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BRIEF ARTICLE

Experimental Study of Liquid Distribution in Packed Column

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Abstract. This work presents the results of an experimental study of liquid distribution for the air/water system, carried out in 0.3m diameter Perspex column packed with 25mm plastic pall rings of equal length and diameter. Measurements of flow rates were performed at different radial and axial positions at the end of the column. The column was operated with gas flow rates varying over the ranges of 0.0 to 1.2kg/m²s, liquid flow rates varying over the range 9.9 to 19.9kg/m²s and with the ratio of the initial flow to the bulk and wall regions varying between 0. 8 and 0.5. The packing height was increased by the addition of a fixed amount at a time, until a height of 1.05m was reached.

Notation

r	radial coordinate
r_i	radius of bulk region
l	thickness of bed
R	dimensionless radial coordinate r/r_i
L	dimensionless length l/r
G	gas flowrate to column
Q	liquid flowrate to column
γ	fraction of liquid distributed uniformly over bulk region
ψ	axisymmetric stream function
ψ/ψ_T	ratio of experimental stream functions

Introduction

Packed columns are often employed in the chemical industry both for separation processes and for chemical reactions. The principal purpose for their use is to bring about an intimate contact between two fluids. The design of these units is sensitive to the porosity of the bed. Knowledge of physical processes occurring inside packed columns is essential for accurate design, testing models and theories of mixing and mass transfer and for upgrading the existing equipment.

A multi-point liquid distributor is designed to study the effects of: i) Liquid flow rates. ii) Counter current air flow rates. iii) Initial distribution i.e. liquid fraction injected in the bulk region. Interstitial velocities are measured so that experimental stream functions may be determined at different radial positions. The stream functions are needed in the analysis of the data.

State of the Art

Until quite recently, the standard methods for design procedure and estimation of performance of packed columns were based on the theory developed by Walker, Lewis and Mc Adams [1]. Their theory was unsatisfactory because it was based on the assumption that a 'uniformly' distributed liquid passed through the column in plug-flow. This led to a large errors in determining the depth of packing required. Numerous experiments have shown [2-4], however, that the distribution of the liquid over the cross-section of the column is not uniform. This is due to channeling in the packing and differences in permeability between the wall region and the bulk region.

Many attempts have been made to redistribute the liquid by some means across the column [5,6]. The early experiments were carried out using a center point source irrigation of the bed, then a line source, until it has come to the modern distributors which provide at least 45 distribution points per m^2. The non-uniformity of the distribution across the column is always there for certain depth of the column, no matter the uniformity of initial distribution applied at the top.

Experimental Apparatus

A line diagram of the apparatus is shown in Fig. 1. The column was held firmly by four tie rods, between a thick perforated brass plate at the bottom of the tube and a steel flange at the top of the tube. The brass plate had four annular grooves on either face in contact with the plate. The grooves in the bottom face were used to fix the four concentric perspex tubes, that found part of the liquid collector.

Liquid was supplied to the column from a constant head tank through a bank of rotameters connected in parallel , and then passed to a brass box resting on the top of three legs fixed to the brass distributor plate. The box, which was placed above the nozzles, contained 5mm diameter Raschig rings, intended to dissipate the kinetic energy of the liquid flowing to the bulk of the packing. A sketch of the distributor is shown in Fig. 2. It consisted of two concentric perspex tubes fixed at their lower end to a brass plate. The inner perspex tube constitutes the bulk region, while the annular section between the two tubes constitutes the wall region. The brass plate contained a large number of copper tubes of 4.76mm diameter with a thin brass disc containing a small diameter orifice plate fixed to the top of each copper tube. There were 98 orifices in the bulk and 42 in the wall region. Eighteen copper tubes of 12.7mm, I.D, were passed through the distributor and the brass box to provide vents for the counter-current gas flow.

For the measurements of interstitial velocities, three calibrated tanks of equal volumes were placed beneath the outlets of the liquid drain pipes, which discharged the liquid from the annular section. For this purpose, a perspex tube 6mm I.D, with three pairs of electrodes, was fixed slant-wise in each tank along one of its inner faces. The arrangement is shown in Fig. 3. The first electrode is for starting the signal, while the other two pairs of electrodes were used for stopping the signal.

In the study of the effects of counter-current gas flow, compressed air at 21 kPa was used. The pressure was then reduced to 11 kPa before feeding to a bank of rotameters. The structural properties of the column, as well as the range of operating conditions used in this work, are summarized in the appendix.

