Experimental Characterization of Liquid Distribution Quality of a Multiple-Nozzle Spray Distributor*

Ž. Olujić+
Delft University of Technology, Process & Energy Laboratory,
Leeghwaterstraat 44, 2628 CA Delft, The Netherlands

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Dedicated to the memory of Professor Dr. Valentin Koloini

Spray distributors as used in conjunction with large diameter packed beds consist of a multiplicity of spray nozzles that produce a circular liquid distribution pattern, arranged in a rectangular grid with a large degree of overlap to avoid "dry spots". This inherent non-uniformity is reflected in an uneven cross sectional distribution of the liquid, the extent of which depends on the factors such as spray angle, homogeneity of spray cones, nozzle pattern, and, importantly, the distance between the nozzles and the bed. The information on the performance of spray distributors is scarce and mainly qualitative, and therefore it is not surprising that rules for spray distributor design are unavailable in open literature. This paper aims at filling this gap and describes experiments carried out to characterize the liquid distribution of a 4-nozzle distributor, equipped with full-cone, wide-angle spray nozzles. The TU Delft column hydraulics simulator with an internal diameter of 1.4 m was used for this purpose. The test system was water/air at atmospheric pressure and ambient temperature. Particular attention was paid to the effects of the nozzle pressure and the spacing between the nozzles and the bed; however, the distance required to smooth out poor initial distribution to an acceptable level appeared to be impractical.

Key words:
Liquid distribution, spray distributors, distillation, packed columns

Introduction

Owing to their rather low cost and low pressure drop, spray distributors are widely used in packed columns to provide liquid distribution to the top surface of rather short beds employed in conjunction with direct heat and/or (less demanding) mass transfer applications, such as quenching, scrubbing, and pumparound sections in refinery main fractionators.[1] The later ones, particularly those operating under vacuum are often columns with very large diameters, which implies high capital expenditures. Therefore, the designers strive for savings in the height of such columns. This can be achieved easily by reducing the spacing between nozzles and the bed, for instance by choosing wide instead of narrow angle spray nozzles. However, the question is how and to what extent this will affect the quality of liquid distribution, which is, according to general belief, inferior to any other type of distributor.[1–4] Indeed, as elaborated theoretically in a recent paper, the nozzles that produce a circular liquid distribution pattern, arranged in a piping manifold in a rectangular grid, cannot apply the liquid evenly over the top of the packed bed.[5] Certainly, factors such as spray angle, distance from the bed, nozzle type and layout influence strongly the quality of liquid distribution. The effect of these factors on the quality of liquid distribution is poorly understood, and good non-proprietary models, which could enable quantitative estimates, are unavailable.

The objective of this study was to observe experimentally the interaction of full-cone wide-angle spray nozzles in a rectangular four-nozzle arrangement. Particular attention has been given to the relationship between the quality of liquid distribution and operating (nozzle) pressure, and, as observed, in all cases the rather bad initial distribution exhibited a strong tendency to improve with increasing the distance between nozzles and the packed bed.

Background

In practice, the liquid is usually introduced through high-pressure, full cone spray nozzles, arranged in a way to avoid bypassing any upflowing vapour. Due to height limitations, in packed columns one-level distributors are commonly employed. In order to cover fully the column cross-section,

