Development of New Types of Contact Devices for Heat-Mass Transfer Apparatuses, Used at Petrochemical Enterprises

I. N. Madyshev, O. S. Dmitrieva and A. V. Dmitriev

Abstract One of the most important ways to increase the efficiency of technological processes is to improve the column heat-mass transfer apparatuses. The design of a jet-film contact device for carrying out the heat-mass transfer processes within gas-liquid systems has been developed. The advantage of this device is a low hydraulic resistance and high mass transfer efficiency with relatively low energy demands. The development of a new technical solution has been carried out with the software module. The separation efficiency of the contact device with its different geometrical dimensions and diameters of the collected drops has been studied. It is established that the greatest separation efficiency of the contact device is provided when its geometrical constant is equal to 0.5, and medium dispersed aerosol particles with a diameter of 20 µm are collected by 99.5%. The high collecting efficiency at small geometrical constant of contact device is explained by the creation of large centrifugal forces due to small radii of gas flow vortices.

Keywords Contact device · Heat-mass transfer · Separation efficiency

1 Introduction

Column heat-mass transfer apparatuses are widely used in chemical, petrochemical, and oil refining industries when carrying out the processes of absorption, rectification, liquid extraction, and gas separation [1, 2]. One of the most important ways to increase the efficiency of such processes is to improve the column heat-mass transfer apparatuses and, above all, contact devices.

I. N. Madyshev · O. S. Dmitrieva
Kazan National Research Technological University,
68, Karl Marx Str., Kazan 420015, Russia

A. V. Dmitriev (✉)
Kazan State Power Engineering University,
51, Krasnoselskaya Str., Kazan 420066, Russia
e-mail: ja2deva@gmail.com

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The tendency for developing the apparatuses with high unit capacity has led to the development of a large number of new designs of random and regular packings in recent decades, having higher throughput and slightly greater efficiency. As a rule, random packings are characterized by higher hydraulic resistance and are less reliable in operation with contaminated media and uneasy to be maintained [3, 4]. Regular packings have a more ordered structure, which has a positive effect on their hydrodynamic and mass transfer parameters. The most famous random packings are manufactured by the following foreign and home companies: HY-PAK, CASCADE-RINGS, GIPH, GIAP, Ingekhim; as for the regular packings—INTALOX of NORTON company, Mellapak of Sulzer company, VAKUPAK, KEDR, Glitch-grid, Flexypack, Perform-grid, Ingekhim, Koch-glitsch, etc. [5–11].

When developing the new designs of contact devices, the main technological task is to increase the specific surface area of contact of phases by implementation of intensive interaction of two-phase gas-liquid flows and to decrease the hydraulic resistance of the apparatuses. The authors propose to solve this issue by using the developed and experimentally tested contact devices with film interaction of gas and liquid, having different modifications [12].

2 Research Materials and Methods

Contact device with film interaction of gas and liquid [13] (Fig. 1) is a nozzle block, consisting of drain cups *1* for collection and distribution of liquid over the cross section of the heat-mass transfer apparatus. Drain cups *1* are arranged on vertical longitudinal and transverse partitions *2*. Round holes, executed within partitions *2*, lead to a decrease in the metal consumption for the proposed design. Within the cross section, the drain cups *1* are made in the form of a square, while in the bottom there are petals *3* in the form of circular segments, bent down and directed to the surface of the vertical partitions *2*.

The contact device with the film interaction of gas and liquid, proposed by the authors, operates as follows. The liquid, dispersing through the distribution device of the heat-mass transfer apparatus, enters the drain cups *1*, which, through the bent petals *3*, forms a film, freely flowing down the surface of the vertical partitions *2*. In this case, an ascending gas flow moves toward the flowing down liquid film. Drain cups *1* are chequerwise arranged in the cross section of the device. Moreover, the below and above arranged drain cups *1* are shifted against the considered level. In this regard, the gas in the proposed nozzle moves along the Z-shaped path, which allows to increase the relative rate of the working media, while intensifying the mass, energy, and momentum transfer processes.

