UDC 532.51

Siberian Journal of Science and Technology. 2017, Vol. 18, No. 3, P. 499–504

STUDY OF HYDRODYNAMICS FEATURES IN THE APPARATUSES WITH MOVABLE NOZZLE

V. P. Danko[1, 2*], V. V. Karnauh[3], A. S. Titlov[4]

[1]Plekhanov Russian University of Economics
360, Severnaya Str., Krasnodar, 350002, Russian Federation
[2]Kuban State Technological University
2, Moskovskaya Str., Krasnodar, 350072, Russian Federation
[3]Donetsk National University of Economy and Trade named after Mykhajlo Tugan-Baranovskogo
31, Schorsa Str., Donetsk, 83050
[4]Odessa National Academy of Food Technologies
112, Kanatnaya Str., Odessa, 65039, Ukraine
[*]E-mail: vladislav.danko@mail.ru

Apparatuses for the heat and mass transfer processes must be designed so that they have a maximum contact surface. Classification of heat-mass exchange apparatuses provides geometric features of the apparatus and the hydrodynamic condition they create. However, the main trend which remains dominant in the design of such apparatus is to create a thin film of liquid on the surface of the nozzle.

The work was aimed at choosing the solution in which the MN of the heat-mass exchange apparatuses can be used to implement the contact handling process of gases and liquids with density values clarification of the nozzle elements (ρ_{ne}) *and the column dynamic height* (H_{cm}) *and obtain the specified calculated dependences which describe the hydrodynamics and mass transfer in the apparatuses with a movable nozzle, that is to create bases for engineering calculations.*

Research methods were theoretical study and experimental studies on heat and mass transfer devices with movable nozzle.

The best ranger for mass transfer processes implementation is that of ρ_{neII} (ρ = 200–700 kg/m^3)*, which is distinguished by a wide working area according to* w_g*, acceptable values of fluid withdrawal and a relatively small dynamic layer height. Within the described mode, we can distinguish the area* $w_g \cong$ 4.7–6.0 m/s*, where there is no dependence of* H_p *on* w_g*.*

Specified calculated dependence obtained which describes the hydrodynamics and heat and mass transfer in the apparatuses with a movable nozzle.

Keywords: movable nozzle, fluidization, heat-mass exchange apparatus, critical speed, loss of pressure in the work area, dynamic height of nozzle layer, stationary mode.

Сибирский журнал науки и технологий. 2017. Т. 18, № 3. С. 499–504

ИЗУЧЕНИЕ ОСОБЕННОСТЕЙ ГИДРОДИНАМИКИ В АППАРАТАХ С ПОДВИЖНОЙ НАСАДКОЙ

В. П. Данько[1, 2*], В. В. Карнаух[3], А. С. Титлов[4]

[1]Российский экономический университет имени Г. В. Плеханова
Российская Федерация, 350002, г. Краснодар, ул. Северная, 360
[2]Кубанский государственный технологический университет
Российская Федерация, 350075, г. Краснодар, ул. Московская, 2
[3]Донецкий национальный университет экономики и торговли имени М. Туган-Барановского
83050, г. Донецк, ул. Щорса, 31
[4]Одесская национальная академия пищевых технологий
Украина, 65039, г. Одесса, ул. Канатная, 112
[*]E-mail: vladislav.danko@mail.ru

Аппараты для проведения процессов тепломассообмена должны конструироваться так, чтобы у них была максимально развитая поверхность контакта. Классификация теплообменных аппаратов (ТМА) предусматривает как геометрические особенности аппарата, так и создаваемую в них гидродинамическую обстановку. Однако основная тенденция при конструировании таких аппаратов – создание тонкой пленки жидкости на поверхности насадки – остается доминирующей. Целью работы – выбрать решения, при которых ТМА с РН может быть использован для реализации процессов контактной обработки газов и жидкостей с уточнением значений плотности элементов насадки ($\rho_{эн}$) *и динамической высоты столба* (H_{cm})*, а также получение уточненных расчетных зависимостей, описывающих гидродинамику и тепломассоперенос в аппаратах с подвижной насадкой АРН, т. е. создать базы для инженерных расчетов. Методами исследования были теоретическое изучение и экспериментальное исследование на натурных образцах тепломассообменных аппаратов* *с подвижной насадкой. Было установлено, что лучшим для реализации массообменных процессов представляется диапазон плотности элементов насадки $\rho_{эн}$ = 200–700 кг/м^3, отличающийся широким диапазоном рабочей скорости $w_г$, приемлемыми значениями вынесенной жидкости и сравнительно небольшой динамической высотой слоя. Диапазон 2,5 < $w_г$ < 6,0 м/с обеспечивает возможность устойчивой эксплуатации АРН в режиме высоких нагрузок. Практическая значимость заключается в получении уточненных расчетных зависимостей, описывающих гидродинамику и тепломассоперенос в аппаратах с подвижной насадкой.*