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+ z.olujic@tudelft.nl

this implies a considerable overlap of sprays and by placing the outer nozzles close to the wall a significant portion of liquid is sent directly to the column walls. Unfortunately, no spray nozzle produces drops with perfectly uniform size (typical drop size range: 0.2 to 2 mm), and those smaller than the design value are prone to premature entrainment that may limit the column capacity. A thorough consideration of this and other aspects of spray distributor operation can be found in a recent paper authored by Trompiz and Fair.[6] They have developed a model for estimating the total entrainment from spray nozzles. However, the model has been validated using data from single spray experiments only. More practical information on the entrainment rate associated with spray distributors is contained in a paper by Pilling and Bannwart.[7] The experiments performed with Air/Isopar system at ambient conditions in a 1.2 column using a single wide-angle nozzle (90°) as liquid distributor in conjunction with different types of Sulzer grid packing have clearly indicated that excessive entrainment caused by spray nozzle distributor limits the capacity of the packings tested. Using a state-of-the-art narrow trough distributor, much higher gas loads were achieved indicating a capacity gain of approximately 50 % over a spray nozzle distributor. Kunesh[8] and Cai and Kunesh[9] provided experimental evidence indicating the spray nozzle as a highly effective heat-transfer device. They arrived at this conclusion experimenting with respectively three- and single full-cone, wide-angle spray nozzle arrangements installed in the 1.2 m ID FRI test column. A general consideration of the design aspects related to spray towers, which usually employ two or three levels of multiple-nozzle arrangements to ensure complete coverage of the column cross-section can be found elsewhere.[3] However, these and other references addressing in more or less detail the performance characteristics of spray distributors do not provide any quantitative information about the quality of liquid distribution from spray distributors. The work described in this paper aims to fill this gap, with particular attention on one-level nozzle arrangement as employed in packed columns.

Experimental

A thorough description of the large diameter (1.4 m ID), column hydraulics simulator available at the Delft University of Technology can be found elsewhere.[10] For the purpose of this study, a high-pressure centrifugal pump has been added into the closed water loop. A spider-like spray distributor (see Fig. 1), with four equidistantly placed, full cone, wide angle (90°) spray nozzles (Lechler

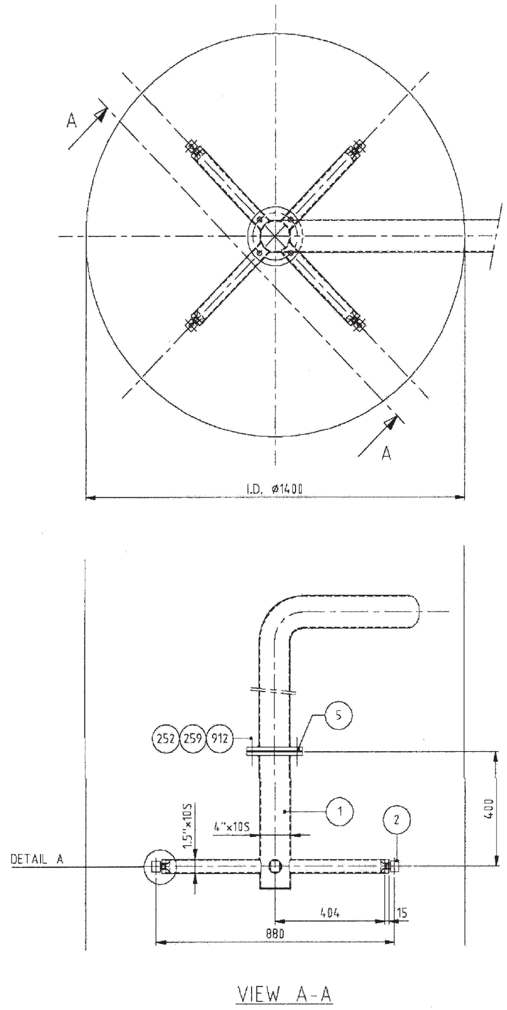
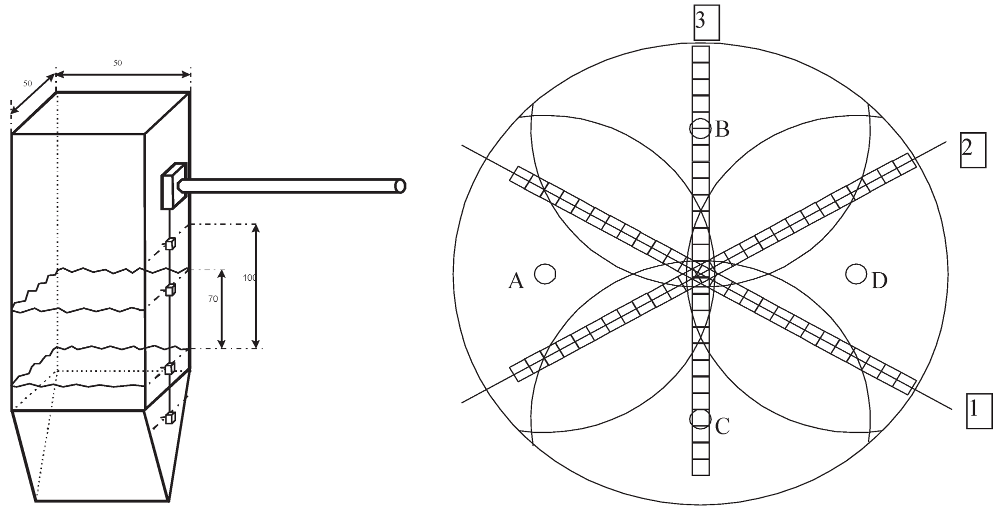


