STUDIES ON LIQUID REDISTRIBUTIONS IN PACKED COLUMN

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ABSTRACT

Liquid distribution and redistribution at high values of liquid initial distribution (0.8 and 0.725) has been studied for air-water system in a 0.3m perspex column packed with 25mm plastic pall rings of equal length and diameter. The height of the packing was increased from 0 to 1.05m. The effects of total flowrates of gas (0.0-1.2 kg/m²s) and liquid (9.9-19.9kg/m²s) were investigated. The experimental values of stream functions were compared with the values obtained from theoretical equation. There were good agreements between the values. Although the boundary conditions of the equation were particularly derived to take the parculiarity of the wall region, the deviations between the experimental and theoretical values were predominant at the wall. A change in the initial liquid distribution from 0.8 to 0.725 appeared to improve the deviations between values of the stream functions.

Keywords: *Initial Distribution, Plastic Pall Rings, Permeability, Stream Function, Wall region*

الملخص

لقد تمت دراسة إعادة توزيع السوائل عند قيم أولية عالية للتوزيع من (γ = ٠,٨ – ٠،٧٢٥) لنظـام مائي هـوائي في عمود من البر سبكي قطـره (٠,٣ متر) محـشو بحلقات بلاستيكيـة (٢٥ ملم) متساوية في الطول والقطر ، وبلـغ طول الحشـوة ١,٠٥متر. وقـد فحصـت تاثيرات معدلات سريان الغـاز ($0.0 - 12\ kg/m^2s$) والسائل ($9.9 - 19.9 kg/m^2$) كما تمت مقارنة القيم التجريبية لوظائف السريان مع القيم النظرية وكان هناك توافق جيد بين القيم. ومع أن الشروط الحدية للمعادلة قد اشتقت بعناية آخذة في الاعتبار ميزة منطقة الجدار ، إلا أن الانحرافات بـين القيـم النظريـة والعمليـة كانت سائـدة في منطقـة الجـدار. وقـد وجـد أن التغير في توزيـع السائل الأولي من (٠,٨ الى ٠,٧٢٥) قد حسن ميلان الانحرافات بين قيم وظائف السريان.

1. INTRODUCTION

In heterogeneous chemical processes, intimate contacts among the fluids and between the fluids and solid are necessary requirement. Columns packed with ceramic, metallic and plastic packages are often employed to enhanced contacts in both separation processes and chemical reactions. In most cases, the denser fluid that moves downward is liquid while the other is gas, which is introduced counterwise. Understanding the physical phenomenon occurring inside the packed column is essential for rational design of new equipment and improving the existing ones. In order to ensure uniform liquid distributions, different mechanical aids are utilized. However, the initial liquid distribution is not maintained for a long distance down the column.

This maldistribution or redistribution have been associated with factors such as dispersion, mass transfer, pore diffussion, radial liquid and vapor mixing and relative permeability of the wall region to bulk. There are several experimental studies of these factors at different operating conditions on the distribution and redistribution of the liquid in the column [Farid and Gunn, 1978; Gunn and Saffar, 1993; Baker and Waldie, 1996]. The source of liquid are designed and located at particular points in the column to improve the effective distribution of liquid. Theoretical equations that attempted to describe the phenomenon in the columns are also developed [Linek et al., 1994; Zuiderweg et al., 1993]. Most of them are inadequate. In some cases, this is because of the assumption that uniformly distributed liquid passed through the column in plug-flow [Walker et al., 1927; Porter, 1968]. This theory is unsatisfactory. It led to large errors in determining the column parameters such as column height and diameter for a particular operation. Experimental results have shown [Ibrahim, 1998; Miyahara et al., 1993; Scott, 1935; Porter et al., 1968; Sundaresan, 1993] a non-uniform distribution at least after some distance down the column.

