FUNCTIONALITY OF A NOVEL DOUBLE-EFFECTIVE PACKING ELEMENT

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ABSTRACT

In packed columns, the detrimental effects of maldistribution of liquid and gas flows on mass transfer are treated – besides a good initial distribution – by a multiple intermediate redistribution of liquid at the expense of additional height of column. These redistribution sections are not very effective since they do not directly contribute to mass transfer. Therefore, a novel packing element was designed which provides both flow redistribution and mass transfer. Experimental results demonstrating the functionality of a prototype of the double-effective packing element are presented.

INTRODUCTION

Packed columns became very important during the past decades. Especially since the introduction of the structured packings in the early seventies, packings are about to replace other types of column internals, namely, separation trays. The reasons for the growing importance of packed columns in separation technology are complex. Besides the pure countercurrent flow of gas and liquid and the low pressure drop, further criteria can be cited [1]. Nevertheless, various problems arise in industrial application of packed columns [2]. The required separation performance of packed columns of random as well as structured type can fail due to non uniform liquid and gas flow rates across the column's cross section. For high separation efficiency plug flow is required. This contains a constant ratio of gas and liquid flow rates on every point in the packing. In reality, maldistribution effects, such as channeling or wall flow, deteriorate the separation performance to a high degree.

Therefore, a great effort has to be made in order to minimize the detrimental effects of maldistribution. In industrial practice, this is performed – besides a good initial liquid distribution – by dividing the total packed bed into several portions with intermediate redistribution sections. Limitations for the height of one packing section are very often related to the column diameter. A bed height to diameter ratio higher than 6 is rare, especially for large diameters. A redistribution section usually consists of three parts: a collecting, a mixing and a redistribution device. In large scale columns the entire redistribution section can require an overall height of up to 2.5 m [3]. Thus, the multiple redistribution results in a drastic increase of column height which does not directly contribute to the mass transfer.

Replacement of the redistribution section(s) with a device that provides both flow redistribution and mass transfer is the main objective for the development of a novel redistributing mass transfer element. These conditions – flow redistribution combined with simultaneous mass transfer – thereby define the double-effectiveness of the intended device. Simplicity of manufacturing and low costs should be included in the design. The approach for the technical implementation is based on the understanding that maldistribution causes the formation of local pinch zones where gas and liquid are in thermodynamic equilibrium. The overcoming of the pinch conditions by splitting and mixing the local gas and liquid streams is the main objective of the redistributing mass transfer element. A first series of experiments with a prototype of the novel packing element proved the required double-effectiveness of the novel design.

IMPLEMENTATION OF THE NOVEL PACKING ELEMENT

Design

The functionality of the novel packing element arises from the understanding that splitting and mixing of gas and liquid streams can overcome the detrimental effects of maldistribution. This functionality can be achieved by a design adapted from a commercial corrugated sheet packing (see Fig. 1). For this purpose, a plane lamella (2) is inserted between two corrugated sheets (1). The plane (2) and corrugated (1) sheets together form separate channels where the phases are in countercurrent flow. The preferred inclination of the channels is 45° corresponding to the usual inclination of a conventional corrugated sheet packing but any other inclination is possible. Due to the different inclinations of the channels this design provides a high level of radial distribution. Furthermore, a zonal liquid stream on the top of a packing element is split into several partial streams which flow downwards in varying directions. Different partial streams flow together at the lower end of the packing element. Thus, a high level of cross-mixing is provided, too.

However, the specified design with separate flow channels for yielding a high radial distribution would cause wall flow since channels ending on the lateral sides of the packing direct gas and liquid flows to the column wall. This fact would considerably impair mass transfer rates. Thus, a mechanism was developed to prevent the detrimental wall flow of the liquid. For this purpose, the plane sheets (2) are provided with openings (3) and flaps (4) at the lateral sides of the packing element. The flaps (4) mesh with the corrugations of adjacent sheets sealing the channels directing liquid to the wall. The openings (3) enable this liquid to flow into an adjacent row of channels. Due to the opposite inclination of adjacent rows of channels, the liquid flows back into the center zone of the packing. The openings (3) also permit the transition of the gas, so that the gas wall flow is also suppressed. In the metal construction, these openings (3) are obtained by bending the triangular flaps (4) punched out of the plane sheets (2).

A further requirement characterizes the design of the novel packing. This takes into account the total capacity range of the column which should not be deteriorated by the novel packing elements. Since the inserted plane sheets (2) increase the surface area a and decrease the porosity ε compared to a regular structured packing with same corrugation height, the equivalent channel diameter d_{eq} has to be increased in order to avoid a rise of pressure drop.

