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CALCULATION OF THE LOWER OPERATING LIMIT OF DUAL-FLOW PLATES WITH DIFFERENT GEOMETRICAL CHARACTERISTICS

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We consider the calculation of lower limit of the effective work of dual-flow plates with different geometrical characteristics. In the equations is proposed to use the parameter T, that allows improve the accuracy of equations. The equations can be used to improve the methods of calculating the dual-flow plates

Keywords: *dual-flow plates, column, hole diameter, calculation, equations*

Розглядається розрахунок нижньої межі ефективної роботи тарілок провального типу з різними геометричними характеристиками. У рівняннях запропоновано використовувати параметр Т, що дозволяє підвищити точність рівнянь. Рівняння можуть бути використані для вдосконалення методики розрахунку тарілок провального типу

Ключові слова: *тарілки провального типу, колона, діаметр отвору, розрахунок, рівняння*

1. Introduction

The dual-flow plate (counterflow plates type) is used in chemical industries. They are simple in making and reliable in exploitation. In the conditions of encrustation of trays by crystalline or polymeric products the application of only dual-flow plates with the big hole diameter (d_0≈0,1 m) is effective. Such trays were used in production of soda [1], for cleaning coke gas [2], in the processes of cleaning from a dust and cooling of industrial gases [3]. In [4] also recommended to apply holes of large diameter in the trays operating in fouling and corrosive environments.

The disadvantage of dual-flow plates is a narrow range of effective work [5]. The cross-flow plates are more generally used than the counterflow plates because of transfer-efficiency advantages and greater operating range [6].

Therefore, application of dual-flow plate requires exact their hydraulic calculation.

The hydraulic parameters of dual-flow plate substantially depend on geometrical descriptions of tray, such as a fractional open area, diameter of tray, of hole diameter of plate.

Existent normative documents determining construction and sizes of TurboGrid tray foresee the slots of one size regardless of diameter of column (width of slot 6 mm and its length 60 mm). The diameters of trays are in limits from 0,4 to 3,0 m.

The hydrodynamic calculation of dual-flow plates and TurboGrid trays is regulated by normative documents which are intended for the calculation of the standardized trays. In these documents the calculation of hydraulic parameters does not depend on the diameter of trays and hole diameter of plates.

Therefore, development of calculation method of dual-flow plates, which takes into big the size hole diameter of plate and the diameter of tray is an actual task.

2. Statement of the Problem

In this article the dual-flow plates on the experimental sets of hydraulic and kinetic tests with columns by the diameter D=2,0, 0,4, 0,3, 0,15 and 0,057 m were explored.

Geometrical parameters of dual-flow plates are represented in the table 1.

Table 1

Geometrical parameters of dual-flow plates

№ tray	Diameter column, *D*, m	Open areas, *f*, %	Hole diameter, d_0, m
1	2,0	16	0,012
2		25	0,012
3		36	0,012
4	0,4	16	0,012
5		36	0,012
6		56	0,012
7	0,3	16	0,008
8		36	0,012
9		56	0,012
10	0,15	16	0,008
11		16	0,012
12		19	0,012
13		22	0,012
14		25	0,012
15		30	0,012
16		36	0,012
17		46	0,007
18	0,057	15,5	0,002
19		14,6	0,005
20		15,8	0,008
21		17,7	0,012
22		16,3	0,013
23		15,8	0,016
24		16,3	0,023
25		24.9	0,002
26		25,4	0,005
27		26,6	0,012
28		24,1	0,0125
29		25,0	0,0285
30		36,1	0,002
31		36,0	0,005
32		35,6	0,012
33		36,9	0,020
34		35,5	0,024
35		35,6	0,034

Trays from № 1 to № 17 were made from steel St3 with thickness δ=0,0015 m. Trays from № 15 to № 35 were made from organic glass with thickness δ=0,004 m.

The dual-flow plates were explored in the wide range of change of loadings on the liquid L=1,6–143 $m^3/(m^2\cdot hour)$ and gas velocity through net area, achieved the value of w_g=4,9 m/s.

For research in columns by the diameter D=2,0, 0,4, 0,15 and 0,057 m the contacting systems air – water were used. In a column with the diameter D=0,3 m of research conducted on the contacting system the methanol – water (50 mol. %).