Ключевые слова: подвижная насадка, псевдосжижение, тепломассообменный аппарат, критическая скорость, потеря напора в рабочей зоне, динамическая высота насадочного слоя, стационарный режим.

Introduction. The defining feature of heat and mass transfer processes, which occurs in the three-phase flows, is the interaction phase, which determines the value of the interfacial surface. Therefore, apparatuses for the heat and mass transfer processes must be designed so that they have a maximum contact surface. Classification of heat-mass exchange apparatuses (HMEA) provides geometric features of the apparatus and the hydrodynamic condition they create. However, the main trend which remains dominant in the design of such apparatus is to create a thin film of liquid on the surface of the nozzle.

Apparatuses with a movable nozzle (AMN) were developed in relation to the implementation process of dedusting and degassing and absorption in a number of countries: Canada, the USA, Germany, Japan, CIS-countries [1; 2]. AMN advantages over other types of contact devices, which determined their widespread occurrence: steady operation in the polluted environments of self-cleaning nozzle surfaces and walls of casing, low sensitivity of the device characteristics to sudden load fluctuations of gas and liquid; indiscriminateness to the initial liquid distribution, which is important for industrial AMN; high lateral uniformity simplifying scalability; a wide range of workload (in [3–7] a value q_l up to 200 m^3/(m^2·h is reported) and w_g up to 8 m/s at an empty AMN intersection); high intensity of exchange processes in the layer; constructive design simplicity; compactness; low weight and cost of the nozzle.

So far published information about the interaction of the three phases in the HMEA varies by the difference in the representation quality and experimental data discrepancies in all major aspects of the movable layers behaviour, so that its practical use in the engineering calculations is complicated. The study of the quite complex "gas–liquid–solid" system behaviour remains largely experimental. Prospects of AMN use for evaporative water cooling require special consideration. AMN is advisable to apply for the organization of such mass transfer processes in which the main resistance of mass transfer is focused in the gas phase, typical for the process of evaporation cooling in the cooling towers [4].

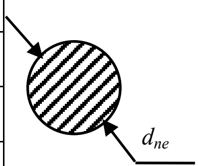
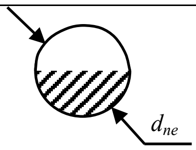
Therefore, the work was aimed at choosing the solution in which the MN of the HMEA can be used to implement the contact handling process of gases and liquids with density values clarification of the nozzle elements (ρ_{ne}) and the column dynamic height (H_{dh}) and obtain the specified calculated dependences which describe the hydrodynamics and mass transfer in AMN, that is to create bases for engineering calculations [8–12].

Studying of evaporative water cooling processes was carried. Studying of evaporative water cooling processes was carried on a laboratory model using different nozzle elements (see table).

From a scientific and practical point of view, the issue concerning the nature of the transit of nozzle layer from a stationary to a moving condition seems important. The issue is complex and poorly studied. Typical modes of movable nozzles (MN) behaviour in the apparatuses are shown in fig. 1.

Fixed layer porosity does not depend on the load of the gas and the liquid. Traditionally, the critical transition velocity (w_0, w_0') is determined by visual pseudo-fluidization curve analysis that is described by the dependence $\Delta p = (w_g, q_l)$. We conducted its specification by constructing selective La (w_g, q_l) under the following conditions: H_{dh} = 0,1 m, d_{ne} = 0,04 m, ρ = 300 kg/m^3, q_l = 15 m^3/(m^{2}h) (fig. 2).