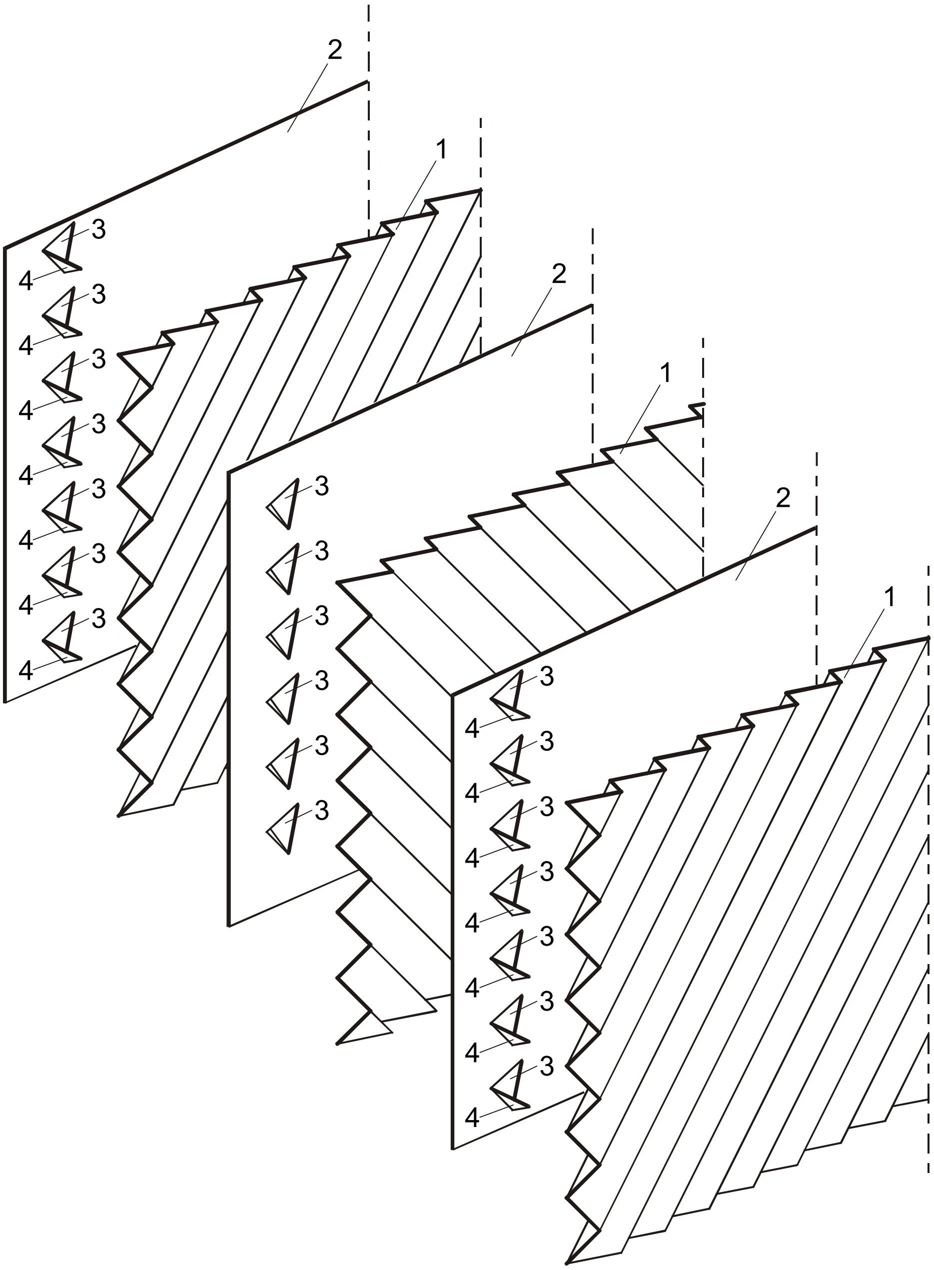


Fig. 1: Detail drawing of the novel packing element in exploded view. Corrugated (1) and plane (2) sheets form separate channels. Plane sheets (2) are provided with openings (3) and flaps (4) for preventing wall flow.

