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# EXPERIMENTAL RESEARCH OF REGULAR PACKING FOR MASS-TRANSFER TOWERS

The article presents a new design of the regular packing for mass-transfer devices. The results of experimental research of pressure drop and efficiency of the developed regular packing are shown. The comparative analysis according to the main characteristics of the developed and existing regular packings is given. The application of this packing will provide rather high efficiency of mass-transfer (until 96% at desorption $CO_2$) at the pressure drop of the one-meter packing not exceeding 180 Pa.

**Introduction.** In the chemical, petrochemical, oil refining and other industries the main type of process equipment used in the enterprises of these industries, a column unit equipped with the contact mass transfer devices of different types and designs, and are intended for specific processes related to the transfer of components between the phases of process stream, contacting implemented during the mass transfer process.

The main functional elements of the column apparatus is a contact device, the correct choice of design and number of which while designing the mass transfer device ensures the efficiency and reliability of its operation in a real industrial environment [1].

Packed columns are widely used during the process of absorption, rectification, liquid extraction, cooling liquids and gases, as well as gas separation. The advantages of packed columns include high efficiency and a wide range of steady work, relatively low cost and simple structure, small flow resistance, which is especially important for vacuum refining columns in [2].

Packed machines are vertical cylindrical columns filled with packing bodies (nozzle). According to the existing classification they can be attributed to either a regular (properly folded) or to the irregular (backfilled in bulk). Packing should have a high specific surface area, a large free volume and low pressure drop.

Currently, regular packings the effectiveness of which practically does not change depending on the diameter of the device due to the proper organization of the hydrodynamic regime are becoming more widely used.

The widespread use of regular packings in the processes of rectification in the world and a significant amount of research in this area confirm that the columns with these packings are one of the most promising areas of the mass-transfer equipment. The diameter of the columns with a regular packing is 1.4–1.8 times and the height of it 1.5–2 times lower than that of most tray columns [3].

**Main part.** Based on the review and analysis of existing regular structured packings for column mass-transfer apparatus at the Department of machines and apparatus of chemical and silicate production of the Belarusian State Technological University a new regular packing shown in Fig. 1 was developed and investigated.

The regular packing installed in the apparatus body *1* consists of two concentric cylinders, on the outer surfaces of which zigzag ribbons *3* are installed, and inside the smallest cylinders vertical partitions *4* are mounted. The outer diameter of the packing corresponds to the inner diameter of the apparatus casing.

The regular packing operates as follows. Uniformly distributed over the cross section of the apparatus body *1* gas flows into the channels formed by concentric cylinders *2*, vertical zigzag ribbons *3*, vertical partitions *4* and apparatus body *1* and rises upwards, interacting with the liquid in the form of film uniformly distributed over the cross section of the apparatus body *1* and flowing across the surface of the packing and the inner surface of the apparatus body.

This structure of a regular packing provides an even distribution of gas flow through the cross section of the apparatus, which eliminates the formation of stagnant zones and increase the surface contact between the phases. More uniform flow distribution of gas through the working section of the apparatus reduces the gas velocity in the channels, and hence the pressure drop of the packing.

The aim of the work was to determine the pressure drop and the efficiency of the packing.

The experimental studies of a developed packing were conducted at the desorption of carbon dioxide ($CO_2$) from a pre-saturated aqueous solution by blowing it with the air. The diagram of the experimental set-up is shown in the work [4].

The inner diameter of the column was equal to $d_{inner}$ = 144 mm, and the height of the packing $h_p$ = 300 mm.

The performance on the gas (air), or *F*-factor of the gas (m/s) · $(kg/m^3)^{-0.5}$, was determined by the equation [5].

$$F = w\rho^{-0.5},$$

where $w$ – the average velocity of the gas (air), calculated on the free cross section of the column, m/s; ρ – density of the gas (air), $kg/m^3$.