Fig. 1 – *Drawing of the 4-nozzle spray distributor employed in this study*

422.926) with tangential liquid feed was employed. A detailed overview of nozzle characteristics, including drop size distribution and liquid flow rate as a function of operating pressure can be found in Lechler's brochure.[11] A paper written by authors associated with Lechler, Inc. provides some guidance for selection of proper nozzle design for various reaction and separation applications.[12]

Liquid distribution measurements were conducted using a flanged segment containing three equidistant moving rods, each containing a constant volume funnel at the end. Directions of measurements with respect to the location of the nozzles, as well as the extent of overlap of the sprays are indicated in Fig. 2. The liquid was collected by turning up the open side of the funnel equipped with electrodes to indicate the level of liquid in the funnel. A sketch of the funnel with main dimensions is shown in Fig. 2. Starting from the low-level mark, the time was measured until reaching the upper-level mark and this was repeated for 26 locations (50 mm spacing) along the cross-section for each of the three di-

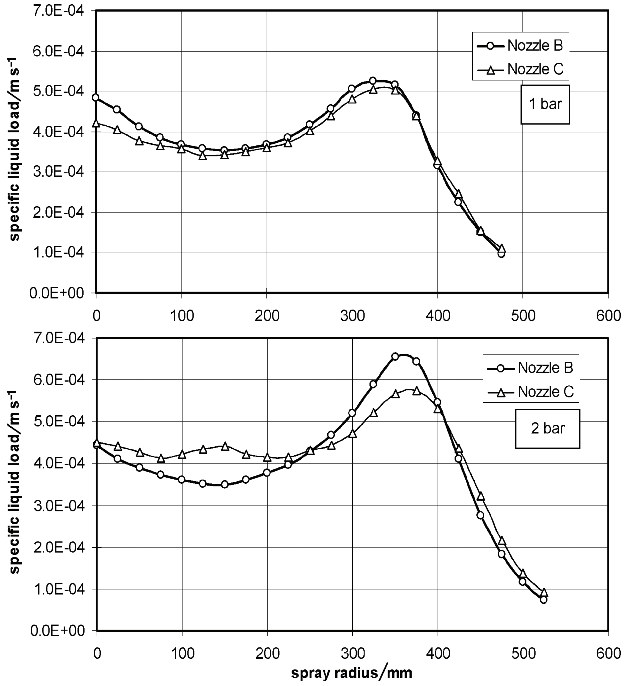


F i g . 2 – *Sketch of the funnel used to collect the liquid below the nozzles, with a top view illustration of the measurement directions with respect to position of nozzles, and the extent of the overlap of four sprays*

rections. Reproducibility of measurements was high and all measurements were carried out in duplicate, and the mean value used for further data processing. The same set of measurements was repeated for each of the three distances from nozzles considered in this study, respectively 500, 750 and 950 mm. Operating nozzle pressures were 1, 2, and 3 bar, respectively, with 2 bar as the design value. Tap water was pumped around at ambient conditions, and only in a limited number of cases, the liquid distribution was measured in the presence of a counter-current air stream.