Studied nozzle elements characteristics

№	NE type	Nozzle material	Geometry	ρ_{ne},	Note
			d_{ne}, mm	kg/m^3	
1		Foamed polypropylene	40.1	248	Commercialization of elements
2			40.3	305	
3			36.6	335	
4			35.6	367	
5		Empty celluloid ball which is partly filled with water	37.1	100–1000 in increments of 100 units	Size ρ_{ne} for the empty element 91 kg/m^3

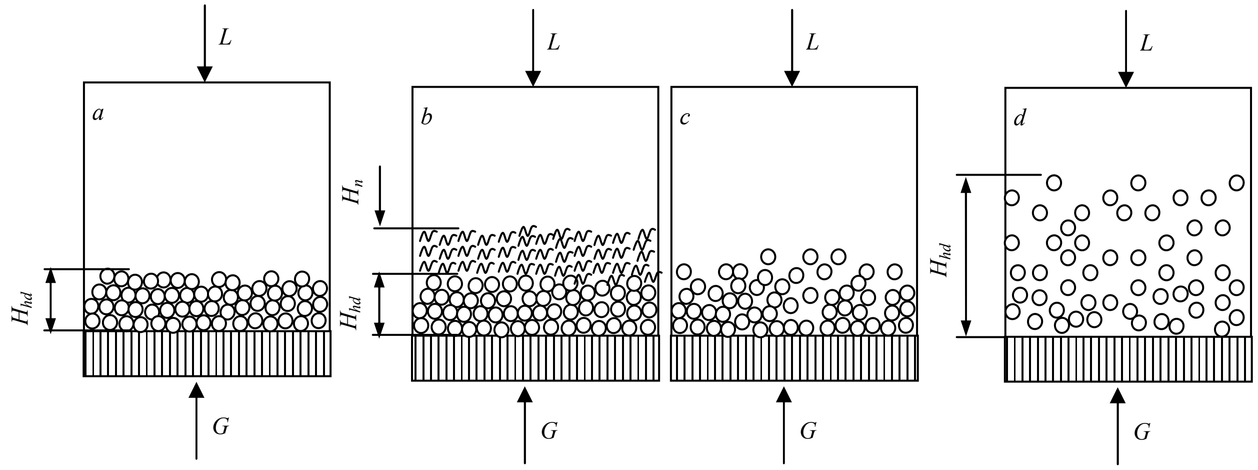


Fig. 1. Typical AMN modes: *a* – stationary; *b* – stationary nozzle flooding; *c* – initial pseudo-fluidization; *d* – developed pseudo-fluidization

Рис. 1. Характерные режимы АПН: *а* – стационарный; *б* – захлебывание стационарной насадки; *в* – начальное псевдоожижение; *г* – развитое псевдоожижение

Speed w_g is given to the empty column crossing; fixed (1, *a*) and initially compacted layer of nozzle elements (1, *b*) having the ability to expand is considered. Value $w_g{}^*$: $w_{отр}$ – the maximum speed at which the curves coincide Δp for fixed and movable layers; $w_з$ – the beginning of stationary nozzle flooding; w_o, w_o' – the beginning of pseudo-fluidization; w_1 – the beginning of active pseudo-fluidization; w_i – inversion beginning. Let us specify some definitions through the variety of existing formulations for $w_g{}^*$: $w_з$ corresponds to the intensive growth Δp, layer turbidity, foam formation atop of the layer (partially inverted cocurrent). For the fixed layer speed $w_з$ is unchanged for specific loadings; for an extending layer $w_з$ depends on the porosity and cannot be described by the known dependencies; w_o is the minimum gas velocity at which steady vertical oscillations of several adjacent NE are observed; w_1 corresponds to the active movement and mixing of NE; w_i is the beginning of NE inversion – their concentration near restrictive gates. The latter mode is almost immediately transformed into "upper" NE flooding, which is typical for the fixed layer (fig. 1, *b*).

Value w_o' is clearly recorded on vibrocurve L_a (w_g) as a leap ($\cong$ 20 dB or 30 %) and mild stated on fluidization curve (column walls vibroacceleration is defined by the movable nozzles state). Almost constant vibroacceleration level ($L_a = 5.5\, w_g^{0,08}$) corresponds to the stationary layer state. The NE transition to movable state was much more difficult, as compared to the traditional presentation. If $w_g \cong w_o'$ then the described unstable pseudo-stationary NE states are formed during periodic movement of an individual NE (layer alteration with changing porosity) at a constant load. Their duration ranges from tens of seconds to several minutes. The layer structure is changing and fluid retention therein varies, i. e. the w_o' value is characterized by a certain range of existence. The width of this range depends on the initial layer density which is determined by NE own weight and the action of external loads and vibrations. For example, for NE with $\rho_{ne} = 300$ kg/m^3 and $d_{ne} = 0{,}037$ m, this value is 0.4 m/s.

