Distillation Column Internals Related Process Intensification Developments

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The purpose of this paper is to introduce some recently commercialised packed column internals and configurations developed by a process equipment manufacturer in close cooperation with universities and industry, which by the virtue of their nature intensify in some way the distillation process. These include the state of the art high capacity structured packings, hybrid packed beds with partially flooded sections, streamlined liquid collectors, catalytic packings and the dividing wall column.

1. Introduction

Although distillation is generally recognized as one of the best developed chemical processing technologies there are still many technical barriers, mainly related to equipment performance, that could, when overcome, secure the position of the distillation and even make it more attractive for use in the future [VISION 2020]. Because of the fact that in the past two decades the support for equipment performance related research declined strongly in industry and universities the equipment related developments were left mainly in the hands of manufacturers. Regarding the complexity and the scale of related research and development effort, as well as limited financial resources, this appeared to be a heavy burden for a well-established medium size company such as Montz. Through a close cooperation with Montz, the Laboratory for Process Equipment had a chance to maintain the quantity and quality of fundamental research in the contacting equipment field. Another essential ingredient of this association was a close cooperation of Montz with a group from BASF, around Dr. G. Kaibel, active in improving the packed column technology utilised mainly in fine chemicals applications. In addition, both Montz and BASF cooperated closely at specific developments with other universities. Looking back, we may say that working in the triangle equipment manufacturer, industrial user and university enabled cross-fertilization of new ideas and models while protecting the proprietary know-how.

This paper focuses on recent advances in structured packings and packed column internals, as well as that related to unique know-how regarding the design and construction of dividing wall-columns. More details on backgrounds, the state of the art and the perspectives for further development could be found elsewhere [Olujic, 2003a].

2. High Capacity/Efficiency Structured Packings

Development of internals for small and large scale vacuum distillation applications is a traditional field of activity of Montz related strongly to TU Delft. Namely, over the years, Montz fully or partly supported the packed column internals related research work at the Laboratory for Process equipment that resulted in four PhD theses [Roes, 1973; Stikkelman, 1989; Stoter, 1993; Woerlee, 1997]. In the last ten years, the joint effort vent largely into improvement of the performance of established structured packings as well as into the development of an overall predictive model. Most of the performance screening work has been done using hydraulic facilities available at TU Delft and Montz in Hilden [Olujic, 1999; Behrens et al., 2001]. Pilot scale, total reflux experiments carried out in a systematic way in cooperation with the Separations Research Program (SRP) at the University of Texas at Austin (Dr. A. F. Seibert and Prof. J. R. Fair) provided experimental evidence on the performance of conventional and advanced packings (M series) in the wide range of operating conditions [Olujic et al., 2000; Olujic et al., 2003b]. The conventional packings data provided also a basis for evaluation and improvement of the predictive accuracy of SRP and Delft models [Fair et al., 2000].

While studying the hydraulic behaviour of conventional structured packing with different corrugation angles it was observed that overall pressure drop comprises three major components: gas liquid interaction at the interface along the flow channels, flow direction change losses with associated entrance effects at the transitions between packing layers and very influential but often ignored one, the gas-gas interaction at the plane separating crossing gas flow channels. The latter two, which are responsible for, say 80 % of total pressure drop in packings with a corrugation angle of 45 degrees, do not contribute greatly to mass transfer. This means that reducing these pressure drop components appropriately could lead to increased capacity without affecting adversely the mass transfer efficiency or vice versa. A possibility for maximizing the ratio of “useful” frictional pressure drop to “useless” pressure drop due to gas/gas interaction was simply by inserting (sandwiching) properly designed flat sheets in between corrugated sheets [Kaibel et al, 1997; Behrens et al., 2001]. This, monolith-like structure with a substantially enlarged specific surface area but the same hydraulic diameter of flow channels produced a lower pressure drop, and consequently allowed a substantial capacity increase. However in conjunction with sheet metal packings it appeared to be prone to development of severe liquid maldistribution, which, particularly in preloading region appeared to be highly detrimental to efficiency.