The geometric dimensions of the contact device with the film interaction of gas and liquid are chosen on the basis of equality of the areas for the passage of gas in the transverse and longitudinal sections of the heat-mass transfer apparatus. Lack of local expansions and narrowings for the ascending gas flow leads to decrease in the

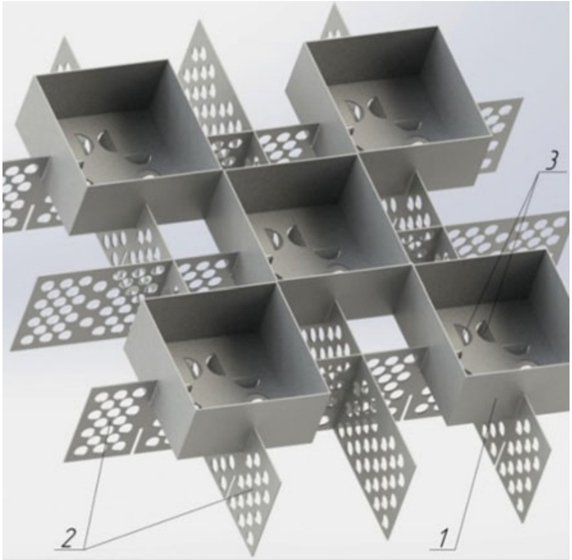

Fig. 1 Contact device with gas and liquid film interaction: *1* drain cup; *2* partitions; *3* petals

hydraulic resistance of the contact device, and lack of parts, manufactured with high accuracy, provides low manufacturing cost of the proposed nozzle blocks.

The purpose of the numerical studies is to determine the efficiency of aerosol particles' settling on the liquid film within the proposed contact device. The studies were conducted by means of ANSYS Fluent software program, which simulated the interaction of gas and liquid flows, as exemplified by air-water system at the temperature of 20 °C. The separation efficiency was estimated both within one contact stage and within the apparatus, consisting of *3* stages. At the same time, in the course of studies the geometrical dimensions of device were changed in a scale, proportional to its characteristic dimensions, namely, to the width of drain cup, equal to 100 mm and the wall height, equal to 47.5 mm. Moreover, dimensions of particles (spherical water drops) were changed within the range of 1–30 μm. The liquid level in the drain cup was taken as maximum.

Hydrodynamic calculations were carried out on the basis of Navier–Stokes equations, using the finite volume method. The calculation was carried out in accordance with the turbulence model—SST, showing satisfactory conformance with experimental data, obtained in the course of previous studies [14–17]. In order to simplify the numerical calculation, the following assumptions were made: Thickness of contact elements and walls of case were not taken onto account, and the adhesion condition was set for the walls of contact elements.

The separation efficiency can be estimated by means of efficiency value of the aerosol particles' settling:

$$E = \frac{N}{N_0}, \quad (1)$$

where N_0—total number of particles; N—number of particles, settled on the flowing down liquid film.

3 Research Results

In the course of numerical studies, the dispersed particles were evenly distributed over the cross section of the contact device, while their total number was 1000. The research results show that the separation efficiency of liquid drops with a diameter of less than 10 µm within one contact stage is almost independent from geometrical constant and is not more than 25% (Fig. 2). When the diameter of particles increases, the separation efficiency also increases. Thus, for example, drops with a diameter of more than 50 µm are collected by 100%.

Analyzing the graph, shown in Fig. 3, it can be seen that the greatest separation efficiency of contact device is provided when its geometrical constant is equal to 0.5, and medium dispersed aerosol particles with a diameter of 20 µm are collected by 99.5%. The high collecting efficiency at small geometrical constant of contact device is explained by creation of large centrifugal forces due to small radii of gas flow vortices.

Figure 4 shows that the separation efficiency of drops with a diameter of 1 µm is 0.74, at geometrical constant M_b = 0.5. With a further increase in geometrical constant, the separation efficiency tends to a value of 0.53. Therefore, when

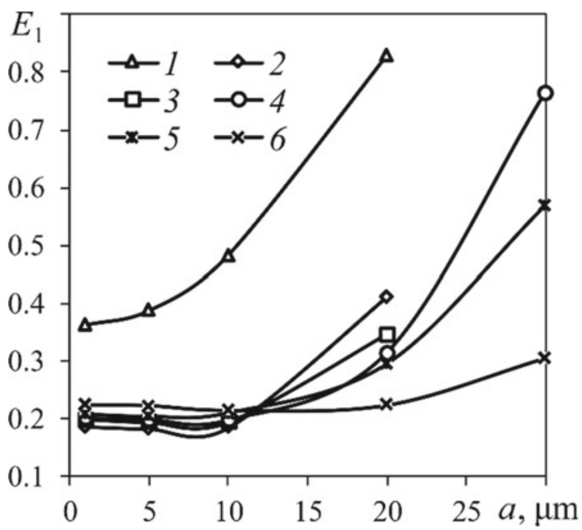

Fig. 2 Dependency of separation efficiency within one contact stage on the diameter of drops at different geometrical constants of contact device M_b: *1* 0.5; *2* 0.6; *3* 0.75; *4* 0.85; *5* 1; *6* 2