The operating range of tray were determined their pressure drop and froth height.

3. Literature review

At certain correlations of contacting phases there are different hydrodynamic regimes on a tray.

Three regimes operation of dual-flow plates were certain:

– regime of continuous barbotage layer;
– regime of mobile gas-liquid layer;
– regime of destruction of gas-liquid layer [7].

In the regime of barbotage layer (Fig. 1, 2) there are homogeneous in all directions cellular froth on a tray, with the horizontal surface of barbotage layer, the height of which does not change in time, for the same liquid/gas ratio phases. It is possible to assume that gravity in such barbotage layer exceed forces of inertia of liquid. In addition, a barbotage layer is practically symmetric in relation to the axes of co-ordinates, origin of which is located on the central vertical axis of dual-flow plates.

Fig. 1. Regime of continuous barbotage layer: tray # 21 (table 1) L=13,5 $m^3/(m^2\cdot h)$, w=0,56 m/s

Fig. 2. Regime of continuous barbotage layer: tray # 10 (table 1) L=12,7 $m^3/(m^2\cdot h)$, w=0,72 m/s

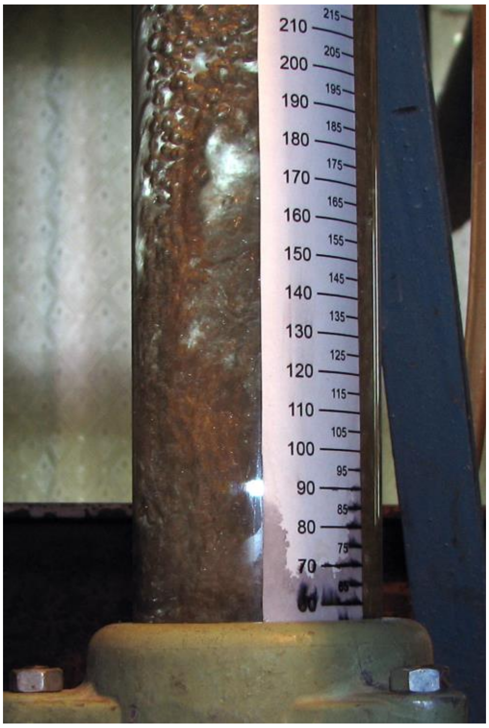

Fig. 3. Regime of mobile gas-liquid layer:
tray # 21 (table 1) L=13,5 m^3/(m^2·h), w=1,44 m/s

Fig. 4. Regime of mobile gas-liquid layer:
tray # 10 (table 1) L=12,7 m^3/(m^2·h), w=0,83 m/s

Under reaching the height of froth of greater H≈0,1 m layer loses stability (Fig. 3, 4). It is formed mobile by gas-liquid layer which is characterized by absence of the structured cellular froth. The free surface of gas-liquid layer is curvilinear. Its height changes in time for the same liquid/gas ratio phases, has amplitude and frequency. It is possible to assume that forces of inertia of liquid in such gas-liquid layer exceed gravities.

Except for it, gas-liquid layer loses symmetry in relation to the axes of co-ordinates, origin of which is located on the central vertical axis of dual-flow plates.

Gas-liquid layer appears on dual-flow plates as a system self-organizing [8]. As correlation of forces operating in the regime continuous barbotage layer and regime of mobile gas-liquid layer is different transit point between the regimes, which the certain liquid/gas ratio phases, it is possible to consider the point of bifurcation.

The point of bifurcation correspond to the height of the gas-liquid layer H≈0,1 m for all explored dual-flow plates (Table 1).

For finding out of reason of such work of dual-flow plates the experiments on measuring of dynamic pressure in a gas phase on the central axis of column by a sensor working on principle of Pitot tube were conducted [9].

A sensor was located on the axis of column above the center of dual-flow plate. The value of dynamic pressure was measured on a different height from the plate, and also common pressure drop of dry tray with the sensor set above it and without the set sensor.

The value of dynamic pressure was measured on a different height from the plate, and also common pressure drop of dry tray with the sensor set above it and without the set sensor.

Trays number 24, 29, 35, 19, 26, 31 from Table 1 are investigated.

