ON THE AUTOMODEL PROPERTIES OF THE COUNTER-CURRENT REGULARLY STACKED TRICKLE BED COLUMNS

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An approach utilizing the automodel properties in describing the hydrodynamic behaviour of counter-current columns has been extended to regularly stacked beds. Two new kinds of the packing have been investigated: The so-called K-packing, developed in the German Democratic Republic and the Cellular packing, developed in Poland. The results of experiments have been presented in the form of plots of the normalized liquid hold-up, $\bar{h}_p$, *versus* the normalized liquid velocity, $\bar{Q}_l$, and two empirical correlations. A comparison with previous results with randomly packed counter-current trickle bed columns has also been made.

There is no doubt that a simple versatile correlation enabling evaluation of liquid hold-up in counter-current packed columns would be attractive particularly from the practical point of view. Unfortunately, due to the complexity of the gas liquid flow through the bed of packing, description on the basis of a physical model is at present practically impossible. An automodel behaviour approach seems to offer a plausible alternative to circumvent this difficulty.

A clearly defined flooding point representing a point of transition between two widely different regimes of the column operation may well represent a critical point in the multidimensional space of variables defining the different phase flow rates and packing and gas–liquid system properties.

In earlier studies[1,2] it has been found that in random beds the normalized liquid hold-up, related to the flooding point, is with reasonable accuracy a versatile function of the normalized liquid flow rate independent of the gas rate, gas–liquid physical properties, and the geometry of the system. Different systems thus behave identically in the same relative distance from the flooding point.

The aim of this work has been to find out whether the automodel approach is also applicable to regularly stacked counter-current trickle beds.

EXPERIMENTAL

The functional relationship between liquid hold-up and gas and liquid flow rates has been investigated experimentally in a column suspended on a tensometric balance. Detailed description of the experimental set-up and the method of measurement have been presented in previous communications[3–7].

Two different kinds of regularly stacked packings have been used in the experiments. The first, the so-called K-packing, was developed in the Bergakademie Freiberg, GDR. Its principal advantages are the resistance to agressive agents (ceramics), relatively low pressure drop and low total weight, associated with high fraction (approximately 0·81). Sketch of a single piece of K--packing 25 × 15 × 2 mm (width × height × thickness) is shown in Fig. 1. Due to the conical shape the packing exhibits a relatively high degree of utilization of the available surface. By now its mass transfer efficiency has been tested both on the laboratory and pilot plant scale[8].

The K-packing may be generally used in the random or the stacked mode. In this work the packing was regularly stacked into a column 90 mm in internal diameter. The outward protruding ribs (Fig. 1) serve to lock into the adjacent pieces and packets of a single piece height were then stacked into the column. Individual packets were placed into the column with the top face of the packing elements (Fig. 1) facing the column bottom.

The second packing, the so-called Cellular packing, was developed in the Silesian Technical University in Gliwice, Poland[9,10]. It is again a packet type packing of fairly simple construction. Each packet is essentially a honeycomb structure of rectangular cells. Sketch of a single cell 20 × 50 × 3 mm (width × height × slit) is shown in Fig. 2. Two opposite vertical walls of the cell are bent inwards forming a bottom of the cell with a slit. The other two vertical walls of the cell are bent outwards and each forms half of the bottom with a slit in the adjacent cell. The packets are manufactured from strips of metal sheet os that, in fact, the packet cannot be disassembled into individual cells like the one shown in Fig. 2.

The packed section of a 200 mm in diameter column consisted of a number of such packets stacked on top of each other with the two neighbouring packets being always turned by 45 degrees with respect to each other. This arrangement provides for good mixing within the packed section

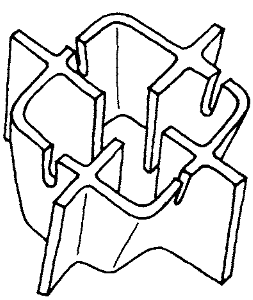

FIG. 1

Sketch of a single piece of K-packing

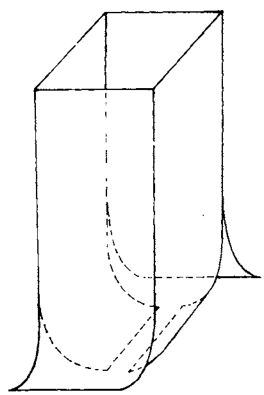

FIG. 2

Sketch of a single cell of the packet of cellular packing and good distribution of liquid over the area of cross section. The pressure drop of the packing is quite low thanks to the high void fraction ranging between 0·90 and 0·96. The Cellular packing has been found to work well over a wide range of gas and liquid rates[11].

In case of both investigated packings the height of the packed section was 1 m. The counter--currently flowing gas was in all cases air. Three kinds of liquids were used to irrigate the packing: water, saturated water solution of isobutanol, and 50% water solution of technical glycerol. Physical properties of these liquids, as well as the ranges of air and liquid rates covered in the experiments are summarized in Table I.