We found that the elements with $\rho_{ne} < 200$ kg/m^3 transferred to a moving state, bypassing flooding in a stationary state, for $\rho_{ne} > 200$ kg/m^3 pseudo-fluidization is carried out in pseudo-stationary flooding condition of the extending layer; for $\rho_{ne} > 700$ kg/m^3 this pattern persists for larger values of H_p, and the part of liquid is taken outside of the layer and placed on top of its upper limit as the layer of foam with thickness H_n over 0.02 meters.

Gas and liquid layer load effecting movable nozzles retaining ability $H_{dh} = 0.1$ m is shown in fig. 3.

The best range to implement mass transfer processes seems to be that of ρ_{neII} (ρ_{ne} = 200–700 kg/m^3). Partial fixed layer flooding precedes the beginning of pseudo-fluidization; the nature of the transition determines the entire future behaviour of the system. The speed of the apparatus starting to flood $w_з$ is quite high ($\approx$ 6 m/s); liquid withdrawal ΔG_l from the working area is slow until the speed value is $w_з$. This range differs by a wide work area of speed w_g, acceptable values of fluid withdrawal ΔG_l and a relatively small dynamic height of the layer H_l.

Regarding this area let us consider the characteristic pseudo-fluidization modes:

1. $0 < w_g \le 2.0$ m/s – Stationary system state with characteristic local restructuring of fixed layer structure and some porosity growth. Linear growth H_l (w_g) until the beginning of the pseudo-fluidization speed w_0' with the progressive flooding of the fixed reconstructed layer.

2. $2.0 < w_g \le 2.5$ m/s – Initial pseudo-fluidization mode (transitional mode). There is a characteristic peak H_p by the speed of gas w_0' (fig. 3, *a*) with the consequent restoration to the previous value; the system is unstable, the part of the layer remains stationary and its periodic restructuring occurs. Fluid retention for $q_l < 5$ m^3/ (m^2·h) (fig. 3, *b*) in active pseudo-fluidization mode decreases to values which are characteristic of the stationary layer. This is a border q_l^* for cooling towers with movable nozzle (CTMN) related to layer drainage; here CTMN operation is not feasible, despite the liquid being in the layer for a long time.

3. 2.5 < $w_g \leq$ 6.0 m/s – Developed pseudo-fluidization mode. The entire nozzle layer is movable, the system is homogeneous. Comparison of system characteristics with the similar mode for the zone $\rho_{ne\text{I}}$ shows that the new transition patterns to mobility impacted the behaviour of the system as a whole: the initial flooding state is supported. However, it does not further develop with the increase of w_g to the developed flooding due to a mechanism that compensates the layer expansion. This kind of situation when the initial flooding supported in a wide range of w_g, provides the possibility of stable AMN operation in the high loads mode. Within the described mode, we can distinguish the area $w_g \cong$ 4.7–6.0 m/s, where there is no dependence of H_l on w_g. This new area precedes a sharp increase of H_l.

4. 6.0 < $w_g \leq$ 8.0 m/s. In fact, that is the previous mode with a sharp increase of flooding component. Conventionally, it can be called a movable layer flooding mode, noting a significant difference from the same mode with a stationary nozzle. Whereas, under the latter conditions, the flooding mode means the practical impossibility of further employment, but concerning the apparatuses with a movable nozzle this possibility remains, due to the liquid capacity of the apparatus and very high intensity of the process.

Processing of experimental information. The most important hydrodynamic characteristics of cooling towers with movable nozzle (CTMN), which are required for engineering calculations, are critical speeds (w_0', w_1), pressure loss in the working area (Δp), fluid retention (H_l) and dynamic layer height ($H_Д$). This information allows selecting the operating mode of heat-mass exchange apparatus (HMEA), calculating the height of the columns and fan power [13–15].