Experimental Procedure

The experiments were designed to measure the liquid flowrates at different radial positions in the column. Liquid was metered to the column by a bank of rotameters and the flowrates to the wall and bulk regions were measured separately. The flow measuring devices were used to determine the relative amounts of liquid flowing from different annular sections, while the flow from the central section was measured with a graduated cylinder and stop-watch. In each experimental run, a comparison was made between the total amount of the liquid collected at the bottom of the column and the total amount of liquid measured by the rotameters and fed at the top of the column. If the discrepancy between the two measurements was found to be greater than 2%, then that run was discarded and the experiment was repeated. The bed height was varied by a fixed amount (15cm) at a time. The total liquid flow to the column was changed over a range of flowrates above the minimum wetting rate. The range extended from 9.9 to 19.9kg/m^{2}s and the proportion of the liquid supplied initially to the bulk region was varied over the range 0. 5 to 0. 8. All experiments were carried out with air and water. The air flowrates varied over the ranges of 0.0 to 1.2kg/m^{2}s.

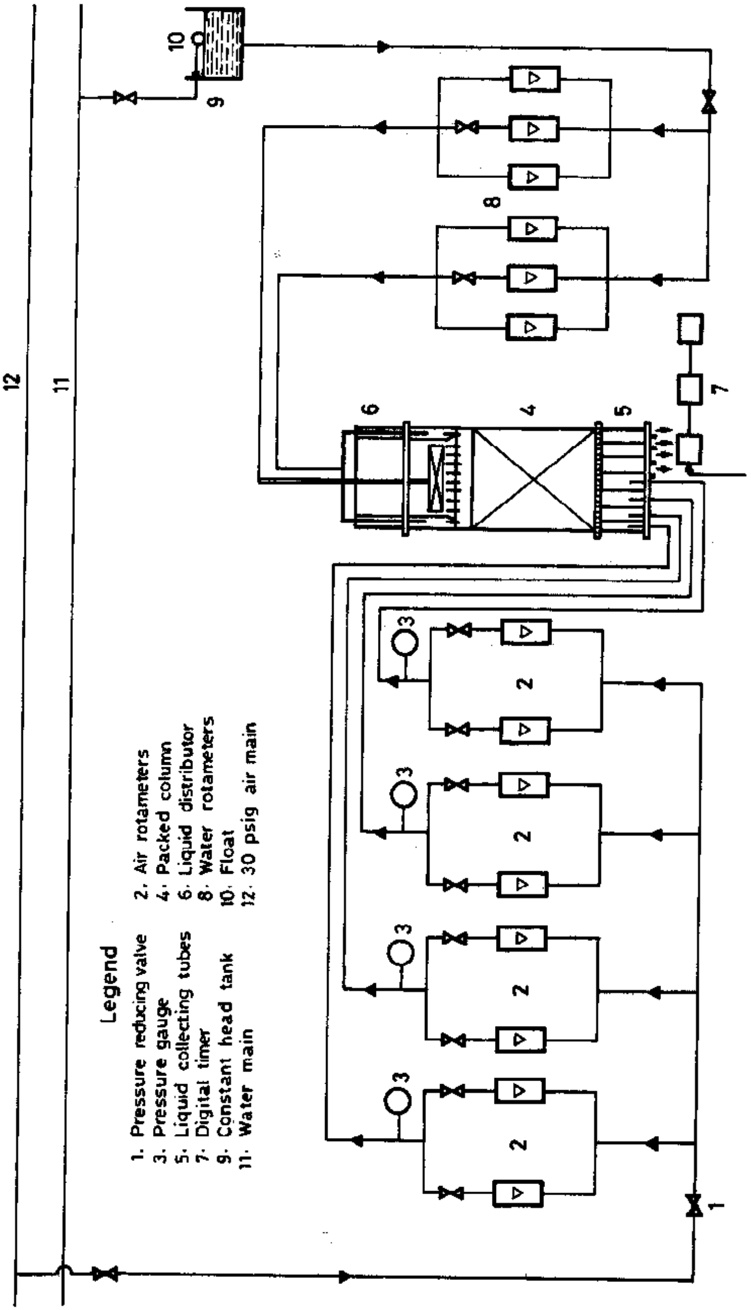

Fig. 1. Line diagram of the apparatus.