In Fig. 5 the graphs of change of dynamic pressure on different distance from the plate (with one opening) for the row of velocity of gas in the section of column are represented.

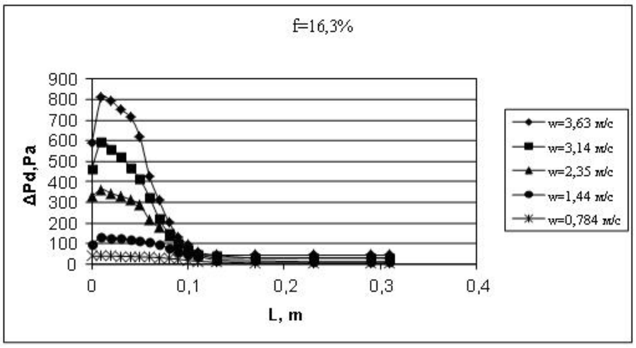

Fig. 5. Graphs of dynamic pressure dependence (*ΔPd*, Pa) from distance to the plate (*L*, m) for different values of velocity of gas in the section of column (w, m/s)

The graphs show that the magnitude of dynamic pressure decreases sharply from a maximum value at the plateau of the tray to a minimum value at a height L = 0,1 m. For all testing plates were obtained similar graphs.

In the article is made some conclusions:

– all investigated trays change the dynamic pressure on the central axis of the column of the gas velocity in the holes of the plates to the gas velocity in the cross section of the column occurs at a height of L=0,05–0,1 m;

– Regime of mobile gas-liquid layer in all the investigated trays occurs at the gas-liquid layer height H≈0,1 m.

Efficiency of dual-flow plates also depends on regimes of operation.

The book [7] shows the graphs of efficiency Murphree plates № 11, table 1 (Fig. 6), and a graph of the hydraulic pressure drop for the same tray (Fig. 7).

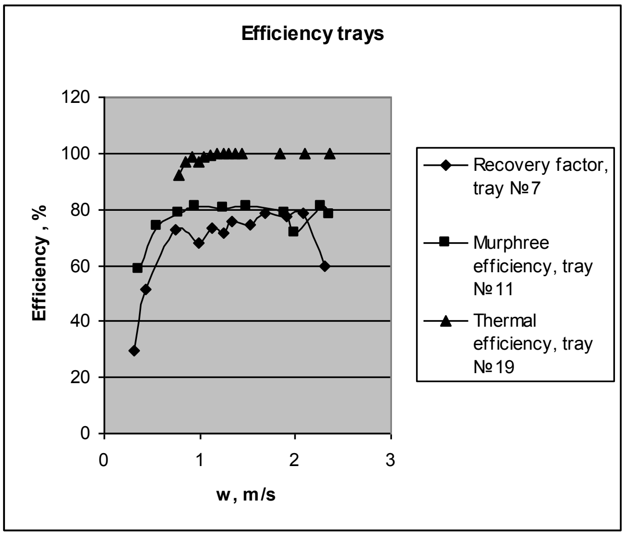

Fig. 6. Plots of the recovery factor for the condition rectification; Murphree efficiency in the liquid phase to conditions desorbing carbon dioxide from water; thermal efficiency for heat transfer conditions in the bubbling layer between the heated air and water and the gas velocity (vapor) in the cross section of the column. Number trays correspond to the plates from the Table 1

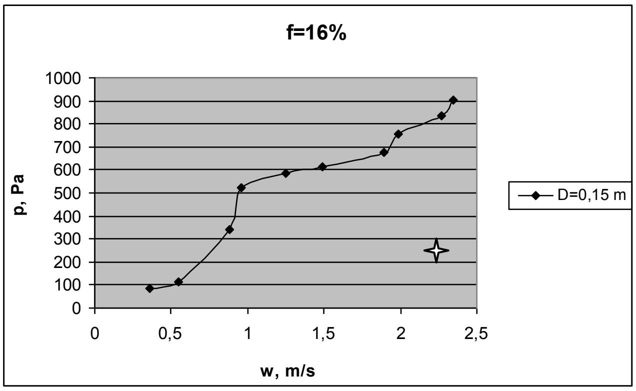

Fig. 7. A plot of the pressure drop of gas velocity in the cross section of the column in the desorption conditions

Density irrigation L=12,7 $m^3(m^2 \cdot h)$. Plate № 11, Table 1.