Application

Fig. 2 demonstrates the designated application of the novel packing element. The column internals consist of alternating sections of dumped or structured packings (5) and novel packing elements with increased radial distribution (6). The height of one section of the double-effective packing depends on the column diameter but have to contain at least one pair of elements with an offset of 90° to one another. The layers are inserted without any spatial discontinuity. Therefore, the entire height of column contributes to mass transfer. A further advantage of the double-effective packing elements is their low sensitivity to a non-horizontal installation.

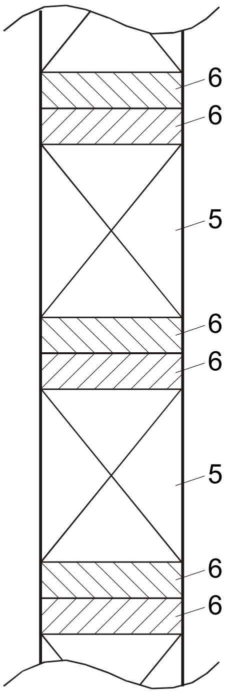


Fig. 2: Schematic of the alternating composition of conventional (5) and novel (6) packings.

EXPERIMENTAL SETUP

An established measuring technique was used for investigating the functionality of the novel packing element. The technique is based on the determination of the liquid temperature profiles inside a packed column. This measuring technique enables, in contrast to other known techniques, the visualization of the distribution behavior inside the column. For this purpose the column has to be operated in a way that mass transfer causes a significant temperature change. This can be most simply performed by operating the column as cooling tower where warm water and air interact in countercurrent flow. In this manner, the mass transfer causes a significant temperature decrease of the liquid phase from the top to the bottom of the column. This temperature variation can be easily measured and evaluated.

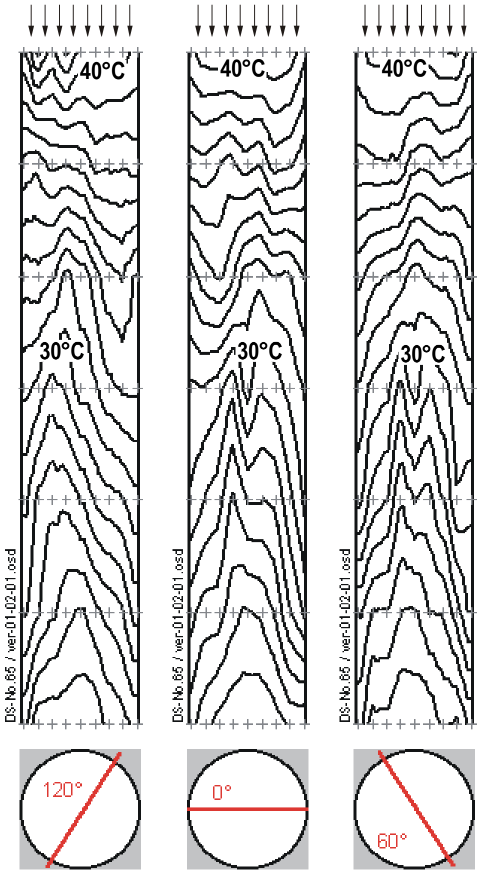
The test column used for the present experiments has a diameter of 0.63 m and a maximum packing height of 3.72 m. Inside the packing there are 427 thermocouples evenly distributed on seven horizontal measuring cross-sections. A detailed description of the experimental device in combination with a schematic flow diagram can be found in [4].

The visualization of the liquid temperature profiles is performed by means of isotherms plotted in vertical cross sections of the column (see Fig. 3). In case of plug flow, these isotherms are supposed to be horizontal straight lines. Any deviations from straight lines are caused by maldistribution. A first approximation considers the isotherms as lines of same residence time. Lower regions of an isotherm mark areas with higher liquid load. In this way, the temperature profiles can be correlated with flow patterns.

EXPERIMENTAL RESULTS

Standard Packing with Uniform Initial Liquid Distribution

The problem of liquid maldistribution is demonstrated by an experiment with the described test column. In Fig. 3 temperature profiles are plotted in three vertical cross sections. The isotherms are shown at 1 °C intervals. The packing of the column consists of dumped Raflux-rings with a nominal size of 25 mm. The gas load F is 2.47 $\sqrt{Pa}$, the liquid load B is 12 m/h. A very uniform initial liquid distribution is achieved by a rotating distributor.



Raflux-Ring 25-8
Polypropylene
$F = 2.47\ \sqrt{\text{Pa}}$
$B = 12.0$ m/h
$H_{OG} = 0.52$ m

Fig. 3: Liquid isotherms within a packing of Raflux-rings and uniform intial liquid distribution.