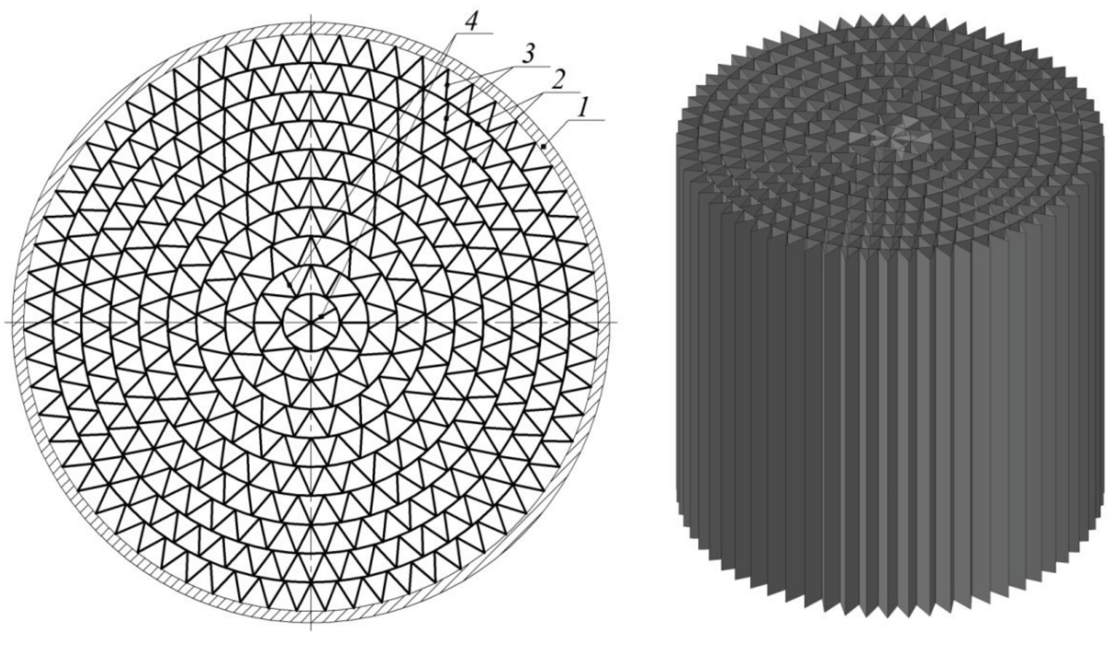


Fig. 1. Regular packing for column mass-transfer devices:
*a* – packing cross-section; *b* – 3D drawing;
*1* – apparatus body; *2* – cylinders; *3* – zigzag ribbons; *4* – vertical partitions

The average air velocity in the column *w*, m/s, was determined by the

$$w = 4V / \pi d_{inner}^2,$$

where *V* – air flow rate, $m^3/s$.

The irrigation density *q*, $m^3/(m^2 \cdot h)$ was calculated by the formula

$$q = 4Q / \pi d_{inner}^2,$$

where *Q* – water flow rate, $m^3/h$.

The value of the hydraulic resistance of the nozzle was determined by the difference of static pressures above and below it.

The effectiveness of the phases interaction was estimated at the extraction ratio [6]

$$\varphi = \frac{x_{in} - x_{out}}{x_{in} - x^*_{out}},$$

where $x_{in}$, $x_{out}$, $x^*_{out}$ – mole fraction of $CO_2$ in the water at the inlet, at the outlet and the equilibrium at the outlet of the column, respectively, kmol $CO_2$/kmol ($CO_2 + H_2O$).

The molar fraction of $CO_2$ in the water were calculated by the formula [7]

$$x = \frac{\bar{C}_x M_{H_2O}}{\rho_x M_{CO_2} + \bar{C}_x \left(M_{H_2O} - M_{CO_2}\right)},$$

where $\bar{C}_x$ – mass volume concentration of $CO_2$ in the water, kg $CO_2/m^3$ ($CO_2 + H_2O$); $M_{H_2O}$, $M_{CO_2}$ – molar masses of $CO_2$ and $H_2O$, equal to 18 and 44 kg/kmol respectively [7]; $\rho_x$ – liquid phase density, $kg/m^3$.

Mass concentration of $CO_2$ in water were calculated by the solution acidity (pH), obtained experimentally by the formula [6]

$$\bar{C}_x = 2{,}69 \cdot 10^{5 - pH}.$$

$CO_2$ concentrations in the water were low, so the density of the mixture $\rho_x$ was taken equal to the density of water.