– Bifurcation point.

In book [7] is shown next conclusion: getting the most efficiency dual-flow plates is observed in regime of mobile gas-liquid layer.

Therefore, for lower working limit dual-flow plates must be taken of the gas velocity corresponding to the bifurcation point.

It is known [10] that an increase in chemical apparatus to industrial size, scale effect is observed. It is need for reduce the efficiency chemical apparatus by increasing their size. This effect exists for increasing the diameter of the dual-flow plates. In [7, 11] to simulate the hydraulic parameters such as the dual-flow plates (especially such as pressure drop of plates and their range of steady work), it is proposed to use the parameter T. The parameter T is the ratio of the sum of the perimeters of all holes of plate plateau to its diameter. The parameter T is the ratio of the sum of the perimeters of all openings plateau trays to the diameter of the tray.

4. Determination of lower operating limit dual-flow plates

Lower operating limit of dual-flow plates depends on the value of the diameter of the plate for the same liquid loads, Fig. 8, 9.

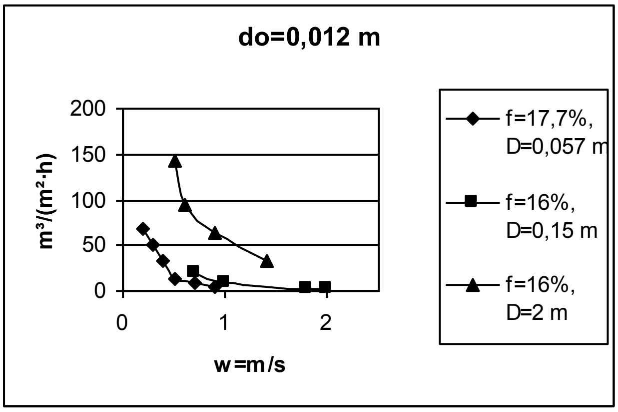

Fig. 8. Dependence of the lower operating limit of the plate diameter of dual-flow plates for f≈16 %.

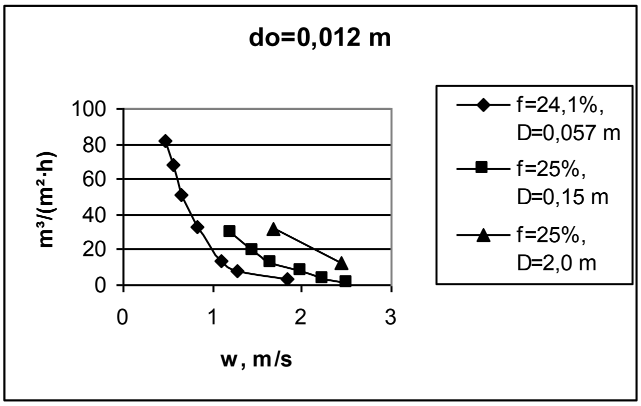

Fig. 9. Dependence of the lower operating limit of the plate diameter of dual-flow plates for f≈25 %

The graphs show that the lower limit of the working dual-flow plates essentially depends on the diameter of the trays. Such dependence is typical for all investigated dual-flow plates.

Size diameter of opening plate affects the hydrodynamic characteristics of dual-flow plates of the same diameter and the same free section.

Fig. 10, 11 shows graphs of the lower working limit for dual-flow plates column diameter D=0,057 mm, and the fractional open area f≈16 and 36 %, respectively.

Hole diameter of the trays were equal do=0,005, 0,012, and 0,034 m.

The graphs show that for the same liquid loads of lower operating limit trays decreases with increasing diameter.