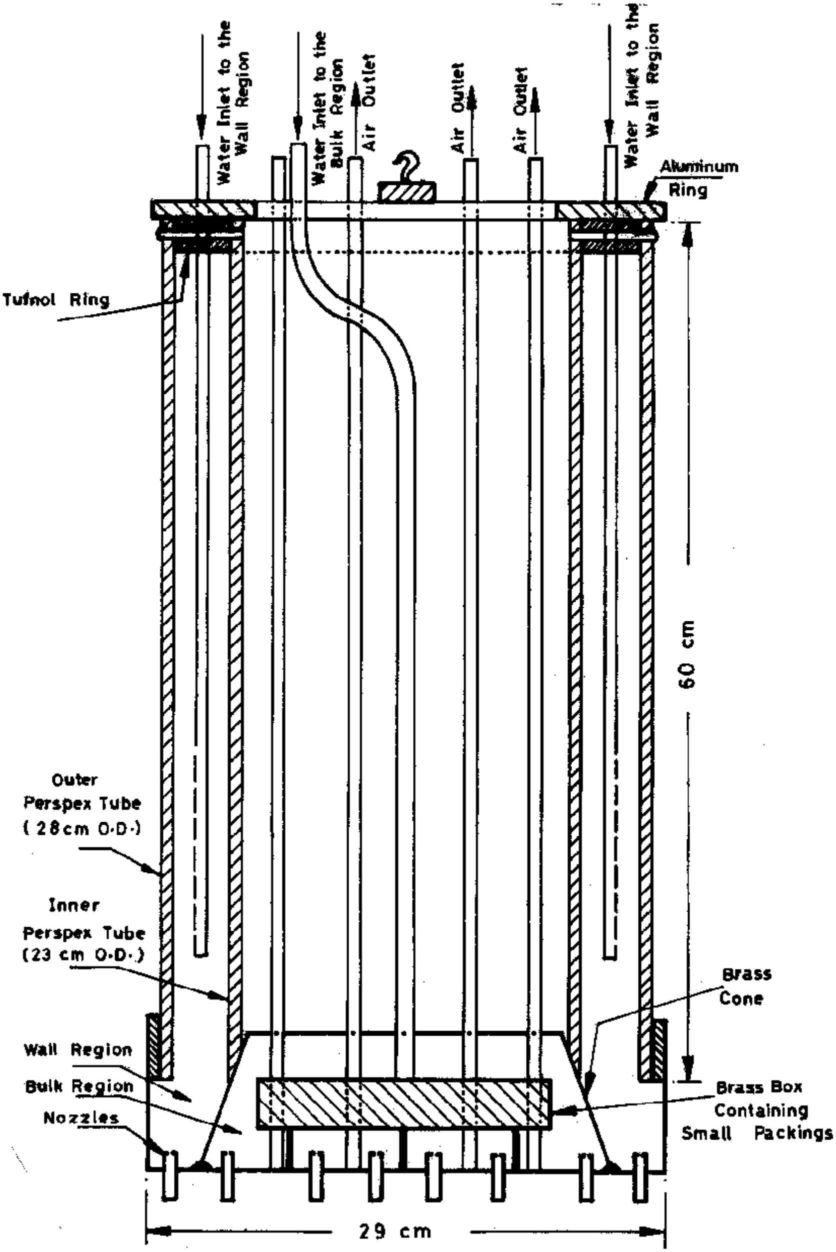

Fig. 2. Liquid distributor.