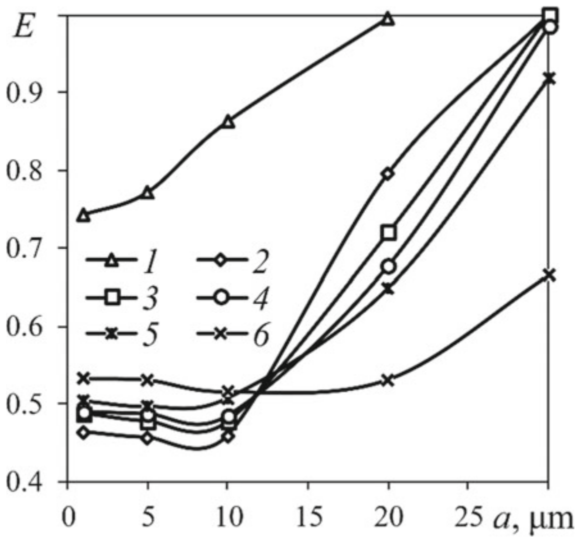

Fig. 3 Dependency of separation efficiency of contact device on the diameter of drops at different geometrical constants M_b: *1* 0.5; *2* 0.6; *3* 0.75; *4* 0.85; *5* 1; *6* 2

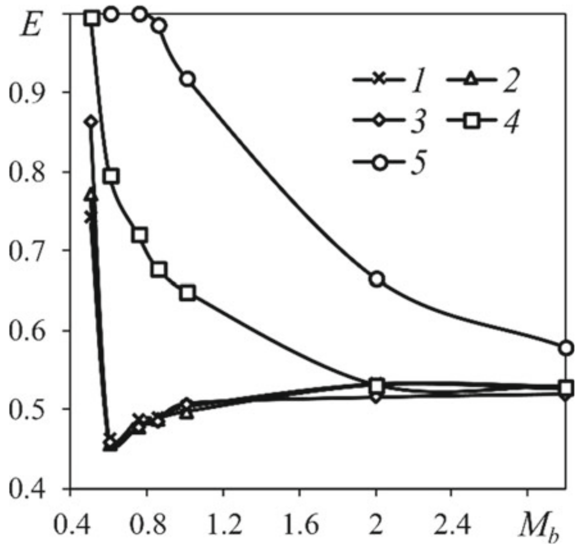

Fig. 4 Dependency of separation efficiency of contact device on geometrical constant at different diameters of drops *a*, µm: *1* 1; *2* 5; *3* 10; *4* 20; *5* 30

developing the design of the contact devices with gas and liquid film interaction, the width of drain cup should be reduced; however, in practice, the use of contact elements with a width of less than 50 mm leads to excessive metal consumption for design.

This paper [18] proposes a dependency for the calculation of critical diameter of the water drop:

$$a_{cr} = \frac{10.7\sigma_L}{\rho_G U_r^2} \tag{2}$$

where σ_L—surface tension, H/m; ρ_G—gas density, kg/m^3; U_r—relative gas flow, m/s.

4 Conclusion

According to the estimated calculations by Eq. 2, when the actual gas flow rate, within the narrowing part of the contact device with gas and liquid film interaction, is equal to 20 m/s, the critical diameter of the formed drops will not exceed 1.6 mm. Thus, the conducted numerical studies show that the settling efficiency of such drops will be 100%, which is confirmed by numerous experimental data [19, 20]. Therefore, when designing the heat-mass transfer apparatuses with the proposed contact devices, there is no need for the use of additional separation devices or drop collectors.