The isotherms at the top of the column are in an almost horizontal orientation indicating uniform liquid flow rates. As the liquid proceeds downwards, the isotherms become more and more curved. The gradients of the curves identify this deviation as wall flow which is a typical behavior of many column packings. The wall flow significantly reduces the mass transfer efficiency of the packing. The height of a transfer unit H_{OG} is as low as 0.52 m which is a rather good value but not the “true” value since optimum packing performance is impaired by maldistribution.

Packing Including Two Elements with Increased Radial Distribution

In order to overcome the detrimental effects of the maldistribution the novel packing elements are designed to provide a high level of radial distribution. As mentioned above, this can easily be achieved by an alternating assembly of plane and corrugated sheets which generates separated inclined channels. Therefore, a first version of a packing element was manufactured with separated channels to determine the radial distribution capability of such a type of packing. It may be noted that this first version does not have any mechanism for preventing wall flow of the phases.

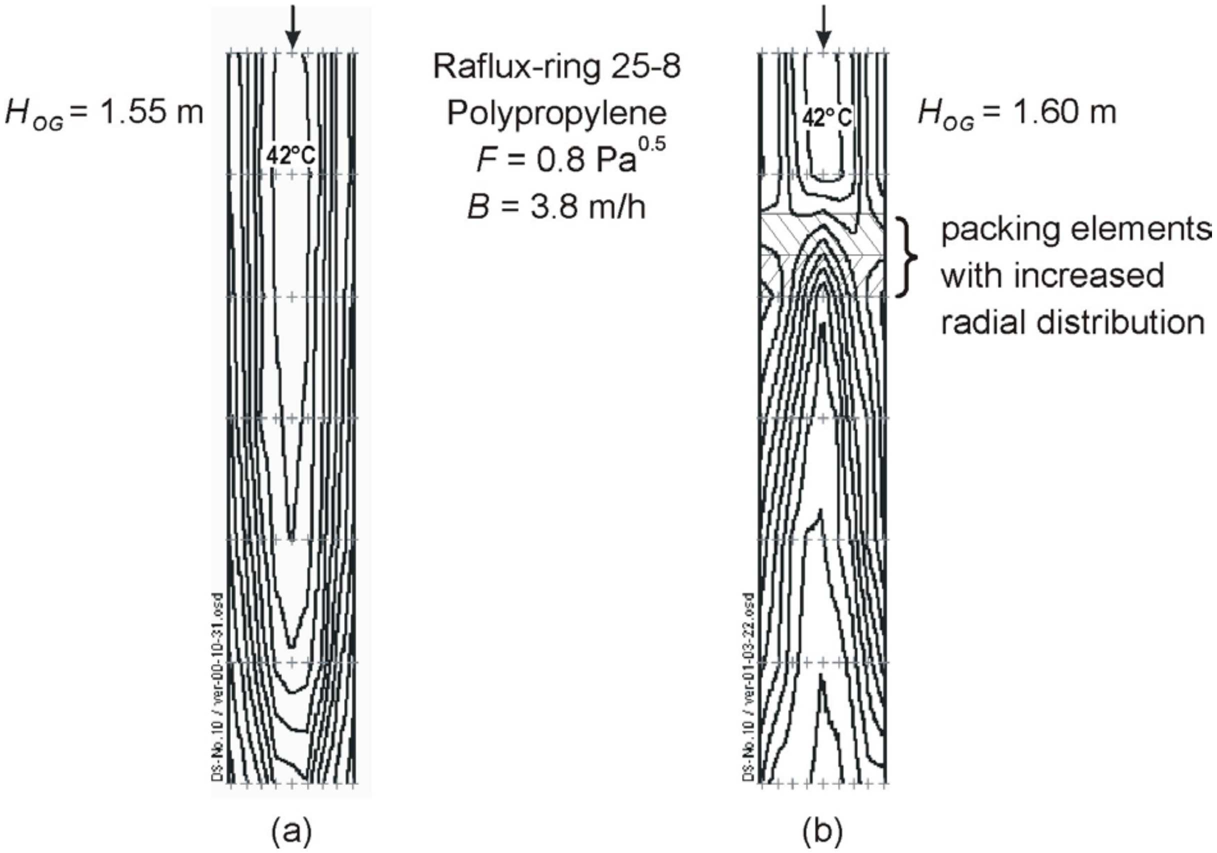


Fig. 4: Liquid isotherms within a packing of Raflux-rings and point source liquid feeding. (a) Reference measurement with standard packing. (b) Measurement with first version packing elements.