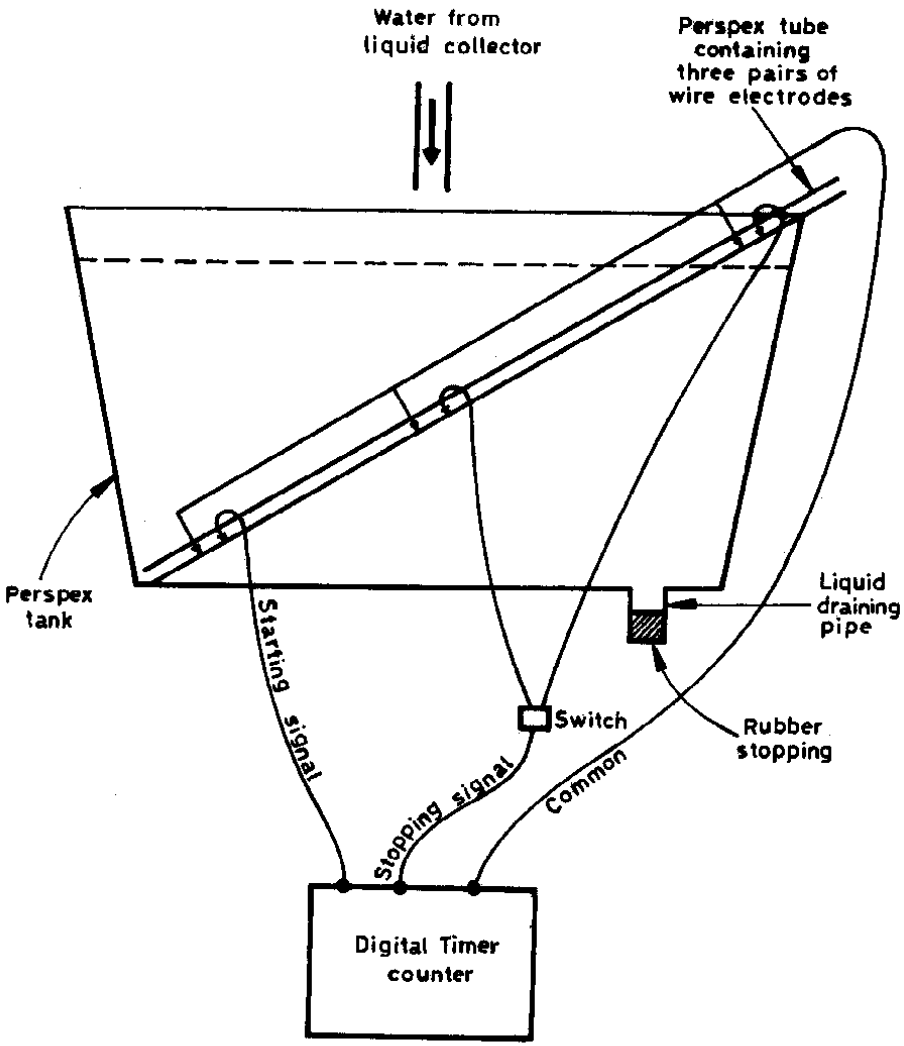

Fig. 3. Sketch of the flow measuring system.

Results and Discussion

The application of the diffusion equation for the description of the liquid distribution in a packed columns underlines the importance of permeability differences between the bulk and wall regions and permits the determination of the stream function ‘ψ. The effect of the wall , which confines the packing and changes the random arrangement of the packing near the wall, alters the void fraction in the radial direction creating different permeabilities between the wall region and bulk zone of the packed column. The values of ψ/ψ_T at different L and R, for fixed values of G, Q and γ are given in Figs. 4-11. The ψ/ψ_T are computed as the ratio of liquid collected at any radial position to the total incoming liquid into the column. Each graph shows the ψ/ψ_T versus L at different R and using parameters such as gas flowrates, total liquid flowrates and initial distributions.

Figures 4-11, show that when the value of L is 2.5 times the column diameter the value of ψ/ψ_T at each R is constant. This means that equilibrium values have been established so that equal distribution over the cross-section of the column is obtained. Dutkai and Ruckenstein [8] reported the necessity of using a small depth of packing to establish the equilibrium condition in the presence of gas flow. However, Scott [9] observed the distribution change continued over a height equal to 40 times the column diameter. In all plots, the deviations from the equilibrium value increase as R increases from (0.16 - 0.85). A maximum deviation of 30 % from the equilibrium value is obtained in Fig. 4 when $\gamma = 0.8$ and R=0.85. The establishment of constant distribution in Fig. 4 at R= 0.85 when G= 0.0 kg/m^{2}s requires a depth of packing 0.5 L higher than for G=1.2 kg/m^{2}s. Figure 7 gives a 9% deviation from equilibrium value at R=0.85. On the other hand, Figs.6,7 indicate that the wall flow equilibrium condition is established at L=3 instead of L=5 as in the cases of Figs. 4,5. This is due to the lower initial distribution rates which provided a higher supply of liquid to the wall region. Figures 4 -11 indicate that gas flow rate has a slight effect on distribution for this packing, as it is increased, it shifts the ψ/ψ_T values 5% upwards and downwards depending on γ. This signifies that the operation is very close to the flooding point and more transfer of liquid is occurring. The effect of γ is shown by Figs.8,9. This shows that the redistribution of liquid before equilibrium at R=0.85 is greater in the case of γ =0.8. A slight effect of Q is shown by Fig. 6, where ψ/ψ_T is 5% higher than its corresponding value in Fig. 7. Both figures show liquid flowing from the wall to the bulk region. Because the permeability of the packing in the wall region is greater than that in the bulk, liquid evenly distributed over the top surface will drain more freely in the wall region. Figures 8 and 9 show the effect of γ, with 5% higher ψ/ψ_T obtained at higher γ and 5% lower ψ/ψ_T at lower γ. On the other hand, at a lower value of γ the wall equilibrium condition is established in a shorter depth of packing (L=3). Similar trends of experimental behaviour are shown in Figs. 10 and 11. For higher γ {0.725 - 0.8] liquid flows from the bulk to the wall regions, while for lower γ [0.6 - 0.5] the liquid flows in the reverse direction. The extent of liquid flow in either case is great for high values of γ .

