Effect of the angle of rotation of structured packing layers on separation efficiency in distillation column

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Abstract. It is well known that a good quality of liquid distribution over the surface of structured packings is crucial for high performance of large diameter columns. The angle of rotation of the packing layers and their number are among the main parameters characterizing the distribution of liquid in a structured packing over the column cross-section and height. This paper presents investigation results on the influence of the rotation angle of structured packing layers on separation efficiency, pressure drop, distribution of local composition of mixture and local liquid flow rate under the packing. The experiments were carried out in distillation column with the internal diameter of 0.9 m on a structured packing with a specific area of 500 m²/m³, and the corrugation angle of packing equal to 45°. The mixture of refrigerants R114 and R21 at the pressure of 3 bar and total reflux was used as the working fluid. The column was packed with 11 packing layers with rotation angles of 20, 45, 70, and 90 degrees. According to experimental results, a decrease in the angle of packing layer rotation from 90 to 20 degrees leads to a decrease in separation efficiency, while the HETP value increases by 10–12%.

1. Introduction

Irrigation of structured packing in distillation columns is characterized by the fact that the number of drip points in the liquid distributor is approximately an order of magnitude smaller than the number of packing channels. When single liquid jets flow onto the upper layer of the packing, liquid flows, oriented in the direction of irrigated packing sheets, are formed at the layer exit since liquid spreading along the sheets is significantly higher than in the transverse direction. In practice, to level liquid distribution over the cross-section, each subsequent layer is turned at a certain angle when assembling the column. After each rotation of the layer, uniformity of underlying layer irrigation increases. The rotation angle of the packing layers and their number are the main parameters characterizing liquid distribution in a structured packing over the cross-section and height of the column. To achieve uniform distribution of liquid over the column cross-section, several layers of packing are usually required [1].

It is well known that achieving a good quality of liquid distribution over the surface of structured packing is crucial for high efficiency of the large-diameter columns [2, 3]. The relationship of the efficiency of mixture separation with maldistribution of local flow characteristics over the column cross-section was shown in [4]. A new approach to develop the method for dynamically controlled packing irrigation by the liquid distributor is suggested in [5]. This method is aimed at the destruction
of large-scale stationary structures of maldistribution of the local flow rates and mixture composition over the packing cross-section and, as a result, at the achievement of high separation efficiency.

In [6], the authors studied the effect of the angle of layer rotation on the efficiency of mixture separation at different methods of structured packing irrigation. In the experiments, the rotation angle of the structured packing layers was varied taking the values of 20° and 70°. The initial maldistribution of liquid irrigation at the packing inlet was generated by closing the holes in the bottom of the liquid distributor. The results of measuring the distribution of the local liquid flow under the packing showed that under the closed row of holes in the liquid distributor at the outlet of packing with a layer rotation angle of 20°, a zone with significantly reduced flow rate was observed. At that, the efficiency of mixture separation was greatly decreased.

This paper presents the results of continuing research on the effect of the rotation angle of the structured packing layers on separation efficiency, pressure drop, distribution of local mixture composition, and local flow rate under the packing.

2. Experimental setup

The experiments were carried out in a column with a diameter of 0.9 m using a packing with a specific surface of 500 m²/m³. The description of the experimental setup and measurement methods are given in [7]. A mixture of refrigerants R114 and R21 at a pressure of 3 bar and total reflux was used as the working fluid. The packing was irrigated by a liquid distributor with a rectangular drip point pattern [6]. The density of drip points was 450 1/m², approximately. There were 11 packing layers in the column, each 0.2 m high. Packing layers were assembled of the corrugated aluminum sheets with the inclination angles of corrugations 45° relative to the horizon. The channels in the adjacent packing sheets were directed in opposite directions. Each subsequent layer, starting from the top, was rotated clockwise at a certain angle. The angles of layer rotation are given in Table 1. This Table also shows the data on a change in the orientation of the packing layer sheets from the top to the bottom of the column. Presentation of data on the rotation angles in radians allows us to estimate the number of a complete rotation of the packing layers in the package by 180° (π radians) relative to the liquid distributor (column body). In the experiments, the total angle of a change in orientation of the packing sheets in the layers from the top to the bottom of the column was from 1.1 to 5 π radians. To compare the results obtained in the packing of various heights, the Table also presents the data on a change in the position of layers per a unit of the packing height.