The mole fraction of $CO_2$ in the air entering the column was zero $y_{in} = 0$, that is why $x^*_{out} = 0$. As a result, the estimated formula for the extraction ratio was simplified

$$\varphi = \frac{x_{in} - x_{out}}{x_{in}}.$$

The results of the experimental studies of the pressure drop and the efficiency of the packing are shown in Fig. 2.

As one can see from Fig. 2 with an increase of the gas velocity in the range from 1 to 3 m/s, as well as the irrigation density, the extraction ratio is increased. A higher efficiency at the highest density of irrigation can be explained by a more uniform irrigation of the packing. This packing has a relatively high efficiency (up to 96%) at the pressure drop of one meter of the packing not exceeding 180 Pa.

The effectiveness of the packing was also estimated by the height equivalent to a theoretical plate (HETP), m, and the number of theoretical plates (NTP) per 1 m of the packing height, 1/m [7]:

$$\mathrm{HETP} = 1 / \mathrm{NTP} = h / n_{0x},$$

where $n_{0x}$ – the number of transfer units according to the liquid phase, defined by the formula [7]

$$n_{0x} = (x_{in} - x_{out}) / \Delta x_{ave},$$

where $\Delta x_{ave}$ – average logarithmic driving force of the process according to the liquid phase, which is equal to [7]

$$\Delta x_{ave} = (\Delta x_{in} - \Delta x_{out}) / \ln (\Delta x_{in} / \Delta x_{out}),$$

where

$$\Delta x_{in} = x_{in} - x_{in}^*;$$

$$\Delta x_{out} = x_{out} - x_{out}^*,$$

where $x_{out}^*$ – equilibrium mole fraction of $CO_2$ in the water at the inlet from the column of kmol $CO_2$/kmol ($CO_2$ + $H_2O$).

Since $CO_2$ is difficult to dissolve in water, the equilibrium mole fraction of $CO_2$ in the water at the inlet from the column $x_{in}^*$ is determined from Henry's law [7]:

$$x_{in}^* = y_{out} / m,$$

where $y_{out}$ – the mole fraction of $CO_2$ in the air at the outlet from the column, respectively, kmol $CO_2$/kmol ($CO_2$ + air); $m = E / P$ – distribution ratio which is constant for a given system gas–liquid at constant temperature and pressure $P$; $E$ – Henry ratio equal to $1{,}44 \cdot 10^8$ Pa [6].

The mole fraction of $CO_2$ in the air at the outlet from the column was calculated by the formula $y_{out}$

$$y_{out} = \frac{M_{air} \bar{Y}_{out}}{M_{air} \bar{Y}_{out} + M_{CO_2}},$$

where $M_{air}$ – molar mass of air that is equal to 29 kg/kmol [6]; $\bar{Y}_{out}$ – relative mass fraction of $CO_2$ in the air at the outlet from the column, kg $CO_2$/kg of the air is determined from the material balance equation [6]:

$$\bar{Y}_{out} = \bar{Y}_{in} + \frac{L}{G}\left(\bar{X}_{in} - \bar{X}_{out}\right),$$

where $\bar{Y}_{н}$ – relative mass fraction of $CO_2$ in the air at the inlet from the column, kg $CO_2$/kg of the air; $L$, $G$ – mass flow rates of the air and water, kg /h; $\bar{X}_{in}$, $\bar{X}_{out}$ – the relative mass proportions of $CO_2$ in the water at the column entrance and exit kg $CO_2$/kg of $H_2O$, determined by the [6]

$$\bar{X} = \frac{M_{CO_2} x}{M_{CO_2} (1 - x)}.$$

The comparative characteristic of the studied packing and some existing regular packing is shown in the Table.

The analysis of data in the table shows that the packing designed on the basic characteristics is superior to a plane-parallel, Z-shaped and corrugated (Performance 2). The corrugated packing (Performance 1) has similar values in almost all the characteristics of the studied packing. However, the developed packing has a smaller flow resistance and operates over a wider range of density irrigation.