Figure 1. Photograph of a segment of the high-capacity packing B1-250M

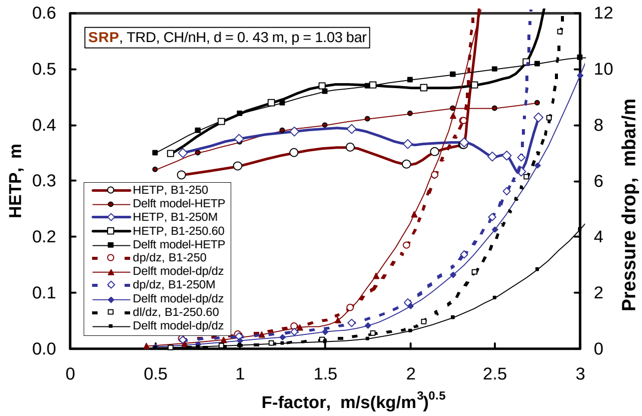

Figure 2. Comparison of total reflux distillation performances of B1-250, B1-250.60 and B1-250M: measured vs. calculated

A real breakthrough was achieved with a second capacity increasing option [Olujic et al., 2001]. The essence of this development is the minimization of gas flow pressure drop created at the transition between packing layers, while allowing a smooth drainage of liquid to the layer below. This was simply achieved by bending smoothly the lower part of corrugations from 45 to 90 degrees (see the photograph shown in Figure 1). Measured pressure drop and efficiency curves shown in Figure 2 clearly indicate that bending only the bottom part of corrugations to the vertical can result in a substantial reduction in pressure drop of conventional structured packing accompanied by a significant increase in the capacity. Experimental evidence from a most recent study [Bender and Moll, 2003] indicates clearly a minor role of the bending the upper part of corrugations. Anyhow, it appears that all proprietary designs perform similar, which means that nowadays the columns containing conventional structured packings can be revamped successfully using their advanced counterparts. Certainly, the application of high capacity structured packings in new designs will lead to leaner columns.

Figure 2 also illustrates a rather good predictive accuracy of the Delft method [Fair et al. 2000; Olujic, 2002]. It should be noted that this method proved to be capable of predicting the effects of packing modifications on the pressure drop and capacity, by adjusting appropriately the geometry related parameters. The mass transfer performance of the modified structure deteriorates slightly, however this is within the limits of predictive accuracy of the original method.

3. CFD Streamlined Liquid Collectors/Gas Redistributors

A potential drawback of further reduction in the pressure drop of a packed bed may be the reduction of the driving force for smoothing out efficiently the heavily maldistributed initial gas profiles generated by conventional liquid collectors installed in between packed beds. A comprehensive experimental and simulation study carried out at TU Delft [Ali et al., 2003] indicated that a state of the art Computational Fluid Dynamics (CFD) tool is capable of predicting reliably the effect of column internals geometry on the single-phase gas flow field. With this in mind, CFD has been used to improve the performance of common low pressure drop liquid collectors that, designed primarily to enable collection and remixing of liquid proved to act as a kind of gas maldistribution generator.

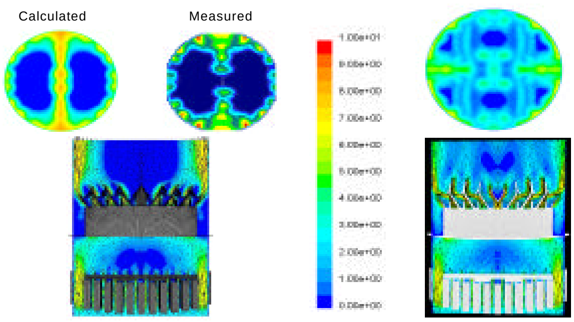

Figure 3. CFD snap-shots of a side cut of the gas flow through liquid redistribution section equipped with a conventional (left) and a modified (right) liquid collector