In all cases, a substantial amount of liquid was contained at column walls. Therefore, to quantify to some extent the wall flow, a separate experiment was carried out. Scrapping the liquid from the column walls in the bottom part indicated that practically 50 % of all liquid supplied through the nozzles into an empty column gets onto the column walls.

Single spray experiments were conducted for two nozzles (B and C in Fig. 2) in line with measurement direction 3. During this single spray distribution experiment, the other three nozzles were in operation; however, the corresponding sprays were confined to guide tubes placed around the nozzles. Fig. 3 shows the measured radial distribution of the liquid at a distance of 500 mm from the nozzle, for respectively 1 and 2 bar operation. At 1 bar, there is practically no difference in the distribution pattern, however at 2 bar there is some shift in the liquid load along the spray radius, and two nozzles exhibit a pronounced difference in liquid distribution pattern. The degree of non-uniformity of the sprays is striking, indicating a pronounced peak load at some distance from the centre. Between the



F i g . 3 – *Single spray liquid distribution, for two nozzles at two operating pressures*

centre zone and the annulus with peak load there is a zone of reduced liquid load as well as in the outer ring. The peak shifts slightly with increasing nozzle pressure/liquid load to the outer end.

For the four-spray nozzle arrangement evaluated in this study, the liquid distribution measurements are presented in terms of liquid superficial velocity as measured along the three equidistantly distributed lines across the column cross-section, with the centre line as the reference location (distance from the centre).

Results and discussion

Fig. 4 shows the effect of the distance between the nozzles and the bed (funnels) on cross-sectional distribution of the liquid for three measurement directions at 2 bar. Trends for all directions are similar, and with increasing distance from the nozzles the liquid distribution profiles flatten out considerably. Striking is the extent of maldistribution at closest distance, most pronounced in direction 3, with a central peak containing two to three times more liquid than the periphery. The peak in the centre is the consequence of the overlap of relatively narrow base sprays from four equidistantly placed nozzles. With increasing distance from nozzles, the spray base as well as the overlap region increases, resulting in the disappearance of the peak, at the expense of an enlarged high liquid load plateau in the central zone of the column. With further increase of the distance, almost the entire cross-section is covered by overlap of four sprays resulting in a quite flat liquid distribution profile. Anyhow, the distribution curves are not quite symmetrical, indicating a deficit of liquid at right-hand side. The sudden increase on this side close to the wall is because the funnel was able to reach the wall and scrap some liquid from the wall. On the opposite side, it was not able to get close to the wall because of a mechanical limitation, i.e. presence of a body used to fix the funnel to the rod.

As shown in Fig. 5, the presence of upflowing air influences the liquid distribution to a lesser extent. The gas load in this case was approximately equivalent to superficial air velocity of 2 m s^{-1}. At this gas load, the smallest drops are entrained and upon impinging on distributor ladder structure drop off and fall down. However, it was difficult to quantify contribution of this liquid to the total quantity collected in funnels during the measurement.

Fig. 6 shows the effect of operating pressure, i.e. the nozzle liquid load on liquid distribution pattern at the distances of 500 and 950 mm, respectively. At common, 500 mm distance, the degree of maldistribution seems to increase with increasing nozzle pressure/liquid load. At the distance of 950 mm all profiles are much flatter, and practically independent of the operating nozzle pressure.

Conclusions

Experimental evidence has been collected on the quality of liquid distribution from a multiple nozzle liquid distributor comprising four equidistantly placed full-cone, wide-angle nozzles. The