The comparison of two experimental results in Fig. 4 proves the expected functionality. In both cases the column is filled with the 25 mm Raflux-rings. The operating conditions, namely gas and liquid load, were the same for both experiments. The liquid is fed by a centric point source at the top of the packing. With this kind of initial liquid distribution the radial spreading capability of a packing can be demonstrated quite clearly. The column on the left side (a) is fully stacked with the dumped packing whereas the column on the right side (b) is additionally equipped with two layers of the packing with increased radial distribution. Their position is marked by a hatching. The liquid isotherms give information about the different distribution capability. For higher clarity, the isotherms are plotted at 2 °C intervals for all experiments with single point liquid feeding.

Fig. 4 (a) provides a good impression of the poor self distribution capability of a standard dumped packing. The almost vertical orientation of the isotherms indicates that the packing is not able to improve the initial non-uniform liquid distribution. The reason for this behavior is related to the high porosity of this modern version of a Pall-ring. Accordingly, the mass transfer is very unsatisfying. This is expressed by a value of H_{OG} = 1.55 m for the height of transfer unit.

The example with two packing layers with increased radial distribution, Fig. 4 (b), impressively shows the high rate of radial liquid spreading. Above the two packing layers the liquid flows almost completely in the center zone of the column due to the point source feeding. In this region the liquid temperature distribution is quite similar to the example on the left hand side. Below the two packing layers, however, the flow pattern is completely different. The packing with separate channels transfers the liquid flow pattern from the center to the wall zone on a big scale. This confirms the high radial distribution but simultaneously uncovers the high wall flow tendency of such a design. This is due to the fact that the liquid which reached the wall never flows back into the packing.

Packing Including Two Novel Elements with Increased Radial Distribution and Reduced Wall Flow

The insufficient performance of the packing elements with separated channels necessitates the enhanced design according to Fig. 1 with provisions that prevent the liquid from flowing to the wall. The performance of an implementation of the novel packing can be observed in Fig. 5. Again, the results are compared with an experiment in the same column without the novel packing elements. A visualization of this reference measurement is represented by Fig. 5 (a). The gas load is $F = 0.8 \sqrt{\text{Pa}}$, the liquid load B = 3.8 m/h. The random packing used in these tests consists of 25 mm Pall-rings made of stainless steel. The observed result when liquid is fed by a point source is quite similar to the example with the Raflux-Ring packing of Fig. 4 (a). The liquid flows down preferably in the center zone of the column. Therefore, a value of the height of transfer unit H_{OG} of 1.06 m expresses the poor mass transfer of the column with the single point liquid feeding.

In contrast to this, a very satisfactory result has been obtained with the two novel packing elements as shown in Fig. 5 (b). Their position is again marked by a hatching. For the same operating conditions, the column's mass transfer efficiency is quite high. The value for the height of transfer unit H_{OG} is as low as 0.47 m. This is nearly as good as the values that could be obtained by experiments with uniform initial liquid distribution.

The excellent performance of the novel packing elements can be apparently explained with the high distribution and the effective suppression of wall flow. Above the two layers the flow pattern is again very similar to the reference experiment shown in Fig. 5 a. The vertical orientation of the isotherms shows that the liquid remains in the center part of the column as impressed by the single point liquid feeding. Below the novel packing layers the distribution profile changes to horizontally orientated isotherms. Thus, the novel packing is able to compensate the heavy initial maldistribution without causing wall flow. This is prevented by the special design of the novel packing element that enables the phases to flow back from the wall zone. This mechanism, in addition to the high radial distribution, facilitates the formation of a distribution pattern that match, to a certain degree, a uniform profile. A second important fact can be read off the distribution pattern. Besides the distribution effect, the temperature decrease of about 2° C in the zone of the novel packing reveals that the novel packing elements contribute to mass transfer. These two features – the high radial distribution/radial mixing effect and the mass transfer contribution – provide the satisfying overall performance of the column in this experiment. Further experiments with various liquid and gas loads confirm this performance for higher flow rates, too.