RESULTS AND DISCUSSION

The experiments yielded directly the hold-ups and pressure drops as functions of the gas superficial mass velocity, Q_g, at constant liquid rate. The trends of the obtained dependences were in agreement with similar data published in the literature[12,13].

The first step of the processing was the evaluation of the characteristics of the flooding point based on the data from a pressure transducer with its tap located just above the packed section. Details of this evaluation may be found elsewhere[1,2,6,7].

The experimentally determined dependences of the hold-up, $h_p = h_p(Q_g)$, at constant superficial liquid mass velocity, Q_l, were then computationally converted, using linear interpolation, into the dependences of the hold-up on the superficial liquid velocity at constant gas rate, *i.e.* $h_p = h_p(Q_l)$ at constant Q_g.

The converted data were in turn transformed to normalized form, $\bar{h}_p = \bar{h}_p(\bar{Q}_l)$, using corresponding values of the hold-up and liquid superficial mass velocity at flooding, h_{pf}, Q_{lf}.

Resulting normalized dependences for K-packing are shown in Fig. 3. Fig. 4 shows analogous dependences for the Cellular packing. Graphical symbols distinguish between different in liquids used in the experiments. The limited number of the points for the Cellular packing in Fig. 4 is the result of our inability to flood

TABLE I

Properties of liquid used and ranges of gas and liquid rates covered in experiments

Liquid in 20°C	ϱ kg/m^3	η mPa . s	σ mN/m	Q_g kg/m^{2}s	Q_l kg/m^{2}s
Water	998·2	1·005	72·90	0 ÷ 2·18	11·03 ÷ 134·26
Water solution of isobutanol	983·9 ÷ 986·3	1·337 ÷ 1·586	25·64 ÷ 26·12	0 ÷ 1·53	16·34 ÷ 101·69
Water solution of technical glycerol	1123·5	6·440	55·43	0 ÷ 2·48	4·96 ÷ 136·52

the Cellular packing bed at low and medium liquid rates owing to its extremely high void fraction. Thus we were unable to determine in these cases the flooding point data and, accordingly, only a smaller part of the experimental data could be converted and plotted in Fig. 4.

From Figs 3 and 4 it is seen that with an accuracy acceptable for technical purposes the hold-up of liquid in the coordinates $\bar{h}_p$, $\bar{Q}_l$ may be regarded independent of the gas velocity and physical properties of the irrigating liquid.

The above plotted data were correlated by a one-parameter straight line and a three-parameter cubic parabola of the type:

$$\bar{h}_p = 1 + A(\bar{Q}_l - 1), \quad (1)$$

$$\bar{h}_p = B + (1 - B)\,\bar{Q}_l + C(\bar{Q}_l - D)(\bar{Q}_l - 1)\,\bar{Q}_l. \quad (2)$$

The form of these correlations ensures that they both pass through the point (1, 1) in the $(\bar{h}_p, \bar{Q}_l)$ plot.

Optimum values of the parameters of the above correlations for various groups of data are summarized in Table II, together with corresponding standard deviations.

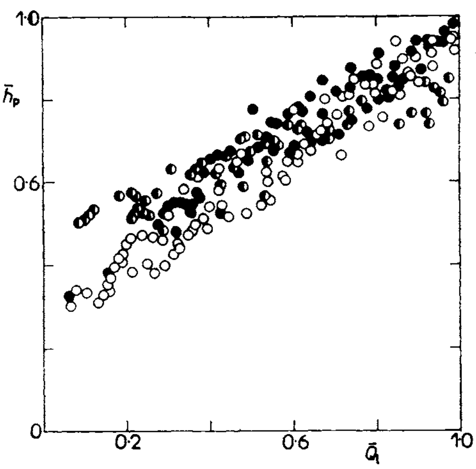

FIG. 3

Plot of normalized hold-up *versus* normalized liquid velocity 25 × 15 × 2 mm K-packing; ○ water, ● saturated water solution of isobutanol, ◐ water solution of technical glycerol

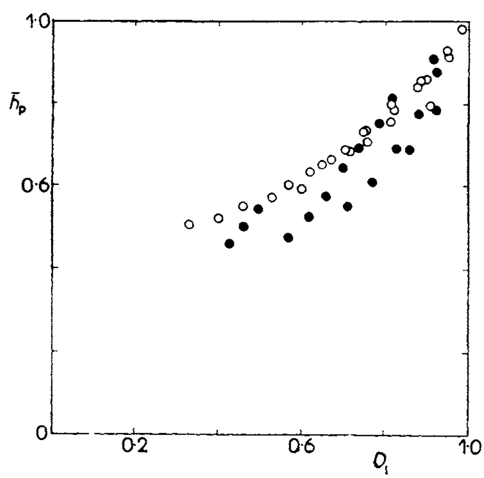

FIG. 4

Plot of normalized hold-up *versus* normalized liquid velocity 20 × 50 × 3 mm cellular packing; ○ water, ● saturated water solution of isobutanol

From the tabulated data, and in fact also from Figs 3 and 4, it may be seen that particularly for foaming liquids Eq. (2) gives a better fit. The explanation for the slightly S-shaped course of the data points may be following. Formation of the foam intensifies with increasing liquid velocity and causes a relatively slower increas of the hold-up because part of the liquid is being dispersed in the gas phase. It is likely that the employed tehnique of measuring the hold-up, in fact, does not reflect the liquid held as a foam. In the above results the tendency to form foam is, of course, maximal in case of surface active agents contaminated technical glycerol.

