Distribution of local flow parameters at separation of liquid mixture under distillation on the structured packing at a periodic change in the drip point pattern

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Distribution of local flow parameters at separation of liquid mixture under distillation on the structured packing at a periodic change in the drip point pattern

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Abstract. The effect of non-stationary irrigation of a structured packing on distribution of flow parameters over the cross-section and height of a distillation column was studied using a controlled liquid distributor. We have determined the characteristic time of switching the valves of the liquid distributor at periodic sequential irrigation of two zones of the column cross-section, corresponding to the most effective suppression of stable large-scale maldistribution of the flow parameters in the packing layers, typical of stationary uniform irrigation. It is shown that application of dynamically controlled liquid distributor in the studied regimes of structured packing irrigation allows an improvement of the efficiency of mixture separation by 20%.

1. Introduction

Today, rectification is used in various areas of chemical technology throughout the world, for example, in the industries of organic synthesis, production of isotopes, polymers, products of cryogenic air separation, and other high purity substances.

Stationary irrigation of the structured packing in large-scale industrial distillation columns is usually performed by the liquid distributors with a fixed drip point density over the column cross-section. For stationary setting of irrigation points under the conditions of the liquid film flow over the packing and the counterflow vapor flow, large-scale maldistributions of the flow density develop over the packing cross-section and height [1]. Maldistribution significantly reduces the efficiency of mixture separation in distillation columns of the large diameter.

Deterioration of separation efficiency of mixtures in the large-scale mass exchange apparatuses of chemical technology, as a rule, has a hydrodynamic nature [2], i.e. it is a consequence of development of liquid and vapor maldistribution over the cross-section and height of the structured packing. Flow maldistribution along the column height can also occur during mixture separation, when the vapor density in the upper part of the column becomes significantly higher than in the lower part [1]. The reverse flows of vapor along with longitudinal mixing [3] also cause deterioration in the efficiency of mixture separation.

One of the methods for suppressing the transverse maldistribution of flow parameters is the creation of an organized and controlled flow structure. The use of the modern structured packing allows much more even distribution of the liquid film over the packing surface [4]. The pulsating supply of the liquid flow [5] makes it possible to create phase distribution in the packed column, when

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the height of transfer unit becomes significantly less than that under the stationary conditions of irrigation. In the experiments presented below, the idea of non-stationary influence on the large-scale stationary structures in the column cross-section with the purpose of their destruction was implemented using a dynamically controlled liquid distributor.

2. Results
The experiments were carried out on the large-scale research setup, whose description is given in [1]. A structured Mellapak 350Y packing was mounted in the distillation column with the diameter of 0.9 m. The experiments were carried out with the packing height of 2.1 and 4 m, respectively. The mixture of R-114 and R-21 Freons was used as a working mixture. All experiments were carried out at pressure $P = 3$ bar at complete reflux. To irrigate the packing, a specially designed controlled liquid distributor was used [6]. In the liquid distributor, there were 128 solenoid valves, overlapping the holes with the diameter of 5 mm. Each valve was controlled by a PC according to any predetermined algorithm. The column response to the action of the liquid distributor was observed in real time by the readings of three groups of thermometers [6]. The thermometers were installed in the lower (two layers from the bottom of the packing), middle and upper (two layers from the top of the packing) cross-sections. In a binary mixture there is a strict relationship between concentration and temperature at a constant pressure. The displayed information made it possible to estimate both the structure of the large-scale maldistribution of temperature and mixture composition, and the magnitude of this maldistribution. An estimate of the degree of temperature maldistribution, which indirectly characterizes the efficiency of mixture separation, is the value of standard deviation of temperature over the packing cross-section.

![Figure 1](image_url)

*Figure 1. Periodical irrigation (Half Column). Packing height is 4 m. a – state of distributor $t_1$; b – state $t_2$."

One of the alternatives of the dynamic effect on the stationary structures is periodic alternating irrigation of two halves of the packing cross-section ($HC$ pattern (*Half Column*)). During time $t_1$, the holes in one half of the distributor are opened, the holes in the second half of the distributor remain closed (figure 1, a). Then, the valves are switched and the irrigated and non-irrigated zones are changed for time $t_2$ (figure 1, b). After this, the cycle is repeated with period $T = t_1 + t_2$. The main data array for the $HC$ pattern was obtained for equal times $t_1 = t_2$ in the range from 2.5 to 120 s.