Attempts have been made towards improving the theoretical equations, particularly the boundary conditions in order to reflect the experimental observations [Porter and Jones, 1963; Ibrahim and Jibril, 2000]. The shortcomings of many of the boundary conditions have been discussed. Alternative approach was given on the basis of difference in permeability between the wall and the bulk region of the packing [Zuiderweg, 1993]. Under normal conditions in a vertical packed column, the liquid moves down by gravity and this movement is being impeded by the countercurrent gas pressure gradient. Both the total liquid flowrate and gas pressure are usually chosen to avoid flooding. The interplay of the magnitudes of the liquid flowrate, gas pressure, packing arrangement and voidage are what bring about the redistribution of liquid. It has been suggested that if the permeability of packing near the wall is higher than in the bulk region, an evenly distributed liquid at the top surface of the packing will move more freely in the wall region. This causes the gas phase pressure gradient to be lower near the wall than the center of the column. The difference in the pressure causes the redistribution. On the basis of this, equation 1 for distribution of liquid and the associated boundary condition equations 2, 3 and 4 were developed by [Gunn, 1978]. The liquid flow in the wall region is given by equation 5.

$$\frac{\partial^2 \psi}{\partial z^2} + \frac{\partial^2 \psi}{\partial r^2} - \frac{1}{r}\frac{\partial \psi}{\partial r} = 0 \qquad (1)$$

$$\frac{\partial \psi}{\partial r} = \frac{2\pi rK}{a_W K_W}(\psi_T - \psi) \quad r = r_i, \quad 0 \le Z \le l \qquad (2)$$

For radial symmetry, the boundary condition at the inflow face is the initial liquid distribution

$$\psi = f(r) \quad z = 0 \;, \quad 0 \le r \le r_i \qquad (3)$$

The boundary condition at the outflow face is

$$\frac{\partial \psi}{\partial z} = 0 \qquad at \quad z = l \qquad (4)$$

The total flow to the column is Ψ_T and the liquid flow in the wall region is given by

$$q_w = \psi_T - \psi \quad at \quad r = r_i \qquad (5)$$

In this work, an experimental study of effect of total liquid gas flowrates on the liquid distribution and redistribution is reported. The experimental results were compared with theoretical values obtained from equation 1.

2. EXPERIMENTAL

2.1 Apparatus

The experimental apparatus consists of a liquid distributor and flow measuring devices. Details diagram of the apparatus setup are given elsewhere [Ibrahim, 1998]. 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. 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 were 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 small diameter Raschig rings, intended to dissipate the kinetic energy of the liquid flowing to the bulk of the packing. The distributor consists of two concentric perspex tubes fixed at their bottom to a brass plate. The inner perspex tube constitutes the bulk region, while the annular section between the two tubes constituted the wall region. The brass plate contained a large number of copper tubes of 4.76 mm 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 12.7 mm, internal diameter (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 6 mm I.D, with three pairs of electrodes, was fixed slant-wise in each tank along one of its inner faces. 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 30 psig was used. The pressure was then reduced to 10 psig 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 Table 1.

2. PROCEDURE

The experiment was 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 supplies to the wall and bulk regions were measured separately. The flow measuring devices were used to determine the relative amounts of liquid flow 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 of liquid flowrates was extended between 9.9 to 19.9 kg/m^2 s. Two values (0.8 and 0.725) of the ratios of the amount of liquid fed initially in the bulk region to the amount fed in the wall region were used. All experiments were carried out with air and water. Two values of air flowrates (0.0 to 1.2kg/m^2 s) were used.

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3. RESULTS AND DISCUSSION

The experiment was conducted over ranges of water and air flowrates. The experimental stream functions were calculated for three radial positions within the column. The dimensional position are R = 0.197, 0.616 and 1.028. R is the ratio of radial position to total radius of the bulk region. Figures 1 - 4, show the comparison of the experimental values of ratios of stream function at the three radial positions. Solid lines indicate the model as represented by equation 1. The equation was solved using FORTRAN IMSL subroutine. For each figure, the initial liquid distribution, total liquid flowrate and gas flowrate are respectively indicated at the top right hand corner of the figure for example 0.8_9.9_0.0 as in fig. 1a. Figures 1(a-d) show the ratios of stream function for different values of water flowrates (9.9 - 19.9 kg/m^2 s) while the water initial distribution (γ=0.8) and gas flow (G=0.0) were kept constant. In figures 2 - 4, the values of gas flowrates are 0.0 and 1.2. Figures 1 and 2 are similar to figs. 3 and 4 with water initial distribution changed to 0.725. Experimental results using gas flows of 0.6, 0.8 and 1.0 (for both liquid initial distributions) were obtained. Since the trends are similar, only the two extreme cases are discussed here.