Conclusions

The results of experimental work on liquid distribution, measured at the base of a 0.3 m diameter perspex column packed with 25mm plastic pall rings of equal length and height, for different values of initial distributions, liquid flowrate, gas flowrate and depth of packing are shown in Figs. 4-11. The experimental results show that the establishment of equilibrium

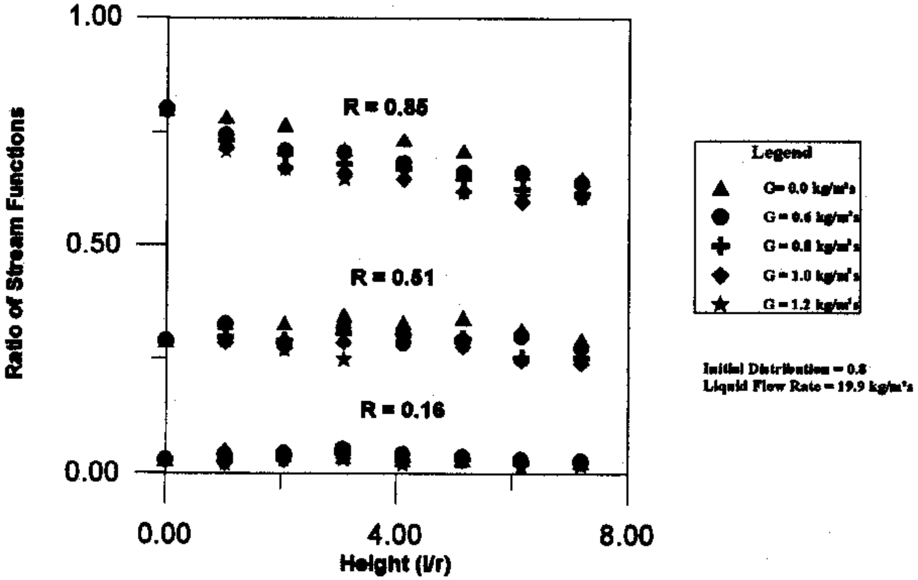

Fig. 4. Experimental stream functions for different gas flow rates.

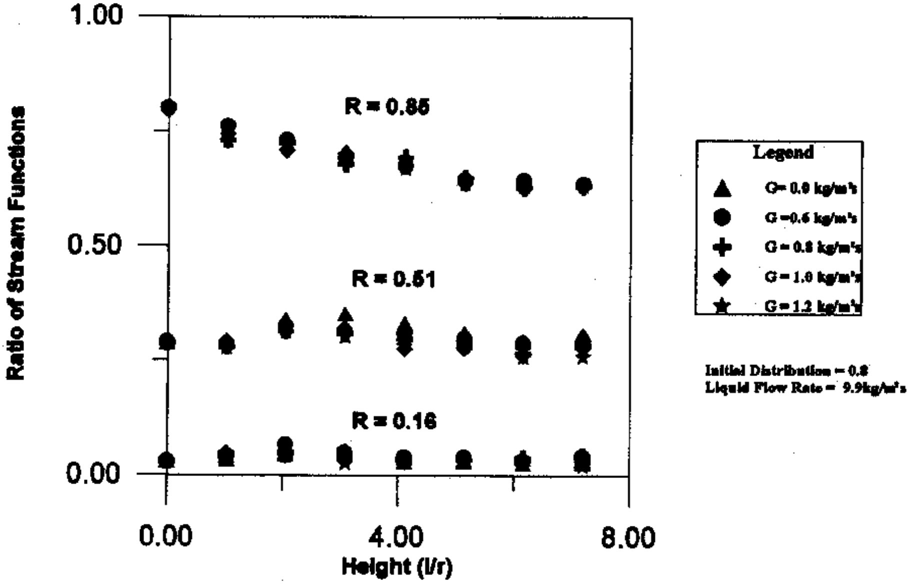

Fig. 5. Experimental stream functions for different gas flow rates.