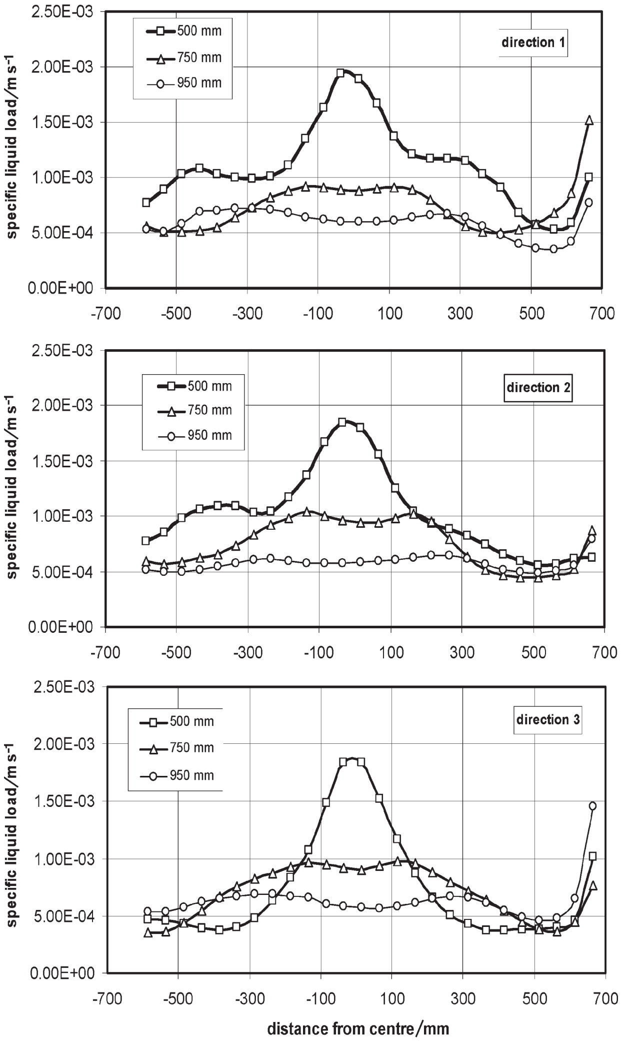


Fig. 4 – *Effect of the distance from the nozzle on the quality of liquid distribution of the 4-nozzle distributor*