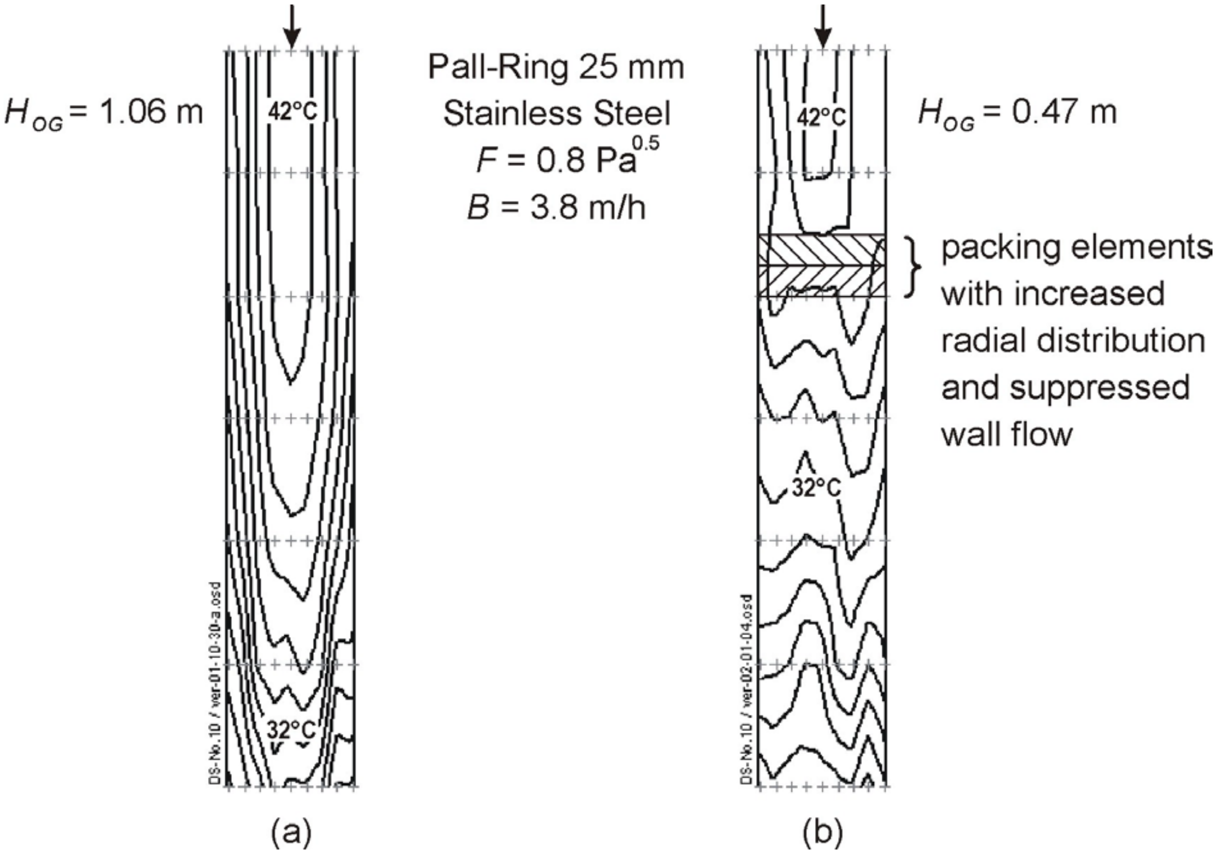


Fig. 5: Liquid isotherms within a packing of Pall-rings and point source liquid feeding. (a) Reference measurement with standard packing. (b) Measurement with the novel packing elements.

CONCLUSION

The implementation of a redistributing packing element with simultaneous mass transfer activity is a promising approach for the replacement of conventional redistribution sections. The novel design bases on a simple but effective design of separated channels. Experiments with a first version of a packing just with separated channels proves the importance to suppress wall flow. Thus, experiments were conducted with a prototype of the novel packing with all these specified features.

Based on preliminary results further investigations are initiated. The determination of the fluiddynamic characteristics and the attainable degree of mass transfer of the novel packing is one important feature. A second point concerns the possibility of an inexpensive and efficient fabrication because this is an important requirement for a successful application to industrial services.

NOMENCLATURE

a	specific area of a packing	[m^2/m^3]
B	liquid load	[$m^3/(m^2h)$]
d_{eq}	equivalent channel diameter $d_{eq} = 4\varepsilon/a$	[m]
F	gas load $F \equiv w_G \cdot \sqrt{\rho_G}$	[$\sqrt{Pa}$]
H_{OG}	height of a (vapor side) transfer unit	[m]
w_G	superficial gas velocity	[m/s]
ε	porosity	
ρ_G	gas density	[kg/m^3]

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