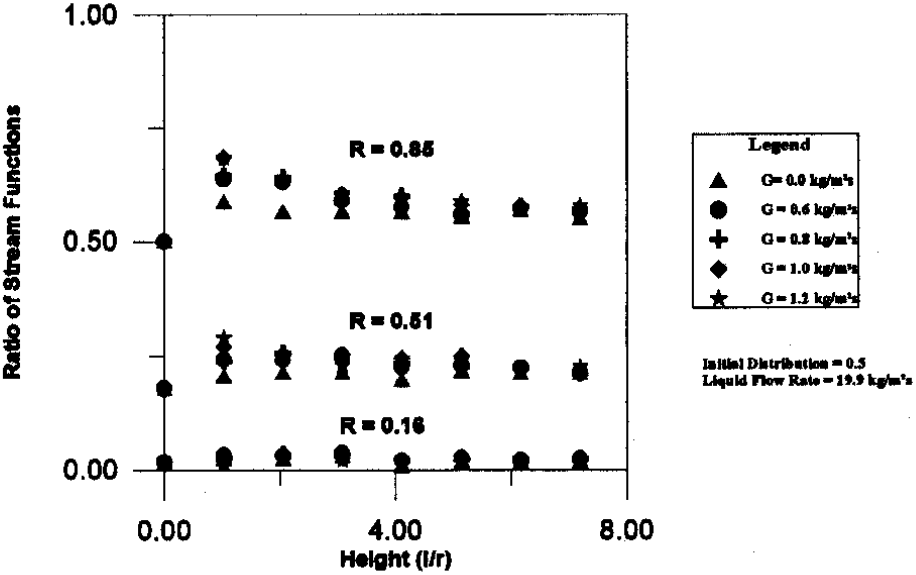

Fig. 6. Experimental stream functions for different gas flow rates.

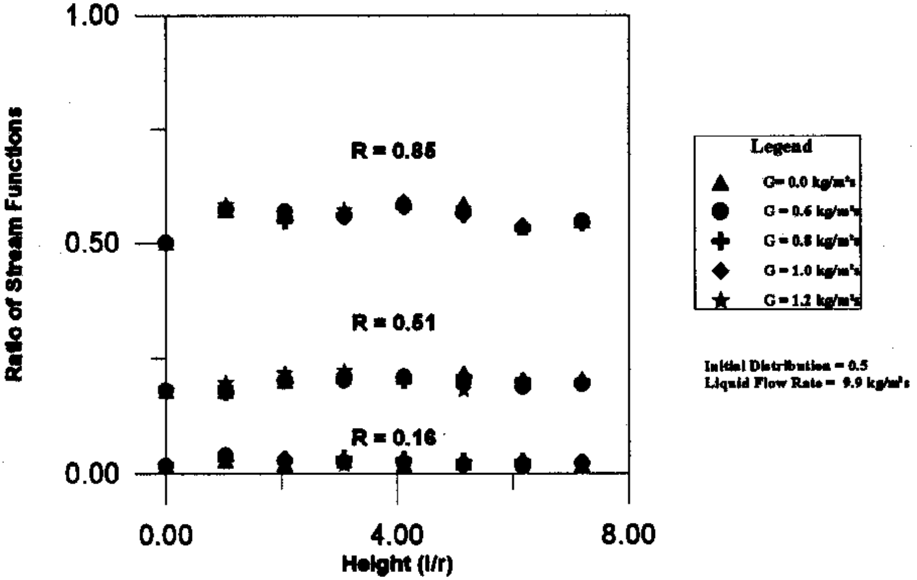

Fig. 7. Experimental steam functions for different gas flow rates.

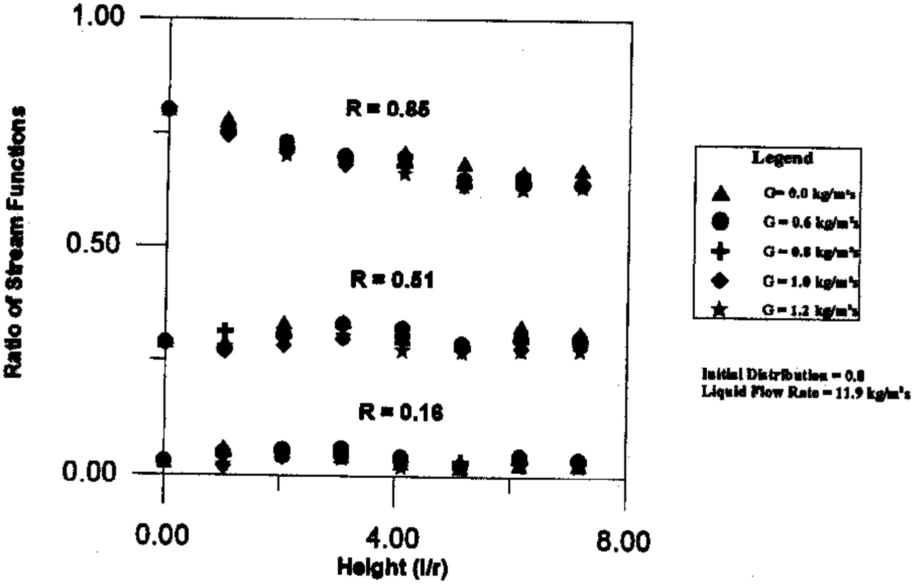

Fig. 8. Experimental stream functions for different gas flow rates.