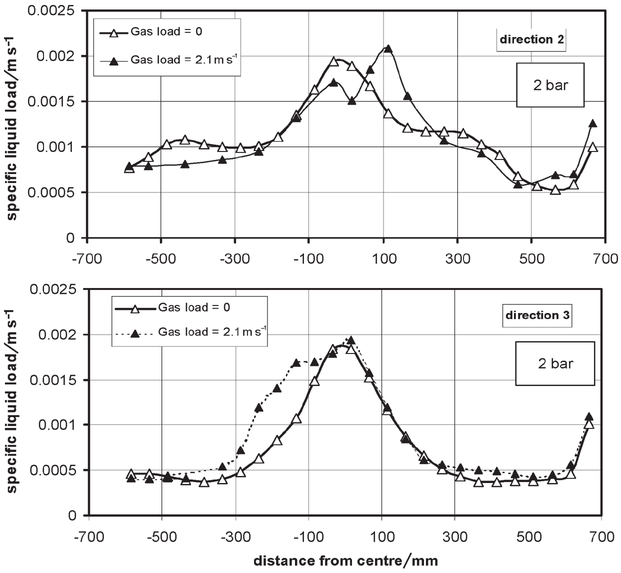
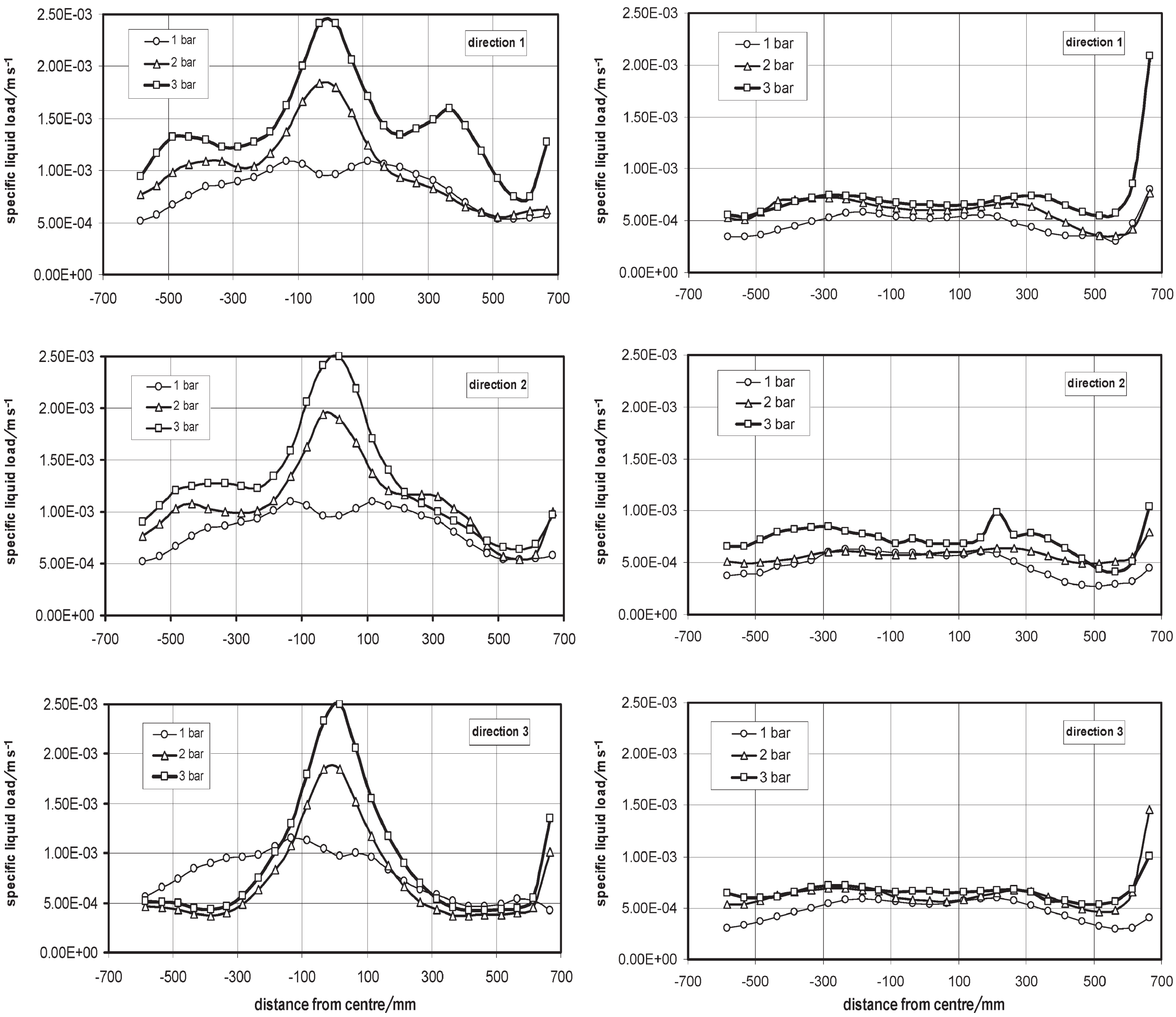


Fig. 5 – *Effect of the air flow on liquid distribution profiles from the 4-nozzle distributor*



F i g . 6 – *Effect of the nozzle pressure on the liquid distribution profiles from the 4-nozzle distributor, at distances of respectively 500 mm (left) and 950 mm (right) from the nozzles*

presence of the counter currently flowing air appeared to have a rather small influence on the liquid distribution pattern.

From single nozzle tests, it became apparent that the nozzles do not distribute liquid evenly. The centre and particularly the annular zone closer to the outer radius get more liquid. In our test (empty column), the 4-nozzle distributor brought nearly half of the supplied liquid onto the column walls. At the shortest distance from the nozzles, as preferred in industrial practice, the liquid is severely maldistributed.

The liquid distribution is generally better at lower nozzle operating pressures and improves with increasing distance from the nozzles. However, at the largest distance, which can be considered impractical from the application point of view, the quality of the liquid distribution is still well below that achievable with high performance, narrow trough distributors.

Regarding the degree of liquid maldistribution and entrainment involved, spray distributors cannot compete with state-of-the-art gravity distributors, and should not be used in conjunction with high performance packings.

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