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Pressure drop of vertical plates with inclined capillary grooves for a redistribution packing layer of packed columns

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The uniform distribution of the liquid phase over the cross-section of a packed column is a major prerequisite for its effective operation. Regarding various distributor designs, the best uniformity is achieved with devices, where the liquid is divided into jets with equal flow-rates. The final liquid redistribution, to obtain uniformity over a cross-section area of the size of a packing element, takes place in the packing itself or in a specially designed redistribution layer. For this purpose a new packing, especially proper for low liquid superficial velocity, has been developed and investigated. It consists of parallel vertical polystyrene plates with inclined crossing capillary grooves stamped on their surface. In the present work experimental data for the pressure drop of the new redistribution packing at different gas velocities and liquid superficial velocities have been obtained and compared with data for other packings designed with the same purpose. The results prove that of all compared redistribution packings, the proposed packing is characterized by the lowest pressure drop which is connected with its advantage to change the direction of the liquid phase without changing the direction of the gas phase.

Key words: packed column, pressure drop, liquid distribution, redistribution layer, capillary grooves, comparison.

INTRODUCTION

Of all existing packing designs the packings with vertical walls and especially the honeycomb packings [1-3] are characterized by the lowest pressure drop for a mass transfer unit, but they have bad liquid distribution properties. With the purpose to operate as a redistribution layer over a basic layer of this type of packings, a new packing is developed and investigated [4-6]. It consists of vertical polystyrene plates with crossing inclined capillary grooves stamped on their surface, especially proper for low liquid superficial velocity. Changing only the direction of the liquid phase by adding a horizontal component to its velocity vector, it avoids the disadvantage of the existing redistribution packings with inclined walls [8-10] to turn also the direction of the gas flow which leads to increasing of the pressure drop. The aim of the present work is to investigate the pressure drop of the new packing and to compare it with the respective data for other redistribution packings.

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EXPERIMENTAL

For evaluation of the pressure drop of the proposed packing, experiments have been carried out with vertical plates with inclined grooves with a height of the packing elements of 90 mm, a distance between the grooves of 20 mm and groove angle 45^o. The grooves are with a square cross-section 2x2 mm with rounded corners formed by stamping on the groove surface. The pressure drop investigations are performed for dry packing and for liquid superficial velocities of $3x10^{-3}$- $21.4x10^{-3}$ $m^3/(m^2s)$, much higher than the operational regime range of the new packing applicable for superficial velocities one order lower (the values in Table 1) than the minimal experimental superficial velocity. The measurements are obtained in these regimes with the purpose of comparing with the available data for other redistribution packings.

The pressure drop of the packing was measured in a packed column with a cross-section of 175×225 mm at a total height of the packing of 1170 mm. The liquid was regularly distributed by means of a shower type distributor located in an enlargement of the column top.

The results for the pressure drop of a layer 1 m high, $\Delta P/H$, where ΔP, Pa, is layer pressure drop and H, m,- total height of the packing, are given in Fig. 1 and compared to data for the pressure drop of inclined Raschig rings [8]. The geometrical characteristics of the rings are as follows: an outside diameter of 49.1 mm, an element height of 41.2 mm and an inclination angle of 16^o. Of all investigated inclined ring packings the described one is characterized by lowest pressure drop for a given degree of redistribution [8]. The lines for the pressure drop of the inclined rings 2', 3', 4' are interpolated from the experimental data in order to compare the pressure drop of the two packings at equal liquid superficial velocities L, m^3/(m^{2}s). The original data in [8] are measured for L=0; 2.3x10^{-3}; 3.3x10^{-3} and 6.4x10^{-3} m^3/(m^{2}s) at the same range of gas velocities w, m/s. It is seen that at a given gas velocity w and liquid superficial velocity L the pressure drop of 1 meter layer of inclined rings is about 40% higher than of the new packing with grooves.