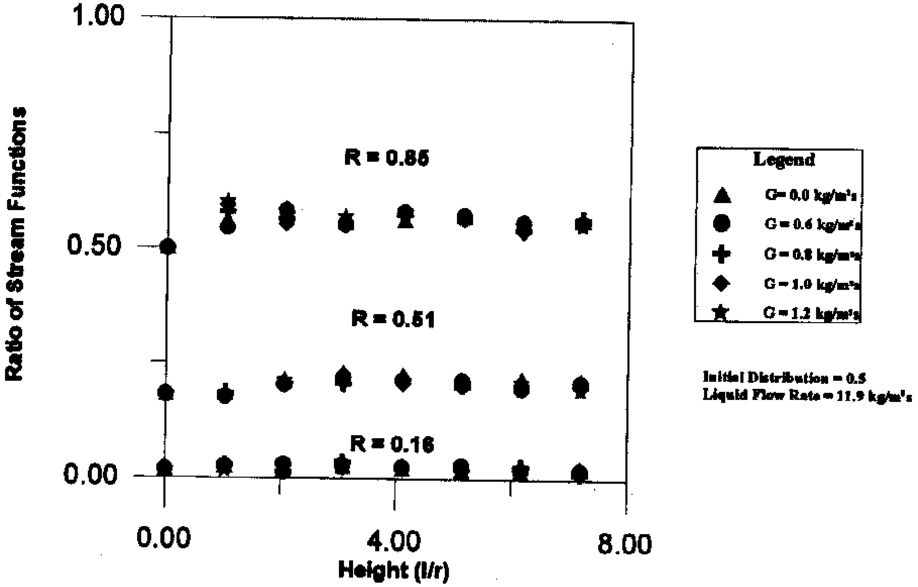

Fig. 9. Experimental steam functions for different gas flow rates.

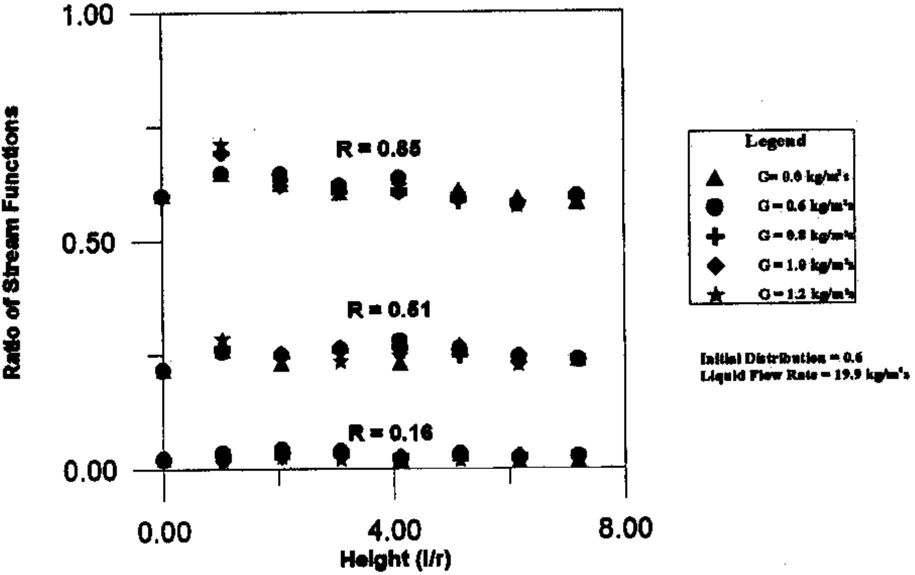

Fig. 10. Experimental stream functions for different gas flow rates.