| The angle of layer rotation, degrees | 20  | 45  | 70  | 90  |
|-------------------------------------|-----|-----|-----|-----|
| Total angle of layer rotation, π rad | 1.11| 2.5 | 3.9 | 5.0 |
| The total angle of layer rotation per a unit of height, π rad/m | 0.49| 1.1 | 1.71| 2.2 |

In the experiments, the mixture composition was measured in the vapor and liquid phases at the inlet and outlet of the column. Using these data, the separation efficiency was determined as a height equivalent to a theoretical plate (HETP). The pressure drop across the structured packing, distribution of the local flow rate of flowing from the bottom end of the packing, and concentration of the volatile component in the flowing liquid were also measured. It should be emphasized that the data on the distribution of the local characteristics of the liquid flow, presented in the work, were obtained in a distillation column in the process of mixture separation. The local flow rates under the packing were measured by the time-of-flight method using a low-pressure flow meter with a collector diameter of 28 mm. The collector was moved according to a given program along two coordinates (radius and angle), measuring the flow rate at 420 positions over the column cross-section. In these positions, the temperature of the liquid in the collector was measured; then, it was used to determine the mixture composition in the liquid phase in the cross-section of the column. The method for calculating the composition of mixture by measuring the temperature based on relationship between the concentration of a volatile component in the mixture and its temperature is given in [8]. Data on the distribution of
local characteristics are presented in the form of topograms, data on the pressure drop and separation efficiency are presented in the form of dependence of corresponding parameters on the vapor load of the column $K = \frac{\rho_v U_v}{\sqrt{\rho_l - \rho_v}}$, m/s, where $\rho$ is the liquid or vapor density, kg/m$^3$; $U_v$ is superficial vapor velocity, m/s.

3. Distribution of the local liquid flow rate over the column cross-section

Data on the distribution of the local liquid flow under the packing in the column cross-section is shown in Fig. 1. The orientation of corrugated sheets in the upper and lower packing layers are shown in the topograms as the rectangles. The position of the lower column layer is the same in all experiments, while the position of the upper layer is varied relative to the column body. The orientation of the rows of holes in the liquid distributor relative to the sheets of the top irrigated packing layer was the same in all experiments. Data are presented as relative flow rates, i.e., the values of local liquid flow rates at a given point, reduced to the average liquid flow rate at the packing outlet under the conditions of experiments. The scale corresponding to the range of changes in the local flow rates is shown next to the topograms.

![Fig. 1. Distribution of local liquid flow rates at the packing outlet. $F_v = 1.4$ Pa$^{1/2}$. The angle of layers rotation: $a – 20°$; $b – 45°$; $c – 70°$; $d – 90°$.](image)

In all cases, the zones in the form of rings 50–100 mm wide with an increased liquid flow are observed at the packing periphery. In topograms, for the angles of 20° and 70°, these zones are located...
almost along the entire perimeter, and for the angles of 45° and 90° they occupy half of the perimeter. In most part of the center area of the column cross-section, the local flow rates of liquid correspond to the average flow rate. For the packing with the angle of layer rotation of 90°, distribution of the local liquid flow in the central part is symmetrical relative to the diametrical line coinciding with the orientation of the corrugated sheets of the packing in the top and bottom layers. In that part of column cross-section, where the flow at the packing periphery is maximal, in the center of packing cross-section, the flow rate of liquid is minimal. The most uniform distributions of local liquid flow in the center section of the column cross-section are observed for the angles of layers rotation of 45° and 70°.