The pattern of the graph for both the experimental and theoretical stream functions may be explained on the basis of the differences in permeability between the bulk and wall regions. It is clear from the graphs that the redistribution of liquid in a packed column along the axial direction is describable by the equation. The difference in permeability is what brought about the redistribution. The presence of the wall, that confines the packing close to it, varies the void fraction in the radial direction and hence the permeability. In this work, consideration is given to higher values of initial distribution, which provides a lower supply of liquid to the wall region. In almost all figures, particularly for the experimental case, the ratio of stream functions at each R approaches a constant value when the L is about 2.5 times the column diameter. This signifies the establishment of equilibrium wall flow that resulted in an equal distribution over the cross-section of the column. Distribution changes even at column length of 40 times the diameter of the column was observed earlier [Scott, 1935]. However, in another report it was found that establishment of equilibrium occurs at small depth of packing particularly when there is a gas flow [Dutkai and Ruckenstein, 1968].

The theoretical model predicts straight line profile for all condition with slight curvature at the inlet of the column. This suggests that constant ratio of stream functions and hence equal distribution across any cross-section is predictable at lower value of L. In the development of the theoretical model, the wall region was assumed to have a constant value of a particle size diameter. This might not necessarily be true and would contribute to deviation of the theoretical from the practical results. The size and effects of the wall region could be improved by designing better experiments.

The figures show better agreement between the theoretical and experimental data for the lowest value of R (0.197) than the highest value (1.028) even in the presence of changes of gas and liquid inputs. This may be attributed to the fact that there are slight variations in voidage close to the center of the column and the distribution is rather uniform. For instance, fig. 2d shows the close agreements between theoretical and experimental data for R = 0.197. But for higher values (R = 0.616), there is 5% deviation mainly about half-way along the axis of the column. While for R = 1.028, similar deviation (about 5 %) occurred at end of the column. Therefore, as R increases, the effect of the wall becomes apparent and deviations start to appear between the experimental and theoretical profiles. The deviation is more pronounced at lower gas flow rates and therefore counter-current gas flow enhances uniform distribution and increases the performance of intimate contacting process in the column. Figures 1d and 2d, for example, have similar liquid inputs (19.9 kg/m^2s) and initial liquid distribution (0.8) with different gas flows of 0.0 and 1.2 kg/m^2 s respectively. It is apparent that the higher gas flow gives better agreement between experimental and theoretical results. The use of higher initial distribution caused the liquid to flow from the bulk to the wall region. Comparing figs. 1 and 3 suggests slight improvement in agreement between the theoretical and experimental values by changing the initial liquid distribution from 0.80 to 0.725. The effect of lower initial distribution is clearly demonstrated by the lower variance between experimental and theoretical results as shown in Table 2. The range of the variance is however higher in this work ($5.97x10^{-4}$ – $1.87x10^{-3}$) than that of a similar work by Farid and Gunn ($1.55x10^{-5}$ – $6.11x10^{-4}$) [Farid and Gunn, 1978]. This may be attributed to the difference in the types of packing employed in the two works. In their work, ceramic raschig rings packing was used while we used plastic pall rings.

4. CONCLUSION

The experimental values of ratios of stream function were determined and compared with theoretical values. There are general good agreements between the values. Although the equation for the stream functions was particularly derived to take into consideration the parculiarity of the boundary conditions at the wall region, the differences between the experimental and theoretical values were predominant at the wall. Probably, this arised from the design of the distribution and sizing of the wall region. Generally, increased in gas flow rate decreased the redistribution. There appeared to be a better agreement between the values of the stream functions at lower value of the initial liquid distribution.