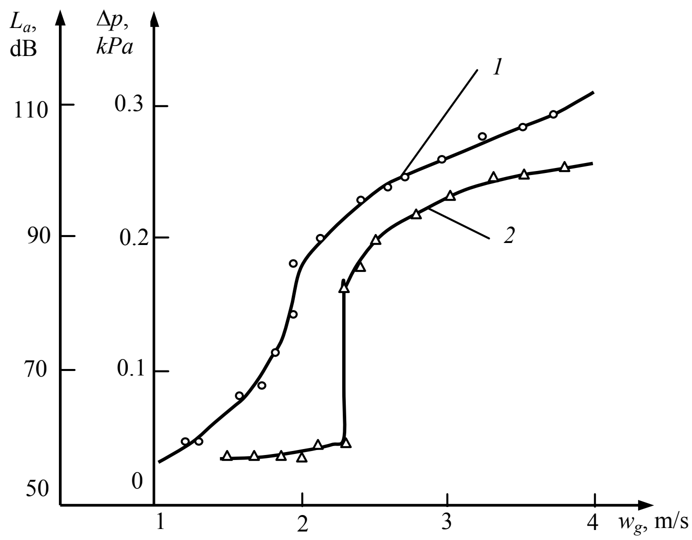


Fig. 2. Experimental dependences: *1* – pseudo-fluidization curve $\Delta p = f(w_g)$; *2* – vibrocurve $L_a = f(w_g)$

Рис. 2. Экспериментальные зависимости: *1* – кривая псевдоожижения $\Delta p = f(w_g)$; *2* – виброкривая $L_a = f(w_g)$

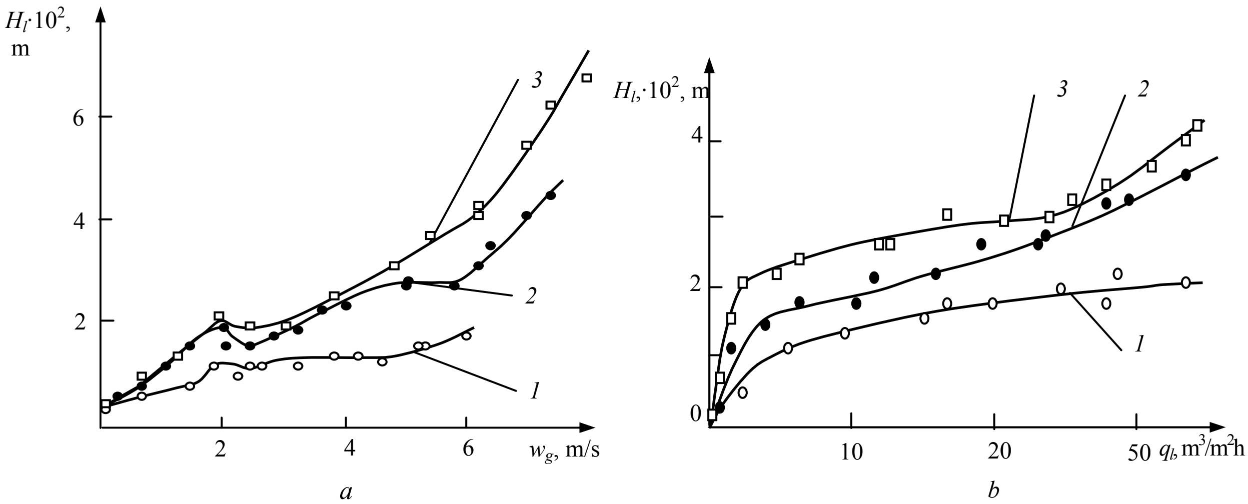


Fig. 3. Dependence of retaining ability of the movable nozzle on gas and liquid loads at H_{dh} = 0.1 m:
1 – ρ_{ne} = 100 kg/m^3, *2* – ρ_{ne} = 500 kg/m^3; *3* – ρ_{ne} = 800 kg/m^3; *a* – $H_l = F(w_g)$; *b* – $H_l = f(q_g)$

Рис. 3. Зависимость удерживающей способности слоя подвижной насадки от нагрузок по газу и жидкости при H_{dh} = 0,1 м: *1* – ρ_{ne} = 100 кг/м^3; *2* – ρ_{ne} = 500 кг/м^3; *3* – ρ_{ne} = 800 кг/м^3; *а* – $H_l = f(w_g)$; *б* – $H_l = f(q_g)$

