Experimental investigation of freon mixture spreading over the structured Sulzer 500X packing at single drip point irrigation

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Abstract. The paper presents the results of experimental studies on liquid spreading over the Sulzer 500X packing at single drip point irrigation. The experiments were carried out using a 10% mixture of R114/R21 freons on one packing layer with a diameter of 0.6 m. The flow rate of liquid flowing from the lower edge of the packing was measured automatically by a flow meter moving along the packing sheets with a given step. The flow meter used volumetric measurement method. The receiving collector of flow meter is 50x50 mm in size, operating range of flow measurement is 0.05 – 50 ml/s. Distributions of liquid over the packing were measured at single-jet irrigation in the range of jet flow rates 2.5 < qirrig < 60 ml/s. Spreading zone in the case of irrigation by a single jet is limited by the corrugation channels coming from the irrigation point. The pattern of spreading at low-flow jet irrigation has the shape of a dome with a low flow rate at the outlet of corrugation channels, which limit the spreading zone. With an increase in the flow rate, the share of liquid in these channels increases and dominates over other parts of the spreading zone.

1. Introduction

The conditions of uniform liquid spreading over a structured packing and uniform distribution of vapor in the packing are the main requirements for highly efficient operation of distillation columns. Achieving a good quality of liquid distribution is crucial for performance of the structured packing with corrugated sheet. According to practical experiences and research work, the sources and nature of large scale liquid maldistribution have been revealed [1]. Corrugated sheets of the structured packing have complex geometry, characterized by a large number of parameters, which greatly complicates modeling of the liquid spreading process [2-3]. In [4], liquid nitrogen spreading over a single sheet of corrugated Sulzer 500Y packing was studied for the case of single jet irrigation. Therefore, a reliable and extensive experimental database on various liquids spreading in various types of structured packings is a necessary condition for the development and verification of models. The purpose of this work is to obtain experimental data on spreading a high wetting liquid (freon mixture) over the sheets of Sulzer 500X packing at single drip point irrigation.
2. Setup and description method

The experiments were carried out on the large-scale research setup "Large Freon Column", whose detailed description is presented in [5]. A 10-% mixture of R114/R21 freons was used as a working fluid. Studies were carried out on a Sulzer 500X packing with a diameter of 600 mm. The setup was equipped with a controlled liquid distributor [6] and automated system for measuring the flow rate of liquid flowing from the structured packing sheets. The controlled liquid distributor allows activation of specified irrigation points with the required diameter in the range of 1.5 - 5.2 mm. The automated system for measuring the liquid flow consisted of a coordinate system for moving the gauge along the packing sheets and flow meter with a square receiving collector of 50x50 mm. The scheme of collector and its position relative to the packing are shown in figure 1.

![Diagram](image)

Figure 1. Layout of collector relative to the packing (a) and picture of measurement process (b).

The flow meter consists of collector (1) and drainage solenoid valves (2). The collector is emptied with the help of valves before a new cycle of liquid flow measurements. The collector has a square cross-section; in the upper part, the face size is 50 mm, in the lower part, it is 25 mm. The height of collector is 200 mm. To measure the collector filling with liquid, two parallel lines (3), equipped with four thermometers, are installed. The scale bar is placed coaxially in a glass tube with an inner diameter of 13 mm. This tube is required to suppress oscillations of the free surface of liquid when measuring the flows and velocity. The bar construction provides overheating of thermometers by 5–10 degrees with respect to the ambient temperature. In the process of collector filling with liquid, the temperature of sensor, reached by the level of liquid free surface, decreases to the temperature of liquid, which is in equilibrium with vapor. The filling of this volume is registered by a sharp change in the temperature of sensors. The range of measured flow rates is 0.05 - 50 ml/s. The flow meter is moved with a coordinate device along the packing sheets, according to the predetermined program. The step of transportation of the flow meter collector can be 10, 25 and 50 mm. The measurement step is preferably 10 mm.

3. Results and discussions

Measurements were carried out at liquid flows through a single drip point in the range $2.5 < q < 60$ ml/s. To ensure such a range of changes in the liquid flow, five nozzles with different hole diameters from 1.5 to 5.2 mm were used. In addition, the flow through the hole was changed by
varying the liquid level in the distributor. The experiments were carried out at liquid levels in the distributor of 460 and 120 mm. Figures 2 show the photographs of liquid flow from the lower edge of the packing at irrigation by a single drip point with different flow rates. The photographs show that with an increase in the flow rate through a single drip point, an increase in the flow at the edges of the spreading area is observed. At the maximal flow rate through the drip point, there are the strong jets at the edges of the spreading area.

![Image](a)

![Image](b)

![Image](c)

Figure 2. Liquid flow from the lower packing edge. Flow rate through a single drip point:

(a) - 4.9; (b) - 21; (c) - \( q_{\text{irig}} = 59 \) ml/s.
The scheme of corrugated sheets in the packing layer is shown in figure 3. Solid lines are vertices of corrugation, dotted lines are depressions of corrugation, red and black lines belong to the adjacent packing sheets, and green cone is the area bounded by the irrigated canals. The zero coordinate at the lower edge of the packing sheets corresponds to drip point projection.

