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Large-diameter experimental evidence on liquid (mal)distribution properties of structured packings

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ABSTRACT

Comprehensive liquid distribution experiments were conducted with common-size conventional and high-capacity, corrugated-sheet structured packings in a 1.4 m internal-diameter column hydraulics simulator using air/water test system at ambient conditions. The objective of the present study was to observe and quantify for various liquid loads and bed depths the relation between the quality of liquid distribution of a packed bed and uniformity and density of initial irrigation profiles, and, in particular, to demonstrate the effects of severe forms of initial liquid maldistribution.

1. Introduction

In answer to ever growing need for fuels and commodity chemicals as well as CO_2 capture installations, the size of distillation, absorption and stripping columns tends to increase well beyond dimensions considered large in the recent past. Such a development confronts tray and packed-column designers with challenges on both mechanical and process design side, and in the case of the latter the need for achieving a uniform liquid and vapour distribution and related uncertainties is a main concern (Stichlmair and Fair, 1998).

The key to proper performance of large-diameter packed columns containing structured packings is achieving and maintaining adequate quality of liquid distribution along a packed bed within the given range of operating conditions. Operating failures experienced in early years of application of large-diameter packed columns, which can be attributed mainly to improper initial liquid distribution due to inadequate quality of liquid distributors at that time, have stimulated both academicians and practitioners to initiate and conduct experimental and theoretical studies on the quality of liquid distribution and its relation to mass-transfer performance of a packed bed. Former have been usually conducted using mainly air–water at ambient conditions as the test system, while the latter were total reflux distillation experiments carried out with some of established test mixtures; only some of these at large enough scale to capture large-scale maldistribution effects that affect adversely performance of industrial-scale columns (Stoter, 1993; Fitz et al., 1999; Olujić et al., 2006).

Although air–water system has often been considered inadequate regarding pronounced differences in liquid spreading behaviour compared to organics (Bennet and Ludwig, 1994), it was used widely, because of its practicality and affordable costs. Indeed, a relatively very high surface tension makes the water to be the worst case regarding the spreading behaviour of liquids in packed beds. However, the fact that many distillations involve aqueous mixtures with considerable fraction of water (in alcohol distilling and many solvent-regeneration applications, water is often a high-purity

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product), which is also a frequent case with solvents used in absorption and regenerated in stripping operations, indicates that the liquid distribution data obtained in air–water tests may also be of direct use for practitioners.

Another issue in this respect is the scale of experimentation. Many efforts in this direction have been undertaken with test columns employing rather small diameters (≤0.5 m), including pronounced wall effects that make packed-bed hydraulics to differ considerably from that exhibited in industrial-scale columns (Olujić and de Graauw, 1989; Stoter, 1993; Olujić, 2003). Therefore, industry was looking for experimentation at large enough scale, and the low- and high-pressure distillation columns with an internal diameter of 1.22 m available at FRI were considered sufficient in this respect. Indeed, a number of devoted studies have been performed at FRI to define the relation between some imposed forms of severe initial liquid maldistributions and performance of a packed bed, showing that a structured packing may be more or less sensitive to certain type of initial maldistribution than random packing and that the structured packing can operate without significant loss of efficiency when the pour point density is reduced to one-third of that considered normal in given case (Fitz et al., 1999).

However, the FRI tests have not provided direct insights into quality of liquid distribution of a packed bed and the depth of penetration of various forms of imposed initial maldistribution. To enable this, in mid-2000s, at the Delft University of Technology (TU Delft), a comprehensive research programme on similar scale has been arranged to study the liquid distribution behaviour of conventional and high-capacity structured packings (Olujić et al., 2006). The complementing experimental data presented here for the first time give an insight into the relation between the quality of initial liquid distribution and the hydraulic performance of a large-diameter packed bed and provide a direct evidence on the depth of penetration of severe forms of large-scale initial liquid maldistribution, similar to those employed in the FRI study (Fitz et al., 1999).

2. Experimental set-up, procedure and data interpretation

A detailed description of the TU Delft column hydraulics' simulator containing a Perspex column with an internal diameter of 1.4 m, using air–water at ambient conditions as test system, can be found elsewhere (Olujić et al., 2006; Olujić, 2003). Fig. 1 shows an installed packed bed comprising five layers of Montz-Pak B1-250, with (above) a narrow trough distributor and (below) a liquid-collecting section. B1-250 is a conventional corrugated-sheet structured packing with a corrugation inclination angle of 45°, and a shallow embossed, imperforated surface. Each packing layer was assembled of three segments made to fit tightly into given space, and packed beds were arranged by stacking subsequent packing layers rotated by 90° to each other. One metre of bed height contained five packing layers, and in the present study, the bed height was varied from 1 to 4 m.

Fig. 2 shows the layout of the narrow trough liquid distributor used in this study. It contains 152 drip tubes (99 drip or pour points per square metre of cross-sectional area). The picture on the right-hand side shows the same distributor with the number of drip points halved by plugging the outlet of every second drip tube. Fig. 3 shows three severe forms of initial liquid maldistribution profile considered in this study, from left

Fig. 1 – Photograph of a short packed bed, consisting of Montz-Pak B1-250, as employed in the present study.

to right: one-half of the distributor blanked (chordal blanking), periphery zone blanked (peripheral blanking) and the central zone of the distributor blanked (central blanking). In the case of chordal blanking, exactly 50% of available drip points have been shut down by plugging the outlet of the drip tubes, while in the case of peripheral and central blanking, the number of closed drip tubes was 47 and 53%, respectively.

Fig. 4 shows the double-wall liquid-collection section, the liquid sampling directions and locations and a drawing with main dimensions of a funnel installed on the end of each of three moving rods. Each rod was moved gradually from one to the other side of the cross-sectional area, which means 25 sampling points, leaving the ring close to the wall uncovered. The liquid leaving the packed bed via walls was collected in a 1 cm wide annulus occupying approximately 1.5% of the cross-sectional area. Funnels were equipped with electronic sensors indicating start and end levels, and the filling time was measured by stopwatch. Reproducibility of this simple but reliable time-volume technique proved to be high, except at vapour loads close to flooding point.

Fig. 5 shows a typical set of measured data using the experimental setup described in short above, illustrating the effect of the gas load on the liquid distribution of a short packed bed (1 m) for a constant specific liquid load (10 m^3/m^2 h or m/h). The numbers shown on the left-hand side represent the measured wall flow in m^3/m^2 h (m/h) and are placed at the level corresponding with the values measured for the same conditions for three cross-sectional liquid sampling directions. In these one-dimensional (1D) plots, the fluctuating lines showing measured local velocities are accompanied by a horizontal line representing average value based on given constant specific liquid load.

Interpolated two-dimensional (2D) liquid distribution profiles are shown on the right-hand side, with, on top of it, a layout of the drip points and the numbers 1–3 indicating the direction of liquid sampling. With a grid superimposed, with