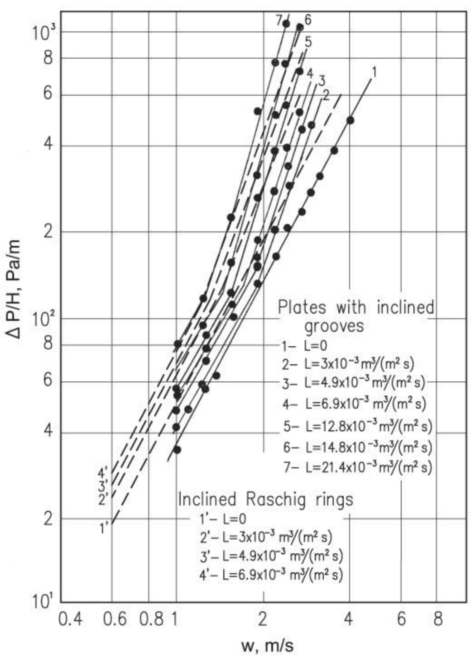


Fig. 1. Pressure drop of plates with inclined grooves and inclined Raschig rings [8] versus the gas velocity at different liquid superficial velocities.

The pressure drop of a redistribution layer with a height h_l ensuring a given degree of uniformity of the liquid superficial velocity is expressed by $\frac{\Delta P}{H} h_l$. The pressure drop of the proposed new redistribution packing layer is compared to the layer pressure drop of the following redistribution packings from literature: arranged packing of inclined ceramic Raschig rings with an outside diameter of 49.1 mm, an element height of 41.2 mm and an inclination angle of 16^o, [8], Fig. 2; block packing of inclined plastic sheets with an inclination angle of 22^o, [9], Fig. 3; inclined ceramic honeycomb packing with an inscribed circle diameter of 27 mm, an element height of 49 mm and inclination angle of 24^o, [10], Fig. 4. The compared data for each type of packing are chosen for these inclination angles of packing elements which are found to be the optimal for the efficiency of the respective picking.

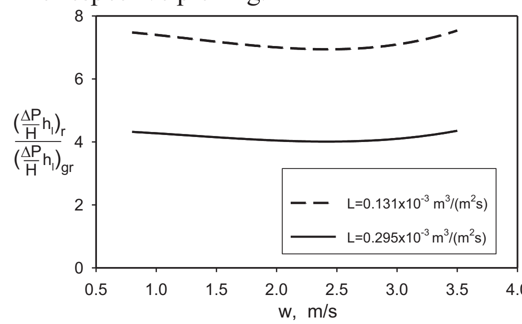


Fig. 2. Ratio of pressure drop of packing layer with inclined Raschig rings [8] to pressure drop of packing layer with grooves $\left(\frac{\Delta P}{H} h_l\right)_r \Big/ \left(\frac{\Delta P}{H} h_l\right)_{gr}$ versus gas velocity at different values of liquid superficial velocity.

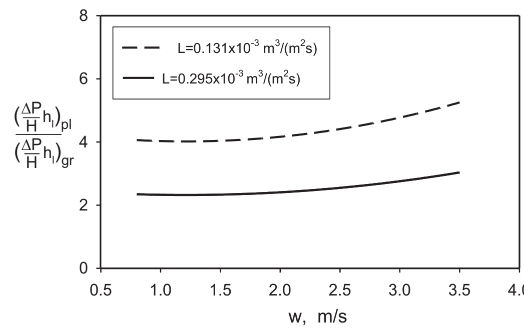


Fig. 3. Ratio of pressure drop of packing layer with inclined plates [9] to pressure drop of packing layer with grooves $\left(\frac{\Delta P}{H} h_l\right)_{pl} \Big/ \left(\frac{\Delta P}{H} h_l\right)_{gr}$ versus gas velocity at different values of liquid superficial velocity.