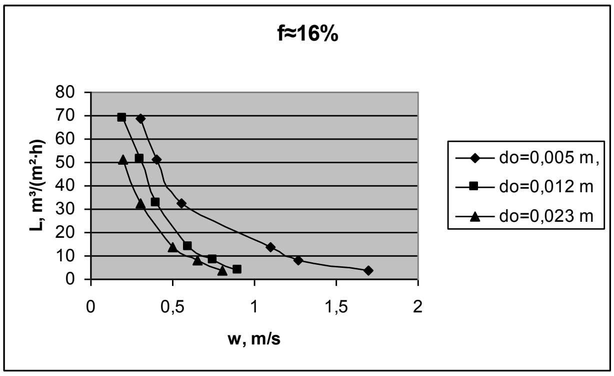

Fig. 10. Dependence of the lower operating limit of the hole diameter of dual-flow plates for f≈16 %

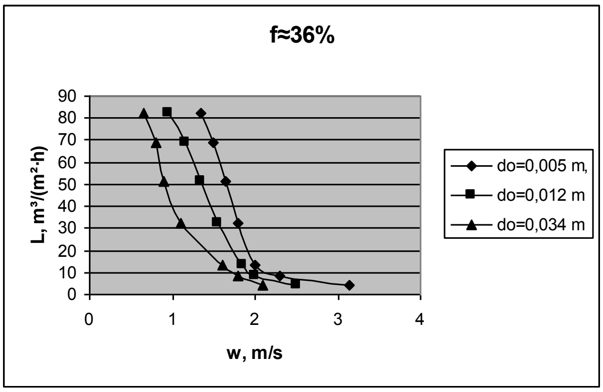

Fig. 11. Dependence of the lower operating limit of the hole diameter of dual-flow plates for f≈36 %

5. Approbation of research results

For the analysis of experimental data for the calculation of the lower operating limit, use method of proposed in [12].

Where

$$Y = B\cdot e^{-ax} \tag{1}$$

$$Y = \frac{w^2}{g\cdot d_e\cdot f^2}\cdot\frac{\gamma_g}{\gamma_l}\cdot\left(\frac{\mu_l}{\mu_w}\right)^{0,16} \tag{2}$$

$$X = \left(\frac{L}{G}\right)^{1/4}\cdot\left(\frac{\gamma_g}{\gamma_l}\right)^{1/8} \tag{3}$$

$\frac{\gamma_g}{\gamma_l}$ – ratio of the specific gravity gas or vapor to the specific gravity of the liquid; $\frac{\mu_l}{\mu_w}$ – ratio of liquid viscosity to viscosity of water at 20°; $\frac{L}{G}$ –weight ratio of loads of liquid and gas or vapor; w – velocity of gas or vapor in the cross section of the column, m/s; f – fractional open area of tray m²/m²; d_e – equivalent diameter of the openings, m; g – acceleration of gravity, m/s²; a – coefficient; B – coefficient.

The coefficients A and B are determined from experimental data by the method of least squares [13].

The lower limit of the dual-flow plates of depends on the geometrical characteristics of trays, as the fractional open area plate, hole diameter of the plate and the diameter of the tray.

Therefore, we must select hole diameter in the plate and the diameter of the tray. Then, the experimental data to find the coefficients a and B is shown in equation (1).

Average relative error between the experimental and calculated data was calculated by the equation (4).

$$A = \frac{1}{n}\cdot\sum\left|\frac{y-y_c}{y}\right|\cdot 100\ \%\,, \tag{4}$$

where n – number of calculation points; y_c – calculated values of $y_c = lgY$ in correlation

$$y_c = b - c\cdot X, \tag{5}$$

y – value calculated from the experimental data; b, c – correlation coefficients.

The experimental data were processed according to the geometric parameters dual-flow plates such as fractional open area of the plates, the diameter of the column, where a tray is set, and hole diameter of the plate.

In equation (1)–(3) the diameter of the column is not included. Therefore, we first chose the experimental data for dual-flow plates different fractional open area of the plate and with different hole diameter of the plate.

Correlations were obtained for dual-flow plates mounted within the column diameter D – 0,057 m.

Plate with a fractional open area of 16 % and a hole diameter of 0,005–0,0228 m, by analogy with equation (5), we obtain equation (6)

$$y_c = 1,13 - 0,967X, \tag{6}$$

where b=1.13; c=1,13

The average relative error is calculated by the equation (6) was – A=380 %.

For plates with a fractional open area of 25 % was obtained equation (7)

$$y_c = 0,397 - 1,78X. \tag{7}$$

The average relative error is calculated by the equation (7) was – A=54,7 %.

