Efficiency of mixture separation in a large-scale model of distillation column at periodic packing irrigation

A N Pavlenko, V E Zhukov, N I Pecherkin, A D Nazarov, E Yu Slesareva, X Li, H Sui, H Li and X Gao
Kutateladze Institute of Thermophysics SB RAS, Lavrentyev av. 1, Novosibirsk, 630090, Russia

E-mail: pavl@itp.nsc.ru

Abstract. Setting the optimal pattern of initial irrigation makes it possible to use the maximal packing height without considerable deterioration of mixture separation efficiency caused by formation of large-scale maldistribution of local mixture flows within the packing. Periodic packing irrigation also allows destruction of large-scale structures of local flow maldistribution within the structured packing. This paper presents data obtained in experiments on Sulzer 500X structured packing with the diameter of 0.6 m and height of 2.2 m at periodic packing irrigation. The working liquid was R114/R21 mixture. The packing was irrigated by a liquid distributor with possibility of independent control of any of 123 drip points. The experiments were carried out under the conditions of total reflux ($L/V = 1$) and $L/V = 1.65$.

1. Introduction

The efficiency of mixture separation in distillation columns depends significantly on uniformity of separated liquid and vapor phase distribution over the packing surface [1-5]. To satisfy this condition, various designs of regular packing with a complex structure made of various materials (including mesh and porous ones) are being developed [6-10]. Setting the optimal structure of the initial irrigation makes it possible to use the maximal height of the packing without appreciable deterioration of mixture separation efficiency caused by formation of large-scale maldistribution of local mixture flows within the packing. Periodic packing irrigation also allows destruction of large-scale structures of local flow maldistribution within the structured packing [11-14].

The aim of this work is to investigate the effect of drip point pattern of a structured packing on the efficiency of freon mixture separation and formation dynamics of large-scale temperature maldistribution in the packing cross-section along the column height under the conditions of periodic irrigation.

2. Set-up and method description

The experiments were carried out on the large-scale research setup “Large Freon Column”, described in detail in [2,3,14]. The structured packing Sulzer 500X with the diameter of 0.6 m was installed in the distillation column. The mixture was separated under the conditions of total reflux ($L/V = 1$) and at $L/V = 1.65$. The experiments were performed on the 10-layer packing with the overall height of 2.2 m. The mixture of Freon R-21 and R-114 was used as the working liquid, chosen by its characteristics to model the separation of cryogenic mixtures. The pressure of Freon mixture was 0.3 MPa. A liquid
distributor specially developed by the authors [14] was used to irrigate the packing. The distributor had 123 independently controlled solenoid valves, which blocked the holes with the diameter of 3.6 mm. The valves were controlled both manually and in automatic valve switching mode, according to any predetermined algorithm. The time shift of switching was 1 s. The response of the column to the action of the liquid distributor was observed in real time by indications of thermometers mounted in three different column cross-sections along the packing height. In each section, 16 thermometers were installed. Their readings were displayed on the computer monitor in the form of topograms. Thermometers were installed in the lower (2 layers from the packing bottom), middle and upper (2 layers from the packing top) cross-sections of the packing. Information displayed on the monitor made it possible to evaluate both the structure of large-scale temperature maldistribution and value of this maldistribution. The value of maldistribution was characterized by standard deviation of temperature, calculated by the readings of 16 thermometers in each cross-section.

In this series of experiments, the packing was periodically irrigated using two different drip point patterns. In one case, one half of the packing cross-section was irrigated periodically, then another half. This mode was designated HC (figure 1). In another case, half of the packing cross-section and a part of the packing in the second half of cross-section were periodically irrigated. This regime was designated HCA (figure 2). HC pattern provides irrigation of a half of the packing cross-section during time $t_1$ (figure 1a), the second half of cross-section stays closed. Then, the valves are switched, and the irrigated and dry halves of cross-section change for period $t_2$ (figure 1b). Then, the cycle repeated periodically. The main data array for the HC pattern is obtained for equal values of $t_1$ and $t_2$ within 5 – 160 s. The pictures of packing irrigation by the HCA pattern are shown in figure 2.

![Figure 1](image1.png)

**Figure 1.** Packing irrigation by the HC pattern. a) – first half of period, $t_1$; b) – second half of period, $t_2$.

![Figure 2](image2.png)

**Figure 2.** Packing irrigation by the HCA pattern. a) – first half of period, $t_1$; b) – second half of period, $t_2$. 
3. Results and discussions
During the experiment, the mixture separation efficiency (the height of transfer unit, HTU) was determined within the range of reduced vapor velocity $0.029 < K_v < 0.053$ m/s; distribution of the temperature field in the packing cross-section at three levels along the column height was recorded. Distribution of the local density of the liquid flow rate, formed during liquid passage along the entire height of the packing, was also measured under the packing.