For non-irrigated layers the equation is obtained:

$$\mathrm{Re}_0 = \frac{\omega_0 d_{ne}}{\nu_g} = \frac{Ar_g}{130\frac{1-\varepsilon_0}{\varepsilon_0^3} + \sqrt{\frac{Ar_g}{\varepsilon_0^3}}}, \quad (1)$$

where, in order to record the peculiarities of the compressed flow of balls with gas stream the stationary layer porosity is used. Equation (1) provides the calculation w_o for the layer of balls with diameter of the nozzle elements d_{ne} = 35...42 mm and density ρ_{en} = 90...1000 kg/m^3 for $H_{cm} > d_{ne}$. Nozzle irrigation leads to a decrease of w_g^* (w_o'), and with the increase of ρ_{ne} the w_o' value decreases. With regard to the influence of q_l and ρ_{ne} let us write down:

$$\omega_0' = \frac{4320 \cdot \rho_{ne}^{-1,21} \cdot \omega_0}{4320\rho_{ne}^{-1,21} + q_l^{(-1,25\cdot 10^{-4}\rho_{ne}+0,275)}}. \quad (2)$$

This equation is fair for $200 \le \rho_{ne} \le 1000$ kg/m^3 and $5 \le q_l \le 25$ m^3/(m^2·h). For ρ_{ne} <200 kg/m^3 dependence of $w_0' = F(\rho_{ne})$ appears to be bigger. The w_1 value characterizes the transition to the developed pseudo-fluidization, i. e. to the uniformly pseudo-fluidized layer:

$$\omega_1 = 1,4 \cdot \omega_0'. \quad (3)$$

The width of the area of initial pseudo-fluidization sharply increases with ρ_{ne} growth and the layers of nozzle elements (NE) with density ρ_{ne} > 500 kg/m^3 operate in practice only in this mode.

Dynamic height is characterized by a mean value of oscillating movable nozzle (MN) level, and was determined visually. In the stationary state, these oscillations are characterized by constant amplitude:

$$H_d = H_{hd} + H_{hd}\left(\omega_g - \omega_0'\right) \times$$
$$\times \left[16,2\exp\left(-0,002\rho_{ne} - 70d_{ne}\right) + 0,007q_l\right]. \quad (4)$$

If $w_g = w_o'$, then value $H_d = H_{dh}$. This formula provides a calculation of H_d for dry layer of MN, as well; it is fair in the range of $w_g = w_o' - 4.5$ m/s; $q_l \le 25$ m^3 /(m^2·h); H_{dh} = 0.5–0.2 m; ρ_{ne} = 90–1000 kg/m^3, d_{ne} = 0,035–0,042 m.

The gas stream pressure loss value Δp determines the capacity of the electric fan motor (excluding energy consumption for separation and loss in communication). Traditionally the ratio $\left(\frac{\Delta p}{H_{hd}}\right)$ is used, but the main MN layer characteristic is its dynamic height H_{dh}. Complex $\left(\frac{\Delta p}{H_{hd}}\right)$ leads to a distortion of the physical scene, as, for example, with ρ_{ne} = 1000 kg/m^3 this value exceeds 10^4 Pa/m. This maximum value corresponds to the weight of the fixed layer NE, where voids are completely filled with liquid. This should result in the inverted cocurrent if losses are greater than 10 Pa/m, which in practice is not observed even at w_g > 8 m/s. So it is worthy using the specific dynamic pressure loss, i. e. the value $\left(\frac{\Delta p}{H_d}\right)$. It consists of a dynamic specific NE weight $\left(\frac{gM_{ne}}{F_к H_d}\right)$ and pressure loss Δp_d, that characterize the contribution to the general value of the detained fluid pressure loss and friction due to the elements mixing in the pseudo-fluidized layer:

$$\Delta p = \Delta p_d H_d + \frac{gM_{ne}}{F_k},$$
$$\Delta p_d = 0,8H_{hd}^{-0,65}\omega_g \times \quad (5)$$
$$\times \exp(1,85\cdot 10^{-3}\rho_{ne} + 1,56\cdot 10^{-2}q_l + 2,86),$$

where M_{ne} – NE layer mass.

The equation is adequate to the experimental data with an average relative error 0.11 and is fair in the ranges: $0.05 \le H_{dh} \le 0.2$ m; $w_o < w_g \le 4.5$ m/s; $5 \le q_l \le 25$ m^3/ (m^2 · h); $200 \le \rho_{ne} \le 1000$ kg/m^3. Increase of H_{dh} leads to the decrease of Δp_d, which indicates pseudo-fluidization quality deterioration. For the elements with ρ_{ne} = 90 kg/m^3 the Δp_d value does not depend on w_g; for $w_g = w_o'$ the smallest difference of Δp_d occurs, which was obtained for different densities ρ_{ne}. Heavier NE correspond to the greater value Δp_d, which match physical presentations. For q_l < 5 m^3/(m^2·h) the exponential nature of equation (5) is disturbed.