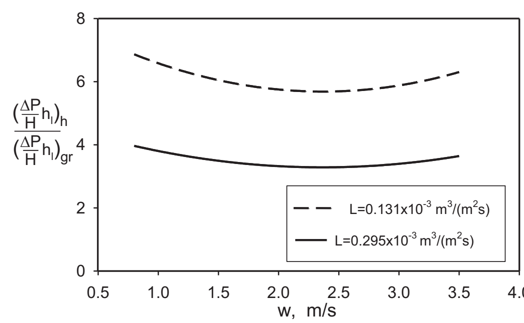


Fig. 4. Ratio of pressure drop of layer with inclined honeycomb packing [10] to pressure drop of packing layer with grooves $\left(\frac{\Delta P}{H} h_l\right)_h \Big/ \left(\frac{\Delta P}{H} h_l\right)_{gr}$ versus gas velocity at different values of liquid superficial velocity.

RESULTS AND DISCUSSION

The heights of the redistribution layers of the compared packings, Table 1, are calculated in [6] at two distances l, m, between the drip points. The liquid superficial velocity is determined as $L=Qn$, where $Q=3.7\text{x}10^{-6}$ m^3/s is the maximal flow-rate the grooves under a drip point can take up without liquid overspilling, calculated in [6] for the considered groove sizes, and n is the number of drip points per square meter of the apparatus cross-section determined from the distance between the drip points as $n=1/l^2$. The comparison is performed using the pressure drop experimental data $\Delta P/H$ for dry packing $L=0$, assuming that for these extremely low superficial velocities the error of calculation with the pressure drop for dry packing is negligible.

The heights of the redistribution layer of plates with grooves in Table 1 are half of the heights obtained in [6] for the same distances between drip points. The calculated height necessary for liquid phase regular distribution is doubled in [6] because the crossing grooves distribute the liquid phase only in one vertical plane and the packing layer should comprise two rows of parallel plates, the plates of the second row perpendicular to the first. But this is not valid when the role of first row is performed by the vertical plates with stamped grooves mounted as a part of the liquid phase distributor [6, Fig. 1]. In that case in the redistribution layer only one row of plates is necessary because the upper row of plates included in the distributor construction spread the liquid in planes perpendicular to the row below. Because the distance between the vertical plates in the distributor is significantly greater, than this in the redistribution packing layer, the flow-rate in the distributor grooves should be greater too. That is why to keep similar hydrodynamic regime in these grooves, each of them should be composed of several single parallel channels like those in the redistribution packing layer. It should be mentioned that the pressure drop of the liquid distributor is negligibly low due to its great free cross-section.

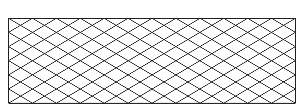
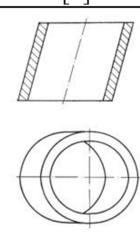
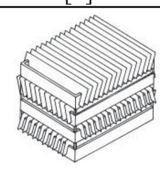
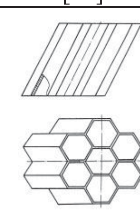
The layer heights of the compared packings from the literature [8-10], Table 1, are obtained in [6] by the relation:

$$h = 0.09695\frac{l^2}{D} ,$$

proposed in [11] using the simple model of Kolev [12], where l, m is distance between drip points and D, m, is radial liquid spreading coefficient.

Fig. 2 shows that the pressure drop of a redistribution layer of the proposed packing with grooves $\left(\frac{\Delta P}{H}h_l\right)_{gr}$ for the same degree of uniformity after it and gas velocity is lower over 4 times at $L=0.295\text{x}10^{-3}$ m^3/(m^{2}s) and over 7 times at $L=0.131\text{x}10^{-3}$ m^3/(m^{2}s) than the pressure drop of a redistribution layer of Raschig rings $\left(\frac{\Delta P}{H}h_l\right)_{r}$. The indices gr and r denote plates with grooves and rings respectively.

