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DEVELOPMENT OF A NOVEL VERTICAL-SHEET STRUCTURED PACKING

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A novel vertical-sheet structured packing has been developed with the objectives of achieving low pressure drop, high capacity and comparable mass transfer efficiency as compared with existing structured packings. A geometrical model and a geometry-based liquid flow model that we developed for randomly packed beds have been extended and validated for structured packings. Based on the models, a computer-assisted approach has been used for the optimal design of the packing. Pressure drop, liquid flow distribution, capacity, and mass transfer efficiency of the packing developed have been tested in a 0.3 m ID air–water column and a distillation column of the same diameter.

Keywords: structured packing; distillation; computer simulation; pressure drop; mass transfer; liquid distribution.

INTRODUCTION

Separations, such as distillation, absorption, extraction, are among the most common unit operations in the chemical process industries. While there are other factors, separation efficiency is mostly dependent on the phase-contacting devices, e.g., trays, random packings and structured packings. Therefore the development of phase-contacting devices has been one of the focuses of separation technology (Bravo, 1998).

Due to their high capacity, low pressure drop and high efficiency, structured packings have been widely used in mass transfer columns in the process industries, especially for vacuum and moderate pressure distillations. Almost all the structured packings used in industries have similar design, consisting essentially of corrugated sheets or gauze. The corrugated design provides inclined surfaces for liquid film flow and inclined channels for vapour/gas flow. The inclination provides the advantage of good liquid spreading on the surfaces. But, at the same time it also makes the surfaces underneath hard to be wetted, although this can be improved by holes or slots perforated on packing sheets. Although corrugated structured packings are generally known as having the lowest pressure drop per theoretical stage, it is less known that only a small fraction of their pressure drop is used in mass transfer processes (Olujic *et al.*, 2001). Three mechanisms contribute to the resistance provided by corrugated structured packings when the packing elements are stacked by rotating each subsequent element to the previous one by 90°: (1) gas–liquid friction at their interface; (2) gas–gas friction at the open crossings of the flow channels; and (3) form drag that comes from flow direction changes at the horizontal interfaces between two adjacent packing elements, at the column wall, and when gas enters and leaves the packed bed (Olujic, 1997; Petre *et al.*, 2003). The latter two mechanisms, which make up more than 80% of the total pressure drop in a 45° packing, do not contribute significantly to mass transfer processes (Olujic *et al.*, 2001). Also, it is found that flooding starts at the inter-element interfaces (Suess and Spiegel, 1992). As analysed by Bender and Moll (2003), the excessive liquid accumulation at the interfaces is caused by the sudden lack of surface area for liquid trickling down at the bottom of a packing sheet and by the shearing force that the gas exerts on the liquid induced by the abrupt direction changes of the flow channels.

Modifications to corrugated structured packings have been studied to increase the capacity of the packings by reducing the 'useless' pressure drop and by avoiding premature flooding at the inter-layer interfaces. Some examples are: height-staggered packing sheets (Billingham and Lockett, 1999; Bender and Moll, 2003); inserting a short vertical-sheet section between adjacent packing layers (Olujic *et al.*, 2001; Bender and Moll, 2003; Larachi *et al.*, 2003); packing sheets with reduced crimp height at the bottom part (Billingham and Lockett, 1999); flattened edges at the bottom end or the top end or both (Bender and Moll, 2003); packing sheets in which the corrugation on the bottom part or on the bottom and top part is bent vertically (Olujic *et al.*, 2001, 2003; Bender and Moll, 2003). The above mentioned examples are modifications at the inter-layer interfaces to reduce the pressure drop of

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the gas phase and the shearing force on the liquid phase from the sudden direction changes of the flow channels. An example of modification for reducing the gas–gas friction at the open crossings of the flow channels is inserting a flat sheet between two adjacent corrugated sheets to form closed flow channels (Behrens *et al.*, 2001; Olujic *et al.*, 2001). Also, increasing the corrugation inclination angle to 60° from the typical 45°, which has been used in industries as high-capacity layout, can dramatically reduce the gas–gas frictional loss as studied by Olujic *et al.* (2000). Some of the modifications have been commercialized by packing manufactures, such as Sulzer MellapakPlus with the corrugation bent to be vertical at the bottom and top ends of a packing element, Montz-Pak Type M with the corrugation bent vertically only at the bottom part, and Koch-Glitsch Flexipac-HC with the corrugation flattened at the bottom end of a packing element (Olujic *et al.*, 2001, 2003; Bender and Moll, 2003).