Figure 3 shows the CFD snap-shots of the gas flow field for the conventional and an improved configuration as well as the corresponding cross sectional velocity distribution patterns at the distance corresponding to the inlet to the bed above. The comparison of predicted and measured gas distribution profiles of the conventional (left hand side) liquid collector indicates that CFD simulation is capable of predicting reliably the gas distribution performance of this kind of packed column internals. A closer inspection of the CFD snap-shot shown on the left hand side of Fig. 3 indicates that in all cases a relatively narrow gas jet is passing along the tip of the opposite blade (side exposed to the liquid draining from the bed above). To avoid this, in the new design, shown on the right hand side of Figure 3, the existing blades are extended and bended smoothly inwards to deflect the gas stream in the vertical direction. In addition, the central part, a chimney like design with two superimposed V-shaped covers, is changed into a simple, upside-down turned V-shape liquid collecting trough. The corresponding Cv (coefficient of local velocity variation) value is 58%, which, compared to 95% of the conventional design indicates a significant reduction in the magnitude of flow variation. This in combination with a more streamlined central part resulted in roughly a 28 % lower pressure drop (63 Pa). From the internals design/performance point of view, this CFD-simulation result is quite encouraging. Namely, it indicates that increased pressure drop is not required to improve the initial gas distribution, i.e. that with respect to conventional designs, there is still a significant potential for improvement in both the quality of the initial gas distribution and the associated pressure loss.

4. Partially Flooded Packed Beds

Another cooperative effort of Montz and BASF, with the University of Karlsruhe (Prof. M. Kind) is concerned with the utilisation of the mass transfer enhancement potential of operating columns preferentially in the loading range. To avoid danger of premature flooding the loading range operation should be controlled in a way. As presented in a recent paper [Kaibel et al, 2000] this can be done by combining low and high specific surface area packings. By operating such a hybrid packed bed (0.1 m internal diameter), some 50 % of efficiency enhancement was achieved. Certainly such operation implies a higher specific pressure drop, however this is not at the cost of capacity. The problem merely lies in the fact that the range of enhanced performance operation appeared to be quite narrow and actually too close to flooding limit.

5. Dividing Wall Column

The major feature of the dividing wall column (DWC) is that it allows substantial energy savings, while separating in a single body a three-component mixture into pure products. In spite of potential benefits, for years DWC remained to be an exotic academic concept and even the energy price explosion of the mid 1970s was not good enough to push toward its industrial implementation. Reintroduced to the distillation community not so long ago [Kaibel, 1987]], the dividing wall column is considered today to be an established technology with a steadily growing application potential. Energy savings with respect to conventional two-column arrangements are in the range of 30 % [Ennenbach et al., 2000; Kolbe and Wenzel, 2002]. However it should be noted that the implementation of this column design concept required specific constructional solutions.
An idea on the internal configuration of a packed DWC can be obtained from Figure 4. Special DWC related know-how was developed from the beginning on at Montz, which built the BASF columns. For instance, the first columns were provided with a fixed dividing wall that was welded on both sides to the column shell. To provide for better flexibility of the internal configuration and to reduce the design accuracy requirements of the system, a free, movable wall system was employed in new designs. For larger diameter columns the dividing wall is built by assembling it in the column from specially designed, easy to install manhole size segments. Such details including the edge seals and other constructive solutions belong to the proprietary know-how of Montz. Modern concepts also provide off-centre positions of the dividing wall to meet special requirements, e.g. for vapour feeds in high vacuum applications. The dividing walls are preferably combined with special self-adjusting packings to avoid assembling problems.

Certainly a considerable research effort proceeded industrial implementation. The necessary knowledge of hydrodynamics of DWC was collected during air/water and tracer testing on large scale (0.8 m inner diameter) carried out in Hilden in cooperation with TU Delft. These experiences helped to develop the full design and construction know-how that represents the basis for the realisation or much larger packed columns than in the beginning (diameters first below 1 m, now up to 4 m). With the increase in diameter it became possible to consider the use of trays in applications where trays offer advantages over packings. Meanwhile several tray DWCs with diameters up to 5 m are in operation.