Table 1. Comparison of packing layer heights calculated in [6] ensuring uniform flow-rate distribution as a function of the distance between the drip points.

Distance between drip points l, m	Superficial velocity L m^3/(m^{2}s) $\times 10^3$	Packing layer height h_l, m					
		Plates with inclined grooves 45°	Plates with inclined grooves 30°	Plates with inclined grooves 15°	Inclined Raschig rings, 16° $D=2.85\times10^{-3}$ m, [8]	Inclined plastic sheets, 22° $D=1.4\times10^{-3}$ m, [9]	Inclined ceramic honeycomb packing 24° $D=2.67\times10^{-3}$ m, [10]
							
0.112	0.295	0.140	0.07275	0.03375	0.4267	0.8687	0.4555
0.168	0.131	0.182	0.11315	0.0525	0.9601	1.9545	1.0248

The results of similar comparison in Figs. 3 and 4 with other redistribution packings from literature are the following:

- The pressure drop of the new redistribution layer is lower over 2 times at L=0.295x10^{-3} m^3/(m^{2}s) and over 4 times at L=0.131x10^{-3} m^3/(m^{2}s) than the pressure drop of a redistribution layer of plate packing, $\left(\frac{\Delta P}{H} h_l\right)_{pl}$, Fig. 3. The index *pl* denotes plate packing.

- The pressure drop of the new redistribution layer is lower over 3 times at L=0.295x10^{-3} m^3/(m^{2}s) and over 6 times at L=0.131x10^{-3} m^3/(m^{2}s) than the pressure drop of a redistribution layer of honeycomb packing $\left(\frac{\Delta P}{H} h_l\right)_{h}$, Fig. 4. The index *h* denotes honeycomb packing.

CONCLUSION

Experimental data for the pressure drop of a new packing, designed to operate at low liquid superficial velocity as a redistribution layer of a packed bed column, are obtained and a comparison with other redistribution packings from literature is carried out. The results show that at liquid superficial velocity of 0.131x10^{-3} m^3/(m^{2}s) the pressure drop of the proposed new packing layer at the same gas velocity and redistribution degree is over 4 times lower than that of inclined ceramic Raschig rings [8], over 2 times lower than that of inclined plastic plates [9] and over 3 times lower than that of inclined ceramic honeycomb packing [10] when using a usual type of liquid phase distributor.

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ХИДРАВЛИЧНО СЪПРОТИВЛЕНИЕ НА ВЕРТИКАЛНИ ПЛАСТИНИ С НАКЛОНЕНИ КАПИЛЯРНИ КАНАЛИ ЗА ПРЕРАЗПРЕДЕЛИТЕЛЕН ПЪЛНЕЖЕН СЛОЙ В КОЛОНИ С ПЪЛНЕЖ

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(Резюме)

Равномерното разпределение на течната фаза по напречното сечение на колоната с пълнеж е основна предпоставка за ефективна работа на апарата. Сред съществуващите оросителни устройства най-добра равномерност се постига при тези от тях, които разпределят течността на струйки с равни дебити. Крайното преразпределение до равномерност по напречно сечение с размери от порядъка на пълнежен елемент се осъществява в самия пълнеж или в специално конструиран преразпределителен пълнежен слой. За тази цел е разработен и изследван нов пълнеж, особено подходящ за ниски плътности на оросяване. Той се състои от успоредни вертикални пластини с наклонени пресичащи се капилярни канали, щамповани върху тях. В настоящата работа са получени експериментални данни за хидравличното съпротивление на новия перерезпределителен пълнеж при различни скорости на газа и плътности на оросяване. Сравнението с данни за други съществуващи пълнежи със същото предназначение доказва, че хидравличното съпротивление на предложеният пълнеж е най-ниско, което се дължи на неговото предимство пред сравняваните перерезпределителни пълнежи да променя посоката на течната фаза без да променя посоката на газа.