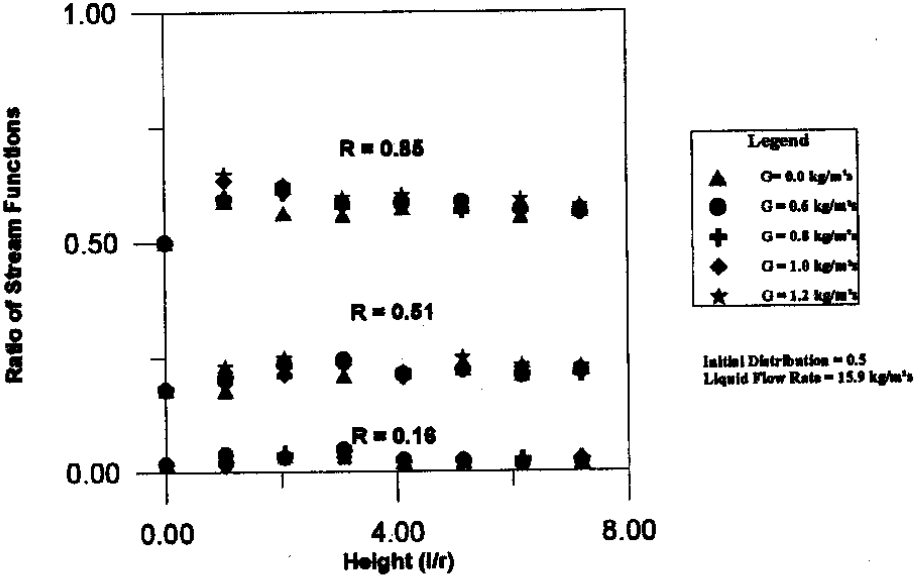

Fig. 11. Experimental steam functions for different gas flow rates.

liquid flow conditions requires a depth of packing equal to 2.5 times the column diameter. The study showed a slight effect of G, Q and γ on redistribution. It is also shown that the initial distribution, as supplied by the distributor, is not maintained under all conditions due to disturbances generated by the initial layers of the packing. This also reveals the influence of the characteristics of the packing such as its wettability.

Further experimental work is required with different types of plastic packing, particularly with different wettability, in order to see if the trends observed in this experimental work are common to all the plastic packings. The effects of γ on the final distribution, over a wide range of γ, Q, and G should be studied. Different liquids need to be used and columns should have arrangements to enable the width of the annular wall region to be varied. The number of distributor points per m^2 is an important variable, therefore a careful design and comprehensive study of the effects of the distributor on distribution of liquid over the packing is strongly recommended After extensive experimental data have been obtained using well established experimental techniques, an attempt should be made to propose a model which will give a better description of the factors affecting liquid distribution.

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Appendix

Physical Data and Operating Conditions

Column Diameter (I.D).. .. 0.292m

Column Height.. 1.8m

Dimensions of the annular collecting areas

Area	Inner radius (m)	Outer radius (m)
1	0	0.0238
2	0.0238	0.0746
3	0.0746	0.1244
4	0.1244	.0.1461

Density of air at 15°C and 1 atm .... 1.226 kg/m^3

Viscosity of air at 15°C and I atm .... 2.8x10^{-5} Ns/m^2

Viscosity of water at 15°C and 1 atm .... 1.0x10^{-3} Ns/m^2

Initial Distribution (γ) :.. 0.8 ; 0.725 ; 0.6 ;*0.5*

Liquid Flow rate (kg/m^{2}s) 9.9; 11.9; 15.9; 19.9

Gas Flow rate (kg/m^{2}s) :.. 0.0; 0.6; 0.8 ; 1.0; 1.2

دراسة تجاربية لتوزيع السائل في الأعمدة المحشوة

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(أستلم في ١٩٩٥/١٠/٤م؛ وقُبل للنشر في ١٩٩٧/٥/٤م)

ملخص البحث. يقدم هذا العمل نتائج دراسة تجاربية لتوزيع السائل في الأعمدة المحشوة في حالتي وجود وعدم وجود تيار غازي معاكس. وأجريت الدراسة في عمود من البريسبكس بقطر ٠,٣م محشي بقطع بلاستيكية يساوي كل من قطرها وطولها ٢٥ملم وتسمح بمرور السائل والغاز من خلالها. وقد أخذت قياسات معدلات الفيض بنهاية العمود عند نقاط يختلف وضعها من حيث العمق القطري والعمق الطولي. وقد كانت معدلات السريان في العمود تتراوح من صفر إلى ١,٢كغم/ م٢ث بالنسبة للغاز ومن ٤٠ إلى ٨٠لتر/ دقيقة بالنسبة للسائل وهي ذات توزيع مبدئي منتظم يعبر عنه بنسبة السائل المار في المنطقة داخل العمود (ولا يشمل السائل عند المنطقة الملامسة لسطح العمود) إلى الكمية الكلية للسائل داخل العمود. وهذه النسبة تتراوح من ٠,٨ إلى ٠,٥، وقد تم زيادة علو الحشوة بإضافات ثابتة كل مرة حتى بلوغ ارتفاع ١,٠٥م.