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Dynamic packing for heat and mass exchange processes

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Abstract. Data of experimental study of hydrodynamics, heat and mass transfer of dynamic packing and some comparative characteristics of the packed device with packing, which have wide industrial application, are given in the article.

Introduction

When updating and engineering column apparatuses for mass exchange processes one of the key tasks is to choose optimum contact packings. Contact packings compared to plate packing have lower flow resistance and a simpler design. Besides, packed columns can work with higher gas and liquid loads, they are less sensitive to contamination if compared to plate packings.

From the point of view of design contact packings can be divided into non-regular (random) packings and regular (structured, preformed) packings. A regular packing with an individual structure consists of separate elements (rings, triangular prisms with constant or variable section by height) which are located in beds in the column tube [1]. Vertically neighbouring beds are displaced with respect to each other in order to avoid the formation of end-to-end channels. To simplify the formation of such packing its elements can be formed in advance in containers which are further on installed in the column tube. Individually formed packings are not widely spread in industry, because they considerably increase labour intensity and cost of the assembly. Compared to regular packings, random (non-regular) ones have a higher flow resistance. They are less reliable when working with contaminated media and inconvenient for maintenance.

The disadvantages of such packings are a small contact surface between the phases where heat and mass exchanges processes occur, and immobility of this surface during these processes that results in the formation of dead zones and decrease in productivity.

In order to avoid afore described disadvantages we have designed the structure of a dynamic packing with an increased surface of heat and mass exchange [2].

The packing consists of bodies that are organised in rows and one inside the other; these bodies have a form of cylindric surface. The inner rotary body is at a distance from the outer rotary body; at that the outer and the inner rings are connected by a spring. The outer diameter of the inner ring relates to the inner diameter of the outer ring as 0.7, and their heights relate to each other as:

$$\frac{h}{H} = 0.8 \div 0.9$$

where *h* and *H* are the heights of the inner and outer rings, respectively.

The packing has an additional rotary body on the outside of the outer ring at a distance from it and connected with the inner ring by a spring passing through the side wall of the outer ring.

The connection between the inner ring, the outer ring and the additional ring at the points located at equal distance from their faces facilitate the oscillation movement of the ring and of the additional rotary body under the influence of the ascending gas flow. Due to this reason smooth liquid films on the side walls of the inner ring and of the additional outer ring start oscillating with these walls, forming waves on the liquid film; their flow velocity and surface are considerably higher than the flow velocity and the surface of the smooth liquid film itself. This increases the intensity of heat and mass exchange at the phase boundary of the gas and liquid flows (Figure 1) [2].

Besides, the additional dynamic elements outside the outer ring eliminates the possibility of liquid and gas phase slip between the outer surfaces of the outer Raschig rings and involves them into an additional intensified heat and mass exchange [2]. Specific surface of the designed packing is 390 m^2/m^3, whereas standard Raschig rings of similar size have a specific surface of 190 m^2/m^3.
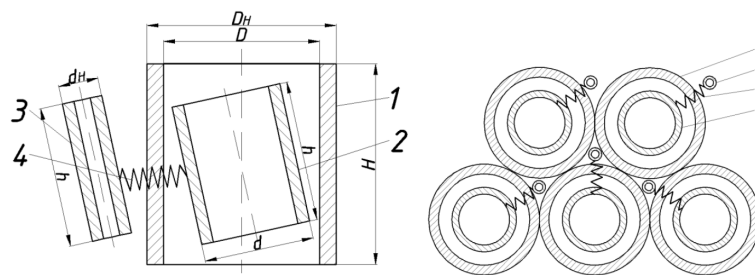

Figure 1. Designed dynamic packing for heat and mass exchange processes
1 – outer Raschig ring; 2 – inner Raschig ring; 3 – additional rotary body; 4 – spring

Experimental part

In order to perform a full range of experimental studies and compare packings having different configurations, we have designed an experimental stand (Figure 2) which is based on the modular study principle and has a cartridge system of replacement packings that provides for a quick and precise study of heat and mass exchange and flow characteristics of the packings [9].