Figure 3. Scheme of corrugated sheets in the packing layer.

Figure 4 shows the results of measuring the distribution of liquid flow density over the 500X packing for different flow rates through a single irrigation point. Coordinates of the drip point (xn), hole diameter (d), level of liquid in the distributor (h) and flow rate in the jet (q) are shown in notation to the diagram. Data in the diagram are presented as dependence of the density of relative fraction of the jet flow rate (mean-integral on the collector scale) on the collector center coordinate.

Figure 4. Distribution of relative density of liquid flow from the lower edge of the packing.
To show correctly the nature of spreading at the edges of the zone, where extreme jets fall only in a partial collector area and the coordinate of collector center can be beyond the spreading area, the measurement results were processed according to the following algorithm. The minimal flow rate measured at the spreading zone edge (usually, this value is in the range of 0.01-0.05 ml/s) was taken as the boundary of the spreading zone. The boundary coordinate corresponded to the coordinate of the collector edge nearest to the spreading zone. Displacement by one step (10 mm) towards the spreading area was interpreted as a flow rate measurement by a virtual collector with a size of 10 mm along the axis of displacement. The mean-integral density of the flow rate was determined at this size and result was reduced to the coordinate corresponding to the middle of this virtual collector. Since the nozzles with different hole diameters have different coordinates, the measurement data are presented in a modified coordinate along the abscissa axis for more visual comparison of the spreading patterns. Zero value of the coordinate corresponds to the position of a nozzle irrigating the packing.

As it can be seen in the diagram, a single jet spreads along the Sulzer 500X packing to a width of 250 - 270 mm for all flow rates through a single drip point. Thus, liquid spreads within a cone (green line) formed by corrugation channels of the adjacent sheets following from the point irrigated by a single jet. The nature of liquid spreading over the packing is different for different flows through the drip point.

At low flow rates (2.5, 4.9 ml/s), asymmetrical liquid spreading is observed. Liquid flows predominantly into the right (in the figure) part of the packing. In this part of the packing, we see a fairly large proportion of the flow from the projection of irrigation jet almost to the lower edge of the corrugation channel, which comes from the point of irrigation. However, along the extreme channel and the channel adjacent to it (the distance between the channels is 12 mm), the flow density is substantially less than that in the area closer to the middle of the spreading zone. To the left of the projection of the irrigation hole, the proportion of flow is twice as less as in the right side. The proportion of flow in two leftmost channels is almost the same as in two rightmost channels. At a distance of 100 mm to the left of the drip point projection, a local maximum of the flow rate is observed. The asymmetrical nature of distribution and small proportion of the flow in the extreme channels can be connected with the fact that these flow rates through the drip point (2.5 and 4.9 ml/s) are achieved through a nozzle with a hole diameter of 1.5 mm. A fairly thin jet, falling into the packing cell, irrigates mainly a channel of one sheet, directed to the right. Thus, spreading is largely implemented in this direction. Under the conditions of small flow through the irrigation hole, the proportion of liquid transported through the contact points and holes is commensurate with the total flow rate and, as a result, an increased flow density is observed in the middle part of the zone of liquid spreading.

In the area of high flow rates (11.6 - 59 ml/s), the pattern of spreading is significantly different from spreading at low flow rates. In the middle part of the spreading zone, a fairly uniform flow density is observed. The proportion of flow in the middle part of the spreading zone is within 0.25 - 0.4% per mm. Moreover, a smaller proportion of flow density in the middle part of the spreading area corresponds to a larger flow rate through the irrigation hole. At the edges of the spreading zone there is a significant increase in the density of the liquid flow. This pattern of spreading can be explained by the fact that a limited amount of liquid transferred through the contact points and holes is non-linearly related to an increase in the flow through the outermost channels limiting the spreading zone. The greater the flow through the irrigation hole, the smaller the proportion of liquid that is redistributed to the middle region of spreading area and the larger the proportion of liquid that flows through the utmost corrugation channels, limiting the spreading area.

4. Conclusions

Liquid distributions over the structured 500X packing were measured at single-jet irrigation in the range of jet flow rates 2.5 < q_{irrig} < 60 ml/s. The spreading zone in case of irrigation with a single jet is limited by corrugation channels coming from the point of irrigation. The pattern of spreading at a low-
Flow jet irrigation represents the shape of a dome with a small flow rate at the outlet of corrugation channels, which limit the spreading zone. With an increase in the flow rate, the portion of liquid in these channels increases and dominates over other parts of the spreading zone. The measurements showed that the character of liquid distribution under the studied unit element of the packing is significantly different at low (2.5, 5 ml/s) and high (15 - 59 ml/s) flow rates at the point of irrigation. At low flow rates, an increased flow density is observed in the middle part of the zone of liquid spreading; at high flow rates, an increased density is observed at the edges of the spreading zone.

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