For plates with a fractional open area of 36 % was obtained equation (8)

$$y_c = 0,314 - 1,75X. \tag{8}$$

The average relative error is calculated by the equation (8) was – A=127 %.

Obtained from the equations (6)–(8) the average relative errors have a great value. Therefore, the same experimental data were processed using the parameter T. When processing according to equation (1) instead of the magnitude Y substituted in the correlation value Y/T.

Then, for dual-flow plates with a fractional open area of 16 % and a hole diameter of 0,005–0,023 m, by analogy with equation (5), we obtain equation (9)

$$Lg(Y/T) = -0,0355 - 1,66X. \tag{9}$$

The average relative error is calculated by the equation (9) was – A=15,2 %.

For trays with a fractional open area 25 % – obtained equation (10)

$$Lg(Y/T)=–0,212–1,72X. \qquad (10)$$

The average relative error is calculated by the equation (10) was – A=7,45 %.

For trays with a fractional open area 36 % – obtained equation (11)

$$Lg(Y/T)=–0,458–1,64X. \qquad (11)$$

The average relative error is calculated by the equation (11) was – A=6,75 %.

Thus, the accuracy of equations (9)–(11) obtained using the parameter T is satisfactory.

Parameter T allows to obtain calculation equations to determine the lower limit of the working dual-flow plates, which take into account not only the hole diameter of the plate, and the diameter of the column in which they are installed.

Processing of the experimental data was performed. At first set the hole diameter of the plate and calculated parameter T for investigated fractional open area of the plate and diameters of the columns (Table 1).

After processing of the experimental data, it was found that the most accurate correlation equation (5) is obtained using parameter $T^{0,5}$.

The result was a correlation (12)

$$Lg(Y/T^{0,5})=0,0751–1,68X. \qquad (12)$$

The average relative error is calculated by the equation (16) was – A=15,1 %.

The hole diameter of the trays was 0,012 m, the fractional open area – f=16 % of the diameter of the columns was varied from D=0,057 m to D=2 m.

6. Conclusions

Analyzing information that given in the article we made the following conclusions:

– the calculation of lower operating limit of dual-flow plates depends on the hole diameter and the diameter of the column, which is not considered by the equations (1)–(3).

– use of parameter T can increase the accuracy of the equations for calculating lower operating of limit dual-flow plates with different geometrical characteristics.

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АСИМПТОТИЧЕСКИЕ ОЦЕНКИ И ОЦЕНКИ СХОДИМОСТИ ФУНКЦИОНАЛЬНЫХ РЯДОВ, ОПИСЫВАЮЩИХ НЕСТАЦИОНАРНЫЕ КОЛЕБАНИЯ ОБОЛОЧЕК

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Установлены свойства решений нестационарных задач для систем дифференциальных уравнений теории оболочек. Решения построены в виде разложений по собственным формам колебаний оболочки. С использованием полученных функциональных рядов найдены асимптотические оценки решений для малых и больших (относительно основного периода собственных колебаний) промежутков времени. Получены общие оценки сходимости функциональных рядов

Ключевые слова: *теория оболочек, нестационарные решения, асимптотические оценки, функциональные ряды*

Properties of solution of non-stationary tasks are set for the systems of differential equations of shell theory. Solutions are built as decompositions to on own the forms of vibrations of shells. With the use of the got functional rows asymptotic estimations are set for the small and large (in relation to the basic period of vibrations of the system) intervals of time. The general estimations of convergence of functional series are received

Keywords: *shell theory, nonstationary solutions, asymptotic estimations, functional series*

1. Введение

Хорошо известно, что одним из наиболее общих методов решения начально-краевых задач, которые рассматриваются в механике деформируемого твердого тела, есть представление искомых величин в виде разложений в ряды по собственным формам колебаний (СФК). Этот метод является обобщением классической схемы Фурье разделения переменных на гиперболические системы высокого порядка, но, при этом, основная тяжесть переносится именно на построение этих СФК.

Некоторые возможности его практической реализации для составных систем оболочек рассмотрены в [1, 2], а в [3, 4] доказаны свойства решений задач установившихся колебаний, которые позволяют использовать их в качестве базисной системы функций при рассмотрении нестационарных задач [5].