Figure 2. Experimental stand for studying characteristics of packings

To confirm the efficiency of the designed packing we have performed a series of experiments. The aim was to receive the data on its basic flow characteristics. The packings chosen for comparison were Raschig and Pall rings and a range of industrial packings [1, 2, 4, 5, 6].

Results and Discussion

Experimental data on flow resistance of dry and spray heat and mass exchange packings are given in Figure 3.
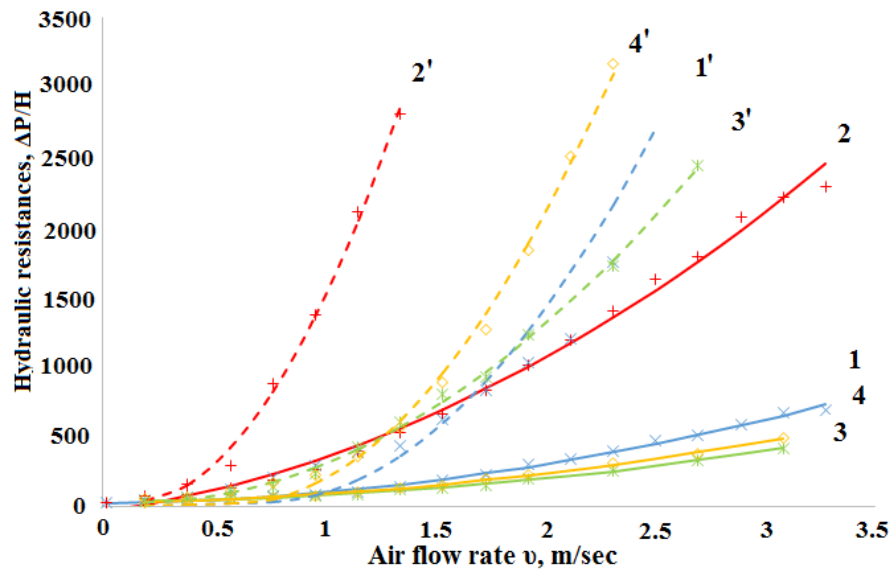

Figure 3. Flow resistance of dry (solid line) and spray (dashed line) packings vs. gas velocity in the column: 1,1' – Pall rings (25x25x1) dry, spray; 2, 2' – Raschig rings (25x25x3) not structured dry, spray; 3,3' – Raschig rings (25x25x3) structured dry, spray; 4,4' – Dynamic packing structured dry, spray (20x40x3)

In order to summarize the experimental data and prepare the comparison of the tested heat and mass exchange packing and packings that are widely spread in the industry, it is offered to use generalized equation $\lambda=f(Re_m)$ as per the method described in papers [5, 6]. Using this generalized equation we can compare their energy efficiency and describe the use of any packings having very complex configurations.

Table 1. The results of mathematical data processing of heat and mass exchange dynamic packing

α, m^{-2}	β, m^{-1}	Re	λ	$l_{x1,}$ m	$l_{x2,}$ m^2
		0.091	28.46		
		0.227	7.62		
$4.565 \cdot 10^6$	15.031	0.364	6.48	0.066	$3.2 \cdot 10^{-6}$
		0.456	6.23		
		0.547	5.8		
		0.638	5.25		
		0.71	5.05		

Based on the filtration curves obtained during experiments (Fig. 3) for the described heat and mass packing [5, 6] we determined linear dimensions l_1 and l_2, α and β values which are viscous and inertial factors in the Dupuit-Forchheimer equation, respectively, modified Reynolds numbers Re_m, and corresponding flow resistance factors λ, given in Table 1. This analysis was performed according to the method described in papers [5, 6]. This method helps to identify the industrial application and analyse the energy requirements for the industrial processes for any packings of any configuration. They can be summarized and are within the mode range of filtration curve $\lambda=f(Re_m)$, shown in Figure 4.

