the phase interaction modes at a constant flow rate.The example of realizing this task is the created class of apparatus with a regular movable packing. Such devices out-perform greatly the widely applied designs of heat and mass transfer apparatus because of low power capacity and high efficiency of the ongoing processes due to the fact that they are based on the principle of creating the in-phase operation of interacting phases.

Research methods. Toper form the studies of hydraulic resistance, the method of direct measurement was used, with applying the well-type manometer and the micro manometer.

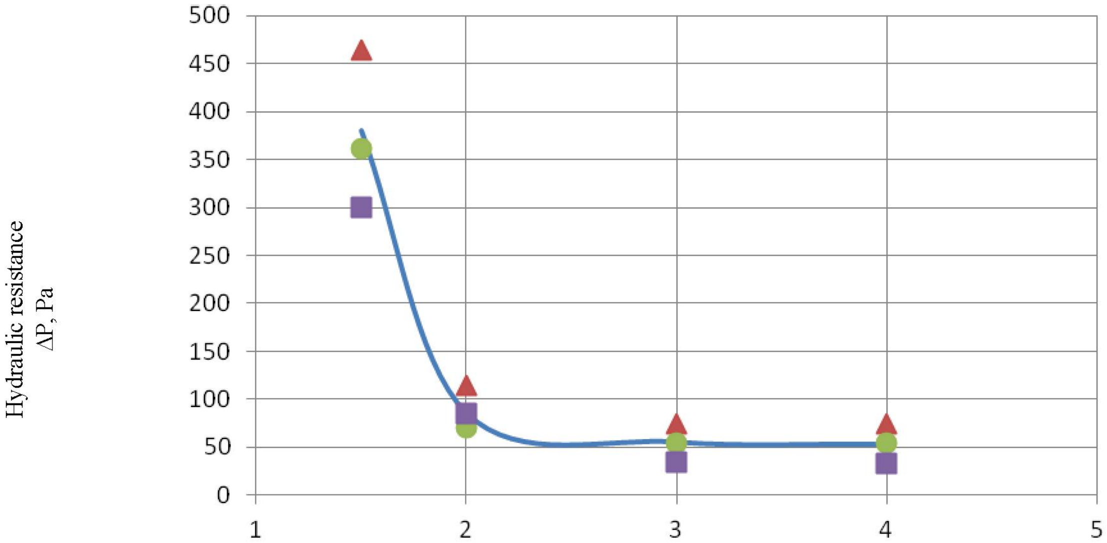
Research results. With in the work, carried out byus, the re have been performed the studies of hydraulic resistance (ΔP) across the tube bank of regular structure, depending on the operating and design parameters, which are compared with the data, received in papers [1,6,7]. Depending on the gas flowrate, there have been determined three hydrodynamic modes: film-dropping, dropping (of a developed turbulence) and splash carrying away modes.

There sults of studiesof hydraulic resistance, depending on the pitches of tube arrangement in the vertical and radial directions, are given in Figures 1 and 2.



Δ – ΔP[17]; o – ΔP[7]; □ – ΔP (our data)

Figure 1 – Dependence of hydraulic resistance Δ Ponthe pitches of tube arrangement in the vertical direction $t_в / в$



Δ – ΔP[17]; o – ΔP[7]; □ – ΔP(our data)

Figure 2 – Dependence of hydraulic resistance Δ Ponthe pitches of tube arrangement in the radial direction $t_p / в$

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, the curve has two extrema on$t_в$/d=2 and 4. A to ther pitch values there is a decrease in the values of Δ P.

When changing the pitches of tube arrangement in the radial directiont_p/d from 1.5 to 2 (Figure 2), the values of hydraulic resistance decrease sharply, and aftert_p/d = 2 this decrease is not great. The explanation for this is as follows.

In papers [1,8,9-11] the vortex interaction mechanisms have been studied in the layer of a ball packing, prismatic packing elements and plates. It is known that behind the spherical bodies there are formed the toroidal vortices, and their separation occurs symmetrically. Behind the plates, prismatic bodies with a round, square, x-shaped, triangular and other section there is a non-symmetrical separation of vortices. Unlike the vortex trail, generated behind the sphere, having a period of motion, the trace behind the plates and prismatic bodies has additionally a half-period. In there sult of this, the packing elements, arranged with a pitch half less than in the symmetrical separation,will form vortices simultaneously.

To determine the degree of interaction of vortices, formed behind the packing elements, arranged along the way of the flow motion with a pitch $t_в$, there is derived an equation [1,8]:

$$\theta_в = 0,85 + 0,15 \sin\left[\frac{\pi}{2}\left(4\frac{t_в \cdot S\ell}{m_k \cdot в} + 1\right)\right]. \quad (1)$$

By processing the results of studies of hydrodynamic parameters and the analysis of data, presented in papers [1,8,12-14], we have derived the equations to determinem_k:

$$m_k = c(1 - e^{-t_b/b}), \quad (2)$$

wherec – the coefficient, found by the processing of experimental data of hydrodynamic and mass transfer characteristics (for example, for ballsc=0,868; cylindersc=0,487; rotating plate elements of a round shapec=0,54, of a square shapec=0,326).