It is obvious that for large values of $t_1$ and $t_2$, irrigation of a half the column cross-section is substantially non-uniform, herewith in the case of stationary irrigation $t_1, t_2 \rightarrow \infty$, the efficiency of mixture separation will be much lower than at uniform packing irrigation. In the case of periodic irrigation of diametrically located regions of the packing cross-section with a period, commensurable with the time of liquid stay in the packing, a tendency to formation of a new large-scale temperature distribution structure is observed in different cross-sections of the column.

Since each switching causes formation of large-scale maldistribution with diametrically opposite location, then for the switching periods, commensurable with times of formation of large-scale maldistribution, a pulsating change in the degree of maldistribution is observed. More efficient mixture separation corresponds to this regime of dynamic packing irrigation. Figure 2 shows the
comparison of a time change in the standard deviation of temperature in the lower packing layer for
the stationary irrigation and HC pattern at \( t_1 = t_2 = 20 \) s, 90 s, and 120 s, respectively.

**Figure 2.** A change in the value of standard deviation of temperature in the lower packing layer with
time. Initial moment – moment of distributor valve switching. Drip pattern: HC-40 \(- t_1 = t_2 = 20\)
\( \) s, HC-180 \(- t_1 = t_2 = 90\) s, HC-240 \(- t_1 = t_2 = 120\) s. \( P_1 - P_5 \) – extreme points of the HC-240 curve.
Reduced vapor velocity \( K_v = 0.028 \) m/s. Packing height \(- 4 \) m.

The periodic character of curves indicates the irrigation sequence of two halves of the packing. According to data presented, for \( t_1 = t_2 \) equal to 90 s and 120 s, a stable large maldistribution (the
 maximal values of temperature deviation) can form along the entire height of the packing. More
uniform distribution of the flows, corresponding to the minimal standard deviations of temperature, is
associated with reformation of the flows along the cross-section and height of the structured packing
during periodic irrigation of two semidiameters of the upper cross-section of the mass exchange
surface. As it can be seen from the data presented, under the regime with time of valve switching \( t_1 = t_2 = 20\) s, the suppression of stable stationary large-scale maldistributions in the packing layers is most
effective as compared to other HC regimes. This regime is more effective than steady-state uniform
irrigation for the given packing height and specified liquid and vapor flow rates.

Diagrams of local temperature distribution over the packing cross-section at the bottom of the
column are presented in figure 3 for period of switching two halves of the distributor at the points
corresponding to the extremes of the standard deviation curve (see figure 2) and they are compared
with temperature distribution at Uniform pattern in the same packing cross-section. Time moments
corresponding to points \( P_1, P_3 \) and \( P_5 \) (figure 3, a, c, e, respectively) are the moments of completion of
irrigation of one and beginning of irrigation of another half of the packing. Time interval from \( P_1 \) to \( P_3 \)
is \( t_1 = 120 \) s. Accordingly, time interval \( P_3 - P_5 \) is \( t_3 = 120 \) s. The isotherms in the diagrams are drawn
in 0.2 K. The range of absolute temperature changes in \( 5 \div 6^\circ C \) (figure 3, a, c, e, respectively)
indicates significant maldistribution of flows along the height and cross-section of the packing. The
diagrams of local temperature distribution of time moments \( P_2 \) and \( P_4 \) (figure 3, b and d, respectively)
reflect the process of flow reformation along the height and cross-section of the structured packing
from one steady distribution, corresponding to irrigation of one packing half, to the state of the flows,
corresponding to irrigation of another half. The range of temperature variation for time moments \( P_2 \)
and \( P_4 \) indicates more even distribution of flows over the height and cross-section of the packing, even
in comparison with the Uniform drip point pattern (figure 3, f).
The results of experiment on investigation of separation efficiency of mixtures for different periods of non-stationary periodic irrigation of the packing half-diameters are shown in figure 4. Based on the analysis of experimental data, we have determined the flow characteristics of distillation column operation, when periodic alternating irrigation of two halves of the packing cross-section provides an increase in separation efficiency as compared to the traditional uniform drip point pattern.
3. Conclusion
Periodic irrigation of the specified zones of the structured packing allows increasing the efficiency of column separation within 20% for the switching period, commensurable with intrinsic characteristic times of formation of large-scale maldistribution of the flow parameters over the cross-section and height of the packing. Thus, when operating the large-scale industrial distillation columns, there is a real opportunity to use new liquid distributors with a controlled drip point pattern to improve the efficiency of mixture separation in such mass exchanging apparatuses.

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