Dependence of mixture separation efficiency $HTU$ on period $t = t_1 + t_2$ is shown in figure 3 for periodic irrigation with different drip point patterns and different values of reduced vapor velocity under the conditions of total reflux ($L/V = 1$).

As it can be seen from the diagram, periodic packing irrigation by drip point pattern HC at $K_v = 0.029$ m/s does not lead to deterioration of separation as compared to uniform irrigation. At $K_v = 0.033$ m/s, a noticeable decrease in the mixture separation efficiency is observed at period $t > 30$ s. When the reduced vapor velocity is increased to $K_v = 0.053$ m/s, periodic irrigation with HC drip point pattern leads to significant deterioration of separation efficiency even at lower values of parameter $t$. The use of the HCA pattern for periodic irrigation made it possible to obtain at period $t = 20$ s significant improvement in separation efficiency as compared to the HC pattern at higher $K_v$ values. Similar data for $L/V = 1.65$ are presented in figure 4.

**Figure 3.** HTU vs. period $t = t_1 + t_2$ at periodic irrigation with different drip point patterns. $L/V = 1$. Sulzer 500X packing.

**Figure 4.** HTU vs. period $t = t_1 + t_2$ at periodic irrigation with different drip point patterns. $L/V = 1.65$. Sulzer 500X packing.
As it can be seen from the diagram, for the HC drip point pattern, separation efficiency during periodic irrigation decreases continuously with increasing irrigation period. For the HCA pattern, separation efficiency within the range of irrigation period less than 40 s is almost the same as at uniform irrigation. For the irrigation period of 40 s or more, the efficiency of mixture separation becomes worse. In the case of stationary irrigation by the HCA drip point pattern (figure 2b), the HTU value at $K_v = 0.04$ m/s is 432 mm.

Periodic irrigation of one or another part of the packing cross-section with a period commensurable with time of liquid flow along the packing leads to cyclic rearrangement of distribution of the local flows within the packing and manifests itself by a change in temperature distribution in the packing cross-sections. Irrigation of diametrically opposite parts of the packing at different half-periods of periodic irrigation leads to a periodic change in the areas of high and low temperatures in the packing cross-section. In the process of such a change, there is a change in temperature maldistribution within the packing cross-section. The diagram of variation of temperature maldistribution degree in different cross-sections of the packing at periodic HCA irrigation is shown in figure 5. As it can be seen in the diagram, the value of standard deviation of temperature changes in each packing cross-section with a period, equal to the packing irrigation period. A phase shift of about 4-5 s is observed from the diagram to diagram, related to different packing cross-sections. Thus, disturbance caused by the liquid distributor spreads along the packing height at $K_v = 0.053$ m/s with the velocity of about 0.1 m/s (the distance between thermometers of the 2nd and 8th layers is 1.26 m).

A diagram of variation in the degree of temperature maldistribution in the lower cross-section of the packing during different periodic irrigations by the HCA is shown in figure 6. As it can be seen in the diagrams, a change in the irrigation period affects significantly the amplitude of a change in the standard deviation. With an increasing period, initially uneven irrigation spreads over the packing, forming a higher maldistribution degree. The change in irrigation half-period prevents further development of maldistribution.
4. Conclusions

Under the conditions of total reflux and small reduced vapor velocities ($K_v = 0.029$ m/s), periodic irrigation with the HC drip point pattern leads to improvement of separation efficiency at a period of 30 s as compared to stationary uniform irrigation. At higher reduced vapor velocities, no improvement in efficiency is observed. Application of the HCA pattern at periodic irrigation made it possible to obtain better separation efficiency at the period of 20 s as compared with the HC pattern at higher values of $K_v$. The disturbing effect of the liquid distributor with periodic irrigation extends along the packing height with the velocity of about 0.1 m/s at $K_v = 0.053$ m/s.

Under conditions of $L/V = 1.65$ and $K_v = 0.04$ m/s, periodic irrigation by the HC pattern leads to deterioration of separation efficiency as compared to uniform stationary irrigation, and at periodic irrigation by the HCA pattern, the efficiency of mixture separation does not decrease within the range of period $t < 30$ s.

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