Conclusion. The apparatuses with a movable nozzle are a promising solution of column HMEA, which enables operation in the extreme conditions (contaminated environment, sharp fluctuations of loads), increased limit loads, high lateral uniformity of fluid (scaling task simplification), and lack of demands to the flow distribution quality. The best ranger for mass transfer processes implementation is that of ρ_{neII} (ρ_{en} = 200–700 kg/m^3), which is distinguished by a wide working area according to w_g, acceptable values of fluid withdrawal and a relatively small dynamic layer height.

Necessary dependencies for engineering calculation were obtained, which determine the critical speed value (w_0'), the pressure loss in the working area (Δp) and the dynamic NE layer height ($H_д$).

It remains necessary to study the dynamics of gas-droplet flows in the system to provide for calculation of fluid distribution units, drop moisture separation, environmental emission and scattering therein, to consider the issues of the applied nature (scale factor, work in long-term inclines and tossing; the accumulation of impurities in the recirculation liquid, etc. An improved constructive design of devices with the movable nozzle shall be developed.

References

1. Veselov F. V., Novikova T. V., Khorshev A. A. [Technological updating of power system as long-term factor of control of increase in prices of the electric power]. *Teploenergetika*. 2015, No. 12, P. 3 (In Russ.).

2. Ginzburg A. S., Belova I. N., Reshetar O. A. [Impact of climatic factors on energy consumption during the heating season]. *Teploenergetika*. 2016, Vol. 63, No. 9. P. 621–627 (In Russ.).

3. Arakelyan V. B., Danko V. P., Grigoryan R. P. Influence of the external noise intensity on the kinetics of ligands binding to receptors. Influence of the external noise intensity on the kinetics of ligands binding to receptors. *Journal of Contemporary Physics.* 2017, Vol. 52, no. 1.

4. Gorin A. N., Doroshenko A.V., Danko V. P. *Teplomasso obmenniye apparati s podviznoy nasadkoy dla tradicionnich I alternativnich energetiheskich system* [Heat-mass exchangers with movable nozzle for traditional and alternative energy systems. Evaporative cooling. Dehumidification and conditioning for air (theory, experiment. practice]. Donetsk, Svit knigi Publ., 2013, 327 p.

5. Karnaukh V. V. *Intensifikacia teplo-massoobmennich proceccov v ventilatornich gradirnach plonocnogo tipa* [Intensification of heat-mass transfer processes in water cooling tower film-type]. Donetsk, DonNUET Publ., 2010, 159 p.

6. Kaiser A. S., Lucas M., Viedma A., Zamora B. Numerical model of evaporative cooling processes in a new type of cooling tower. *International Journal of Heat and Mass Transfer*. 2005, No. 2, P. 986–999.

7. Kroshilin A. E., Kroshilin V. E. [Correct numerical simulation of a two-phase coolant]. *Teploenergetika*. 2016, Vol. 63, No. 2, P. 98–106 (In Russ.).

8. Danko V. P., Karnaukh V. V. [Experimental researches of heat transfer in a layer moving fitting stripping contour solar systems]. *Vestnik Mezhdunarodnoi Akademii Kholoda.* 2016, No. 3, P. 73–77 (In Russ.).

9. Danko V. P., Kudrin A. B., Radionenko V. N. *Ispol'zovanie al'ternativnyh istochnikov energii i vtorichnyh energoresursov v holodil'noy otrasli* [Use of alternative energy sources and secondary energy resources in refrigerating branch]. Samara, Lada-Print Publ., 2015, 157 p.

10. Poddubnyi I. I., Razuvanov N. G. [Research of hydrodynamics and heat exchange at a lowering current of liquid metal in the channel of rectangular section in a coplanar magnetic field]. *Teploenergetika.* 2016, No. 2, P. 13 (In Russ.).

11. Shestova T. D., Markvart A. S., Lozovsky T. L., Zhelezny V. P. Cubical equations of state for predicting the phase equilibria of poorly studied substances. *Russian Journal of Physical.* Chemistry A. 2013, Vol. 87, No. 6, P. 883.