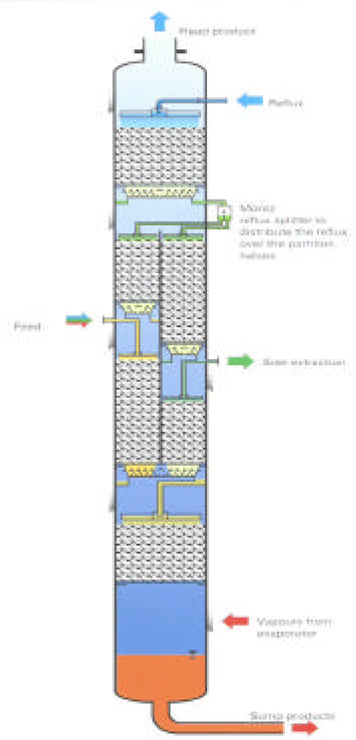

Figure 4. Artist's impression of a packed DWC

6. Catalytic Structured Packing

A cooperative effort with the Prof. A. Gorak's group from the University of Essen, now with the University of Dortmund, led to the development and commercialisation of a hybrid type, catalytic structured packing (Montz Multipak), containing vertically oriented, segmental designed gauze material catalytic bags placed in between corrugated wire gauze sheets with alternatively oriented flow channels. Hydraulic and mass transfer performances of Multipak as determined using pilot scale installations with different internal diameters and packed heights are described thoroughly elsewhere [Gorak and Hoffmann, 2001; Kolodziej et al., 2001]. In the meantime Montz decided to drop this line of development and transferred its rights for Multipak to Sulzer Chemtech.

7. Concluding Remarks

During the last ten years, Montz an established, worldwide operating medium size process equipment manufacturer managed in a number of cooperative efforts with some German and a Dutch university as well as BASF to make technology advances which helped to preserve its share in ever harshening distillation equipment market. Among others, the nature of pressure drop in a corrugated sheet structured packing has been revealed and manipulated accordingly. A significant improvement in capacity of a conventional corrugated sheet structured packing has been achieved. With respect to the performance of 60^0 packing, the capacity of M-series packing is still on the shorter side, indicating that the considerable pressure drop due to gas/gas interaction also influences the capacity. In the range of interest for application of this packing the efficiency matches that of the original packing. Certainly, further packing performance improvement is possible, and optimising the liquid redistributor design will compensate for a loss of gas distribution capability of a bed due to reduced packing pressure drop.
The Delft model proved to be versatile enough to account appropriately for all geometry manipulations considered in our packing improvement studies. Since it does not require

any empirical, packing specific constant it enables a tailor made approach to the design and retrofitting of distillation columns containing corrugated sheet structured packing.

CFD appeared to predict well the single phase flow fields in configurations encountered in packed columns and the simulation tools like Fluent may be considered as a useful aid for design and evaluation of performance of packed column internals. However, immense run time associated with CFD simulations may work adversely to potential users. The simulation capability, regarding the real, two-phase flow situations is still in an early stage of development.

Hybrid packed beds with gas-liquid contacting enhancement means may prove useful, if not widely for separation purposes than certainly for catalytic distillation purposes. Modular catalytic packing elements proved to work in practice and can further be optimised. However, further mechanical design effort is needed to arrive at an economically sound catalyst encapsulation technique.

The dividing wall column is now considered to be an accepted technology and is expected to improve and grow steadily in the number and variety of applications in industrial practice.

In a changing market with a strong globalisation trend, faster innovation cycles are an imperative. It is our belief that a more effective utilization of available resources in conjunction with the synergetic potential within the proven collaboration triangle: equipment manufacturer, industrial user and university is a key to preserve the capability to respond successfully to future distillation technology challenges.

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