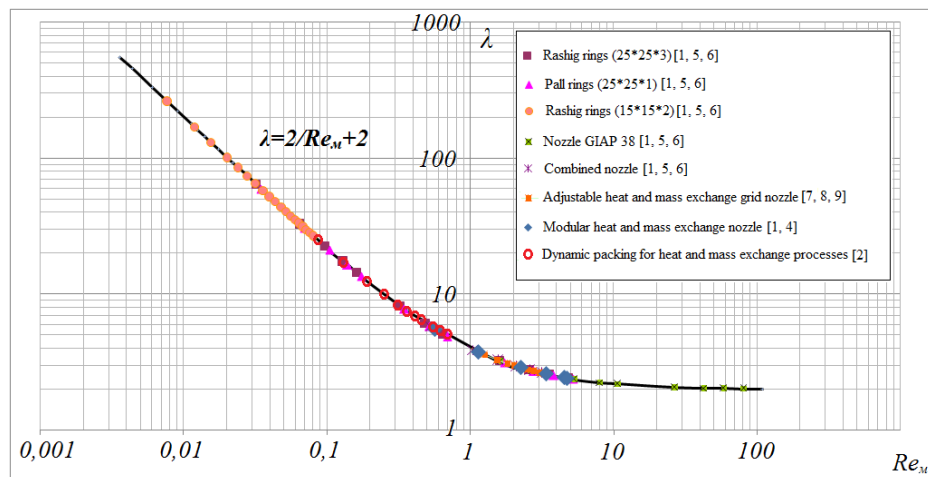The result of the comparison of the packings is given in Figure 4.

Figure 4. $\lambda=f(Re_m)$ diagram for packings with different structures [5, 6]

One of flow characteristics of packings which from our point of view is critical for identifying the industrial purposes of the packing and which we take as the basic one for our calculations [7, 8, 9] together with heat and mass transfer factors is retaining capacity, i. e. how the packing accumulates certain amount of liquid depending on the operation mode. This characteristic shows the total time of water retaining and mass transfer surface for a range of packings [7, 8, 9]. Figure 5 shows diagrams depicting the retaining capacity determined experimentally for different packings depending on gas velocity in the column.
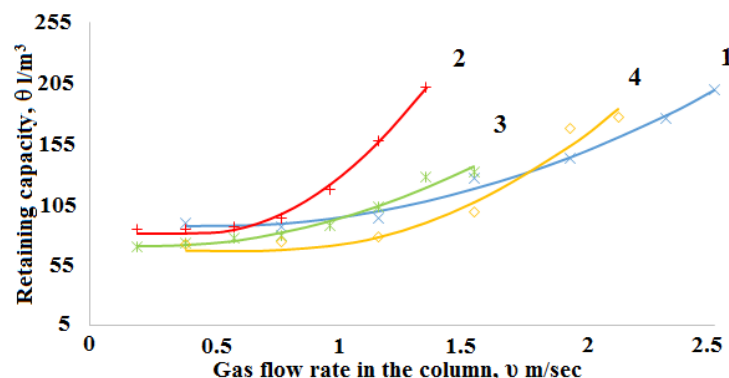

Figure 5. Retaining capacity of spray packings vs. gas velocity in the column
1 – Pall rings (25x25x1); 2 – Raschig rings (25x25x3) not structured; 3 – Raschig rings (25x25x3) structured; 4 – Dynamic heat and mass exchange packing structured (20x40x3)

Conclusions

Comparing with a range of industrial packings analysed during the experiment, the designed heat and mass exchange packing has a rather high retaining capacity that is shown in Figure 5. Based on the data on energy efficiency, flow resistance values of spray packings and a rather high retaining capacity for liquid we can conclude that this packing is promising for industry, especially for such processes as absorption and fractionation. But it should be noted that this packing can exhibit its quality only in certain resonant modes that positively influence the intensification of heat and mass exchange processes occurring in the packing, but on the other hand require fine and sensitive adjustment.

The prototype of the offered heat and mass exchange packing is manufactured of PVC tubes that makes it cheap and rather easy in design though it may seem complex. Besides, it can provide different surface properties that facilitate the customization of the designed packing for the needs of the specific process.

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