![Fig. 2](image1.png)

**Fig. 2.** Distribution of liquid phase composition at the packing outlet. $F_v = 1.4 \text{ Pa}^{1/2}$.

The angle of layers rotation: $a – 20°; b – 45°; c – 70°; d – 90°.$

Topograms of distribution of volatile component concentration (R114) in the liquid phase at the packing outlet are shown in Fig. 2 for four values of the layers rotation angle. Orientation of corrugated sheets in the upper and lower packing layers is also shown there. Concentrations shown in this figure are expressed in the mole fractions of a volatile component in the mixture. They are obtained by measuring the temperatures of the liquid in the collector under the package, which are then converted to concentrations. These results on the distribution of mixture composition in the column cross-section can be used to compare qualitatively the data obtained under different conditions. To calculate the parameters characterizing separation efficiency, it is necessary to use the data on mixture composition obtained by the chromatograph. Significant maldistribution is typical of all cases and maximal maldistribution is observed at the rotation angle of 20° (Fig. 2 a). Also, a rather large area with an increased concentration of volatile component was obtained in experiments with a...
layer rotation angle of 45° (Fig. 2 b). Maximal concentration in these experiments is much less than for the rotation angle of 20°. On the packing with rotation angles of 70° the mixture composition over column cross-section is more uniform (Fig. 2 c). On the packing with a rotation angle of 90°, an annular region with increased concentration of a volatile component is distinguished at the packing periphery (Fig. 2 d). Locations of concentration maximum for almost all cases correspond to the zones with increased flow rates in Fig. 1.

These results show significant dependence of the distribution of the local liquid flow and mixture composition over the column cross-section on the rotation angle of the layers of structured packing. The most uniform distribution of local parameters over the column cross-section was obtained in experiments with the angles of layers rotation of 45° and 70°.

4. Effect of the angle of packing layers rotation on separation efficiency

Data on the effect of vapor flow rate on the efficiency of mixture separation for different angles of packing layers rotation are shown in Fig. 3. In the studied range of changes in the vapor flow rate, a decrease in separation efficiency is observed for all angles of packing layer rotation with a decrease in vapor flow rate. The highest HETP values are obtained for the angle of layers rotation of 20°.

With an increase in the rotation angle, the separation efficiency increases. For rotation angles of 45° and 70°, the difference in HETP is small. The relative pressure drop is almost independent of the angle of packing layer rotation (Fig. 4).

In experiments with a rotation angle of 20°, there is a minimal change in the nature of irrigation of the underlying packing layers along the package height. For example, incomplete wetting of the upper layer surface due to the relatively low drip point density may be preserved on more layers than in the case of intensive redistribution of liquid on the packing with a large angle of layers rotation. As it was already noted in Introduction, the defect of irrigation at the column top can be spread for these conditions to the entire height of the structured packing. Improving the liquid mixing along the packing height with an increase in the angle of layers rotation led to an increase in the efficiency of mixture separation, Fig. 5. According to the results of this study, increasing the angle of packing layers rotation from 20 to 90 degrees leads to an increase in separation efficiency, while the HETP value decreases by 10–12%.

Fig. 3. Dependence of HETP on $F_r$-factor for different turn angles of the packing layers.

Fig. 4. Dependence of the relative pressure drop on $F_r$-factor for different turn angles of the packing layers.
5. Conclusion
In this paper, we studied the effect of the rotation angle of structured packing layers on the separation efficiency of a binary mixture in a distillation column. It is shown that a decrease in the layer rotation angle leads to a significant decrease in the efficiency of mixture separation. A decrease in separation efficiency is associated with an increase in maldistribution of the local liquid flow rate and mixture composition over the cross-section and height of the column.

![Fig. 5. The efficiency of mixture separation vs. rotation angle of structured packing layers, $F_v = 1.4 \text{ Pa}^{1/2}$.](image-url)

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