Optimum values of parameters of the correlation (2) presented in Table II for K-packing indicate that B and D change little with the physical properties of liquid. Most conspicious change is seen in the value of the parameter C, reflecting the degree of curvature of the curve. Thus maximum value of C is found for the solution of technical glycerol having, as noted above, maximum tendency to foaming. On the

TABLE II

Coefficients of correlations

Correlation		Eq. (*1*)		Eq. (*2*)			
Liquid	Packing	A	δ	B	C	D	δ
Water	K-packing	0·770	0·0510	0·183	0·905	0·575	0·0503
Water solution of isobutanol	K-packing	0·697	0·0452	0·163	1·123	0·791	0·0427
Water solution of technical glycerol	K-packing	0·623	0·0783	0·157	3·736	0·606	0·0712
Three above liquids summarily	K-packing	0·700	0·0677	0·200	1·677	0·606	0·0657
Water	Cellular packing	0·927	0·0561	0·047	1·921	0·608	0·0236
Water solution of isobutanol	Cellular packing	1·142	0·0906	0·014	2·255	0·486	0·0579
Two above liquids summarily	Cellular packing	1·015	0·1318	0·086	1·968	0·501	0·0511
The above liquids summarily	K-packing and Cellular packing summarily	0·719	0·0789	0·199	1·855	0·579	0·0700
Four different liquids summarily, see ref.[2]	three types of random packings of dofferent sizes summarily, see ref.[2]	0·861	0·0670	0·169	0·757	0·372	0·0585

other hand, a comparison of the standard deviations for the straight line and the cubic parabola indicates that a change from the one-parameter to the three parameter curve causes only a minor improvement even for the glycerol solution where the difference is maximal.

For practical purposes it is thus justifiable to settle for the straight line. Inspection of values of the parameter A for K-packing well confirms the earlier conclusion of the versatility of the correlation with respect to the properties of the trickling liquid. Optimum values for all liquids on K-packing summarily are given in the fourth line of Table II.

Optimum values of the parameter A for the Cellular packing and two liquids used are distinctly higher. In fact, optimum A in excess of unity, as is the case for water solution of isobutanol, is physically meaningless (negative hold-up at low irrigation rates). In the low liquid rate region these data must be regarded as only qualitative for the experimental points that could be obtained for technical reasons covered only the upper right hand side of the plot (Fig. 4).

CONCLUSION

The obtained experimental data on the hold-up of liquid in counter-current regularly stacked packed bed systems for two kinds of packings and three kinds of liquids seem to support the idea of the automodel behaviour even in these systems.

With reasonable accuracy the empirical correlation, with its parameters independent of the gas velocity, physical properties of irrigating liquid, and (with some reservation) type of the stacked packing, can be used to calculate liquid hold-up (the eighth line in Table II). In view of the limited number of regular packings used and the limited range of liquid rates covered in case of the Cellular packing, use of the more complex correlation (Eq. (*2*)) is not fully justified and the one-parameter straight line should be at present more adequate. On the other hand, the standard deviation of the simpler one-parameter correlation impairs only by about 11% (data in the eighth line of Table II).

A comparison of the versatile correlations for the regularly stacked packings (line 8) and for the earlier studied[2] random packings (line 9 of Table II) shows that there is a difference, which, for instance, for the parameter A exceeds the standard deviation of the correlation.

A correlation "versatile" for regular as well as random packing would have the standard deviation at a level of about 10%. Although this might be still acceptable for technical purposes, it is felt that a further investigation into the role of the foaming would be more appropriate. This opinion is strengthend by the fact that in packings which fundamentally differ in void fraction (large/small for regular/ /random beds) the so far not quite understood role of foaming may be crucial.

LIST OF SYMBOLS

A, B, C, D	parameters of correlations in Eqs (*1*) and (*2*)
h_p	hold-up in packed section
h_{pf}	hold-up at flooding
$\bar{h}_p = h_p/h_{pf}$	normalized hold-up
Q_g	superficial gas mass velocity, kg/m^2s
Q_l	superficial liquid mass velocity, kg/m^2s
$\bar{Q}_l = Q_l/Q_{lf}$	normalized liquid velocity
δ	standard deviation
η	viscosity, mPa . s
σ	surface tension, mN/m
ϱ	density, kg/m^3

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