By reviewing the modifications to the corrugated structured packings, one can find that a vertical-sheet structured packing, which is assembled with parallel vertical-sheets, has almost all the characteristics of the modifications: the sheets are vertical (or 90° inclination) and flat, the flow channels are straight and closed. There are no gas–gas frictional loss from the open crossings of the flow channels and no form drag caused by the zigzag flow channels, as in corrugated structured packings. Therefore vertical-sheet structured packings provide us an appealing perspective for new packing structures.

The idea of vertical-sheet structured packing has a long history. For example, in a US Patent, Alexander (1925) proposed a packing assembly comprising a series of spaced parallel sheets with gas and liquid deflecting projections extending between adjacent sheets. In another US Patent, Sayles (1936) described a structured packing assembly also composed of a number of vertical metal sheets with a complex design of collector at the top of each layer of the packing for distributing liquid over the subjacent sheets. While the parallel-sheet concept has long been available, there is still a need for research on how to stack the sheets together with a simple but structurally firm manner, how to distribute liquid over the sheets as uniform as possible, and how to transfer liquid and gas across sheets for good lateral mixing.

Packing development is a process characterized by design–fabrication–test cycles that is time consuming. If computer simulation is introduced into the packing developing process, the number of the cycles can be reduced and the process can be accelerated. To achieve this, computer models are needed to quantify the influence of geometries on the performance of non-existing packings.

In the present study, a novel structured packing, consisting of an assembly of vertical sheets with folded-out tabs has been developed. The tabs act as spacers and spreaders for controlling the spacing between sheets and for providing enhanced fluid distribution and contact. A geometrical model (Nandakumar *et al.*, 1999) and a geometry-based liquid flow model (Wen *et al.*, 2001) that we developed for randomly packed beds have been extended to and validated for structured packings. Based on the models, a computer-assisted approach for packing development has been established and utilized in the development of the novel packing. Pressure drop, liquid-flow distribution, capacity, and mass-transfer efficiency of the new packing have been measured and compared with conventional structured packings.

CONCEPT

Although vertical sheets may not spread liquid as well as inclined surfaces, both sides of a sheet can be equally wetted. The assembly of vertical sheets also can eliminate the 'useless' gas–gas friction and form drag associated with the zigzag and open channels of the corrugated structured packings, as discussed in the Introduction section.

The thickness of liquid film on a inclined surface (a vertical sheet is a special case of inclined surface with the inclined angle $\alpha = 90°$) is proportional to $(\sin\alpha)^{-1/3}$ for laminar flow or to $(\sin\alpha)^{-0.3}$ for turbulent flow, as shown in the equations below (John and Haberman, 1980):

$$\delta = \left(\frac{3\mu_L Q}{\rho_L g W \sin\alpha}\right)^{1/3} \qquad (1)$$

$$\delta = \left(\frac{nQ}{W}\right)^{3/5} (\sin\alpha)^{-0.3} \qquad (2)$$

The relations show that, for the same liquid flow rate, Q, and the same wetted width, W, a vertical sheet has the smallest thickness of liquid film and therefore the lowest liquid holdup when the wetted area is the same. The thin liquid film and low liquid holdup on a vertical-sheet structured packing will reduce both the resistance to gas phase flow (pressure drop) and the resistance to mass transfer. The low liquid holdup and low pressure drop then lead to high capacity of the packing. Therefore, if its wetted area is equivalent to that of the conventional structured packings, a vertical-sheet structured packing will have superior performance. The key issue of developing the packing is to design the geometry so that it has large wetted area.

Figure 1 shows a schematic of the conceptual design of a single plate. Slots are punched on a sheet with a certain pattern. Spacers, as indicated in the figure, are formed by

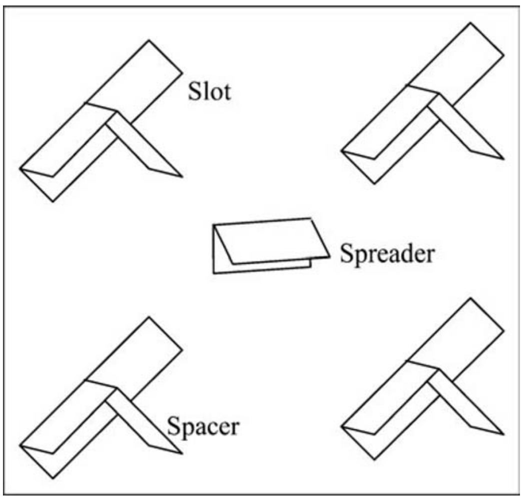

Figure 1. Schematic of the concept of the novel structured packing.