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Table 1. Operating conditions and some physical properties

Density (kg/m^3) of air at 15 °C and 1 atm	1.226
Viscosity (Ns/m^2) of air at 15 °C and 1 atm	2.8E-5
Viscosity (Ns/m^2) of water at 15 °C and 1 atm	1.0E-3
Initial Distribution (γ)	0.8 and 0.725
Liquid Flow rate ($kg/m^2 s$)	9.9 – 19.9
Gas Flow rate ($kg/m^2 s$)	0.0 – 1.2
Column Diameter (ID) (m)	0.292
Column Height (m)	1.05

Dimension of Annular Collecting Areas

Area	1	2	3	4
Inner Radius (m)	0	0.024	0.075	0.124
Outer Radius (m)	0.024	0.075	0.124	0.146

Table 2. Model variances (σ^2) for total liquid flow, L = 19.9 kg/m^2s (i) Initial distribution, γ = 0.8 and (ii) γ = 0.725 for different gas flow.

Gas Flow Rate (kg/m^2s)	(i) ($\sigma^2 X10^3$)	(ii) ($\sigma^2 X10^3$)
0.0	1.867	1.423
0.6	0.974	0.801
0.8	0.978	0.550
1.0	0.799	0.585
1.2	0.720	0.597

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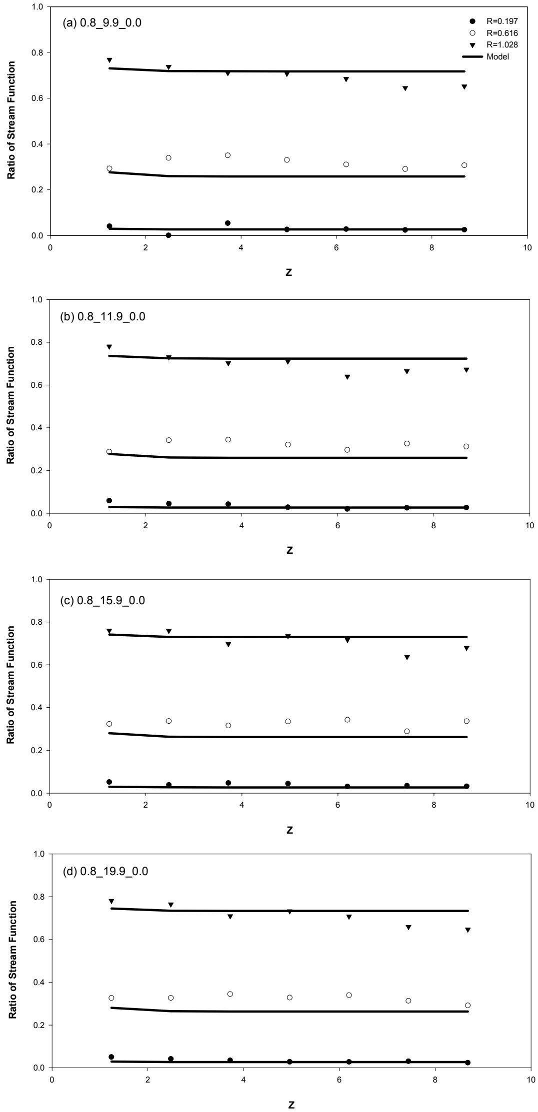

Figure 1. Liquid Distribution for Different Total Liquid Flow at $\gamma = 0.8$ and $G = 0.0\ kg/m^2s$