The Strouhal number $S\ell$, include dinto equation (1), set supa close relationship between the vortex separation frequency f, flow rate $W_Г$and body width b, and within a certain range of Reynolds numbers it is a constant value, depending only on the geometric shape of the streamlined body. For balls $S\ell$ =0,183, for cylinders $S\ell$ = 0,2, for plates $S\ell$ =0,137÷0,157.

The importance of considering the influence of the pitch of the stream lined solid bodies' arrangement nearby across the streamlined flow (t_p) is marked in papers [1,8,11,15,16]. Inpaper [5] there is determined a certain critic al distance between solid bodies, the excess of which results in the formation of vortices with a frequency, depending on the characteristic size of streamlined bodies. The arrangement of solid bodies at adistance less than the critical one results in the fact that the vortex separation frequency is determined not by the size of streamlined bodies, but by the size of a clearance, formed by the elements, adjacent in the transverse direction. The smaller the gap, the greater the frequency of vortex formation and separation. The growing number of vortices, generated with small clearance values causes the considerable consumption of flow energy.

According to [5,8], the bodies, arrange dinoneline, perpendicularly to the streamlined flow, initiate the generation of vortices of the size λ. Forthebodies, arranged discretely inoneline, perpendicularly to the streamlined flow, there are possible two cases: in the first one the size and frequencyof vortices are determined by the body's width (at$t_p \geq 2d_p \lambda = d_p$), while in the second one - by the size of clearance between the bodies (at$t_p < 2d_p \lambda = t_p - d_p$).

From the condition of parallel vertical jets interaction nit follows that the coefficient, characterizing the degree of vortex interaction in the radial direction, with taking into account the change in the vortex formation frequency, $\theta_p$can be determined by the formula:

$$\theta_p = \frac{t_p - \lambda}{t_p - d_p} \tag{3}$$

Among the devices with regular arrangemen to packing elements there searchers' attention is attracted by the apparatus with a tubular packing. The particularity of the developed and studied design of the apparatus with a tubular packing of regular structure 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 contac the reoccurs through the walls of tubes, and the heat transfer fluid's movement does not affect the composition of the gas-liquid layer in the apparatus.

The apparatus with a tubular packing of regular structure belongs to a large group of direct contact type heat exchange apparatuses.

The flow pressure losses, spent by formation and interaction of vortices in the apparatus tube bank, by change of the gas flow direction, by friction of gas on the surface of packing elements and the liquid film, can be calculated by the following dependence [1,6,7,8]:

$$\Delta P_L = \xi_L \cdot \frac{H}{t_в} \cdot \frac{\rho_г W_г^2}{2\varepsilon_0^2}, \tag{4}$$

where$H$ – the packing height, m; $\rho_Г$ - the gasdensity, kg/m^3; $W_г$– the gasvelocity, m/s; ξ_L - there sistance coefficient, taking into account the pressure losses by vortex interaction in the vertical and radial directions, by friction of gas on the surface of packing elements and the liquid film; ε_0 - the porosity of the packing line

$$\varepsilon_0 = 1 - \frac{d}{t_p} \tag{5}$$

By processing the experimental dataΔP_L [6,7,17] there have been derived the almost identical calculated dependences to determine the coefficientsξ_L:

$$\xi_L = 0{,}25 \cdot \theta_в \cdot \theta_р \cdot \mathrm{Re}_{жс}^{0,1}, \quad (6)$$

In formula (6) $Re_ж$ – the Reynolds number:

$$Re_ж = \frac{U_ж \cdot d_{экв}}{\nu_ж}, \quad (7)$$

where $U_ж$ =L/3600 – the fluidvelocity, m/s; $\nu_ж$ – the coefficient of kinematic fluid viscosity, m^2/s; L – the spraying density, $m^3/m^2 \cdot h$; $d_{экв}$ – the equivalent packing diameter, m.

To calculate the pressure loss by friction on the shell sides of the surface heat exchanger, the equations that take into account the design and regime parameters are proposed in [18-20]. We have derived the equation, structurally similar to equation (4):

$$\Delta p_{МТ} = \lambda_{тр} \cdot \frac{D}{t_в} \cdot \frac{\rho_ж \cdot W_{МТ}^2}{2} \quad (8)$$

Here D – the apparatus inner diameter, m; $t_в$ – the tubes arrangement pitch along the way of a moving flow.

To calculate the coefficient $\lambda_{тр}$, we have derived the equation, taking into account the vortex interaction degree when streamlining the tubes along the way of and across the moving flow:

$$\lambda_{тр} = 2{,}275 \cdot \theta_в \cdot \theta_р \cdot Re^{-0,2} \quad (9)$$

Coefficients $\theta_в$ and $\theta_п$ in the equation are calculated by formulae (1) and (3).

Conclusions. There are described and experimentally proved the interaction mechanisms of vortices, formed behind the tubes in the vertical and radial directions. There is shown the presence of in-phase modes, when changing the vertical pitches, as well as the importance of the critical pitch in the radial direction, differentiating the two mechanisms of vortex formation.

With using the common approach, there are derived the equations for calculation of hydraulic resistance of contact and surface apparatus, with taking into account the vortex interaction degree.

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