12. Doroshenko A. V., Vasyutinskii S. Yu., Danko V. P., Glauberman M. A. [Research of processes in the teplomassoobmennykh devices with a mobile nozzle for solar multipurpose systems]. *Fizika aerodispersnykh system*. 2012, No. 49, P. 14–26 (In Russ.).

13. Valueva E. P., Purdin M. S. [Hydrodynamics and heat exchange of the pulsing laminar stream in channels]. *Teploenergetika*. 2015, No. 9, P. 24.

14. Imre A. R., Házi G., Horváth Á., Maráczy C., Mazur V., Artemenko S. The effect of low-concentration inorganic materials on the behaviour of supercritical water. *Nuclear Engineering and Design.* 2011, Vol. 241, No. 1, P. 296–300.

15. Danko V. P. [Solar collectors with a metal-polymeric absorber for systems of heatcold supply]. *Nauchnye trudy Odesskoi natsional'noi akademii pishchevykh proizvodstv*. 2014, Vol. 45, No. 1, P. 88–94.

Библиографические ссылки

1. Веселов Ф. В., Новикова Т. В., Хоршев А. А. Технологическое обновление теплоэнергетики как долгосрочный фактор сдерживания роста цен электроэнергии // Теплоэнергетика. 2015. № 12. С. 3.

2. Гинзбург А. С., Решетарь О. А., Белова И. Н. Влияние климатических факторов на энергопотребление в отопительный сезон // Теплоэнергетика. 2016. № 9. С. 20–27.

3. Arakelyan V. B., Danko V. P., Grigoryan R. P. Influence of the external noise intensity on the kinetics of ligands binding to receptors. Influence of the external noise intensity on the kinetics of ligands binding to receptors // Journal of Contemporary Physics, 2017. Vol. 52, № 1.

4. Горин А. Н., Дорошенко А. В., Данько В. П. Тепломассообменые аппараты с подвижной насадкой для традиционных и альтернативных энергетических систем. Испарительное охлаждение, осушение и кондиционирование воздуха: теория, эксперимент, практика. Донецк : Світ книги, 2013. 327 с.

5. Карнаух В. В. Интенсификация тепломассообменных процессов в вентиляторных градирнях пленочного типа : монография. Донецк : ДонНУЭТ, 2010. 159 с.

6. Numerical model of evaporative cooling processes in a new type of cooling tower / A. S. Kaiser [et al.] // International Journal of Heat and Mass Transfer. 2005. № 2. Pp. 986–999.

7. Крошилин А. Е., Крошилин В. Е. Корректное численное моделирование двухфазного теплоносителя // Теплоэнергетика. 2016. № 2. С. 22.

8. Данько В. П., Карнаух В. В. Исследование влияния концентрации раствора абсорбента на охлаждающую способность тепломассообменных аппаратов с подвижной насадкой // Вестник Международной академии холода. 2016. № 3. С. 73–77.

9. Данько В. П., Кудрин А. Б., Радионенко В. Н. Использование альтернативных источников энергии и вторичных энергоресурсов в холодильной отрасли. Самара : Лада-принт, 2015. 157 с.

10. Поддубный И. И., Разуванов Н. Г. Исследование гидродинамики и теплообмена при опускном течении жидкого металла в канале прямоугольного сечения в компланарном магнитном поле // Теплоэнергетика. 2016. № 2. С. 13.

11. Cubical equations of state for predicting the phase equilibria of poorly studied substances / T. D. Shestova [et al.] // Russian Journal of Physical Chemistry A. 2013. Vol. 87, no. 6. p. 883.

12. Исследование процессов в тепломассообменных аппаратах с подвижной насадкой для солнечных многофункциональных систем / А. В. Дорошенко [и др.] // Физика аэродисперсных систем. 2012. № 49. С. 14–26.

13. Валуева Е. П., Пурдин М. С. Гидродинамика и теплообмен пульсирующего ламинарного потока в каналах // Теплоэнергетика. 2015. № 9. С. 24.

14. The effect of low-concentration inorganic materials on the behaviour of supercritical water / A. R. Imre [et al.] // Nuclear Engineering and Design. 2011. Vol. 241, no. 1. P. 296–300.

15. Данько В. П. Солнечные коллекторы с металлополимерным абсорбером для систем теплохладоснабжения // Научные труды Одесской национальной академии пищевых производств. 2014. Вып. 45, т. 1. С. 88–94.