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References

1. Kulov NN, Gordeev LS (2014) Mathematical modeling in chemical engineering and biotechnology. Theor Found Chem Eng 48:225–229. https://doi.org/10.1134/S0040579514030099
2. Khafizov FSh, Afanasenko VG, Khafizov IF, Ash Khaibrakhmanov, Boev EV (2008) Use of vortex apparatuses in gas cleaning process. Chem Pet Eng 44:425–428. https://doi.org/10.1007/s10556-008-9081-z
3. Kolev N, Kralev B, Kolev D (2013) Gas side controlled mass transfer in a new packing with stamped horizontal lamellae operating at extremely low liquid loads. Chem Eng Process 63:44–49. https://doi.org/10.1016/j.cep.2012.07.004
4. Wei ZJ, You ZL, Gui SQ (2010) Gas pressure drop and mass transfer characteristics in a cross-flow rotating packed bed with porous plate packing. Ind Eng Chem Res 49:3732–3740. https://doi.org/10.1021/ie9009777
5. Farakhov MI, Laptev AG, Basharov MM (2015) Modernization of mass-exchange equipment by new packings in chemical engineering. Theor Found Chem Eng 49:233–238. https://doi.org/10.1134/S0040579515030033
6. Maćkowiak J (2011) Model for the prediction of liquid phase mass transfer of random packed columns for gas-liquid systems. Chem Eng Res Des 89:1308–1320. https://doi.org/10.1016/j.cherd.2011.01.021
7. Contact elements for the column apparatuses (System INTALOX®, Packed Tower System). Catalogue of the company "KOCH-GLITSCH"

8. “Metal Random Packings” (Catalogue of the company “Sulzer Chemtech”, 22.64.06. 40-v04-50)
9. Boev EV, Ivanov SP, Afanasenko VG, Nikolaev EA (2009) Polymeric drop-film sprinklers for cooling towers. Chem Pet Eng 45:454–459. https://doi.org/10.1007/s10556-009-9209-9
10. Bessou V, Rouzineau D, Prévost M, Abbé F, Dumont C, Maumus J-P, Meyer M (2010) Performance characteristics of a new structured packing. Chem Eng Sci 65:4855–4865. https://doi.org/10.1016/j.ces.2010.05.029
11. Li X, Yang X, Li H, Shi Q, Gao X (2018) Significantly enhanced vapor-liquid mass transfer in distillation process based on carbon foam ring random packing. Chem Eng Process 124:245–254. https://doi.org/10.1016/j.cep.2018.01.005
12. Dmitrieva OS, Dmitriev AV, Madyshev IN, Nikolaev AN (2017) Flow dynamics of mass exchangers with jet-bubbling contact devices. Chem Pet Eng 53:130–134. https://doi.org/10.1007/s10556-017-0308-8
13. Dmitriev AV, Dmitrieva OS, Madyshev IN, Nikolaev AN, Kruglov LV (2017) Contact device with film flow of liquid for heat and mass transfer apparatus. RU Patent 171022, 17 May 2017
14. Solovev SA, Soloveva OV, Popkova OS (2018) Numerical simulation of the motion of aerosol particles in open cell foam materials. Russ J Phys Chem A 92:603–606. https://doi.org/10.1134/S0036024418030275
15. Borisov BV (2016) Features applications of the approaches when constructing efficient algorithms during the modelling of some intracanal flows. EPJ Web of Conf 110:01012. https://doi.org/10.1051/epjconf/201611001012
16. Ponomarev KO, Orlova EG, Feoktistov DV (2016) Effect of the heat flux density on the evaporation rate of a distilled water drop. EPJ Web of Conf 110:01060. https://doi.org/10.1051/epjconf/201611001060
17. Zaripov SK, Solov’eva OV, Solov’ev SA (2015) Inertial deposition of aerosol particles in a periodic row of porous cylinders. Aerosol Sci Technol 49:400–408. https://doi.org/10.1080/02786826.2015.1036834
18. Klinskiy BM, Kudravtsev AV (2012) Justification of requirement to the vakue of mass concentration and dispersivity of water drops when designing the bench-scale plant for simulation of rain falling. Eng 81:10–12
19. Dmitriev AV, Madyshev IN, Dmitrieva OS, Nikolaev AN (2017) Research dispersing liquid and gas in the contact device with an increased range of stable operation. Ecol and Ind of Russ 21:12–15. https://doi.org/10.18412/1816-0395-2017-3-12-15
20. Madyshev IN, Dmitrieva OS, Dmitriev AV, Nikolaev AN (2015) Assessment of change in torque of stream-bubble contact mass transfer devices. Chem Pet Eng 51:383–387. https://doi.org/10.1007/s10556-015-0056-6