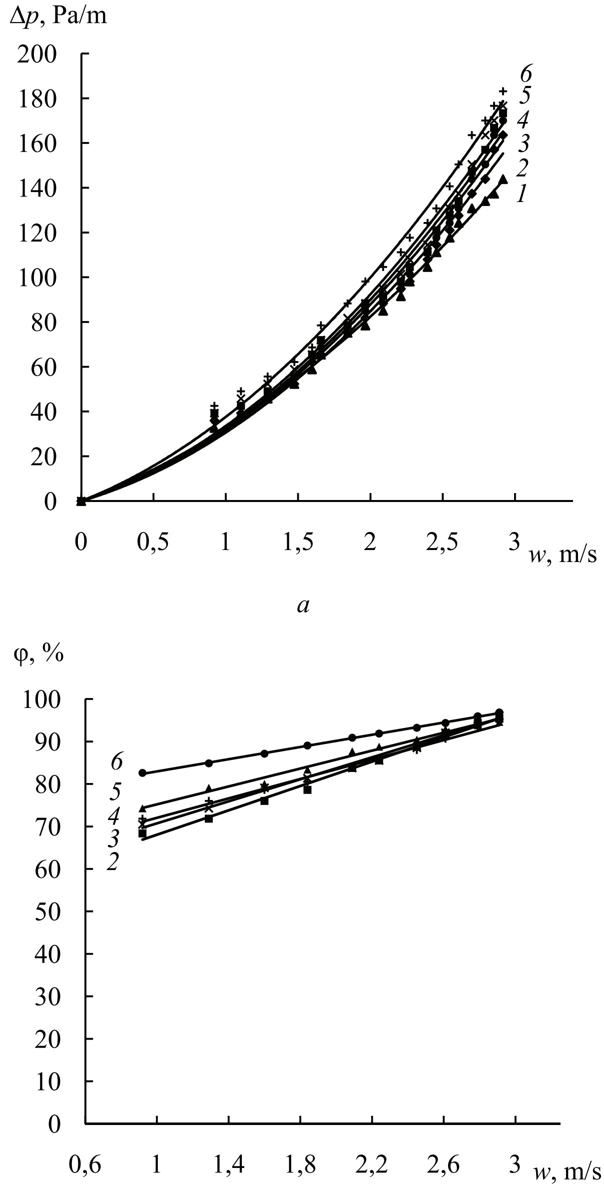


Fig. 2. The dependence of the pressure drop (*a*) and the effectiveness (*b*) of the developed packing on the average velocity of the gas in the apparatus *w*, m/s, at different densities of irrigation *q*, $m^3/(m^2 \cdot h)$: *1* – 0; *2* – 10.9; *3* – 17.8; *4* – 22.3; *5* – 26.9; *6* – 36

**Comparative characteristics of regular packings**

| Parameter of a nozzle | Type of a regular packing | | | | |
|---|---|---|---|---|---|
| | Plane-parallel | Z-shaped | Corrugated | | Developed |
| | | | Performance 1 | Performance 2 | |
| Specific surface, $m^2/m^3$ | 180–95 | 140–85 | 450 | 200 | 430 |
| Irrigation density, $m^3/(m^2 \cdot h)$ | 0.5–120 | 1–120 | 0.1–10 | 0.2–2.5 | 0–36 |
| $F$-factor, $(m/s) \cdot (kg/m^3)^{-0.5}$ | 0.55–8.0 | 0.4–5 | 0.2–2.5 | 0.5–3.5 | 0.8–2.7 |
| HETP, m | 0.6–1.5 | 0.5–1 | 0.175–0.2 | 0.75–0.4 | 0.15–0.2 |
| Pressure drop, Pa/m | 1.33–3.33 | 4–400 | 20–300 | 10–600 | 20–180 |

**Conclusion.** The experimental studies of the developed packing were carried out at the desorption of $CO_2$ out of the water when the main resistance to the mass transfer is concentrated in the liquid phase. In future experimental studies of the given packing at the water evaporation from the surface is planned, that is, when the main resistance to the mass transfer is concentrated in the gas phase. Since the resistance to the mass transfer of the majority of existing media lies between these model media, then the effectiveness of the packing for different mass transfer processes will be judged by the results of the research.

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