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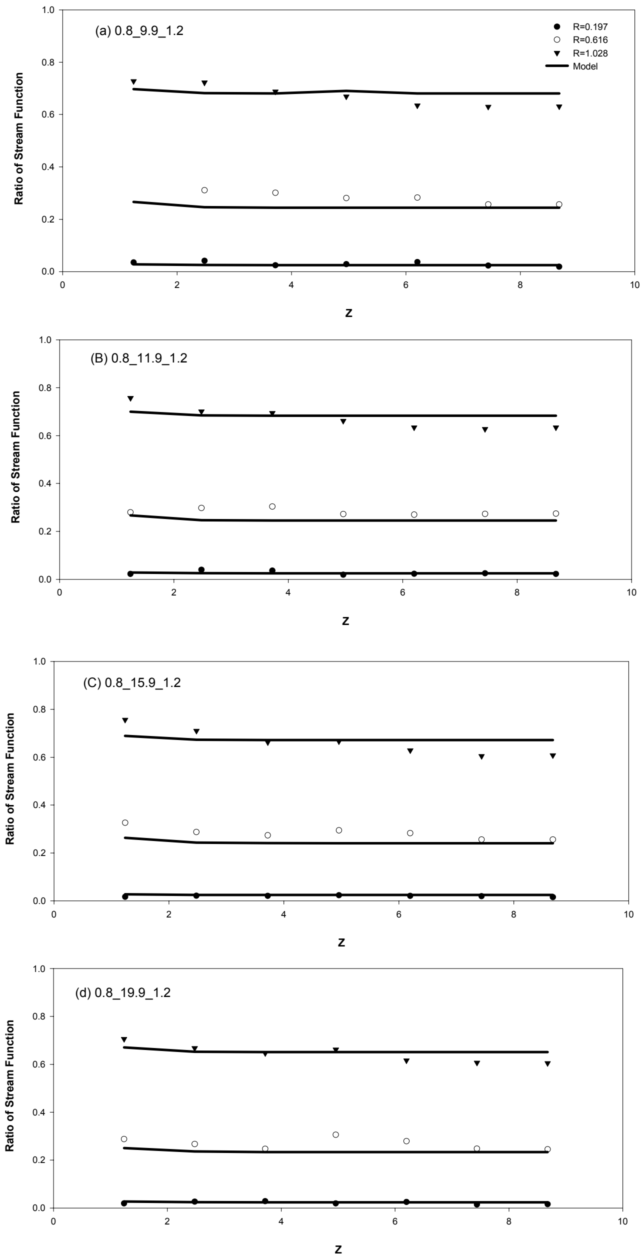

Figure 2. Liquid Distribution for Different Total Liquid Flow at $\gamma = 0.8$ and $G = 1.2\ kg/m^2s$

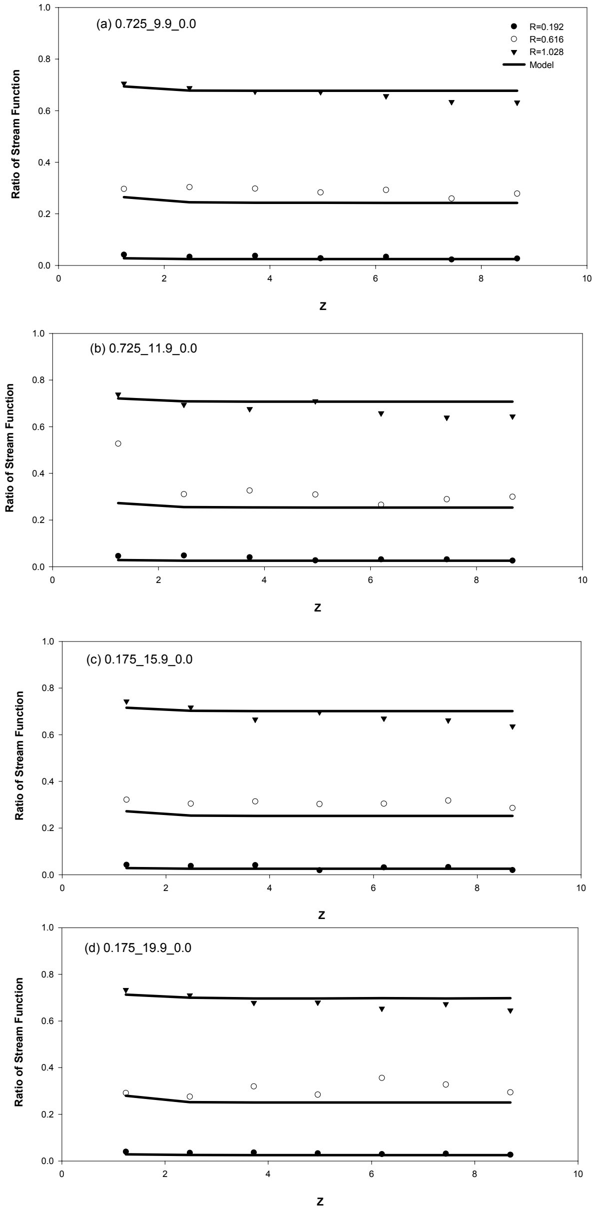

Figure 3. Liquid Distribution for Different Total Liquid Flow at $\gamma = 0.725$ and $G = 0.0$

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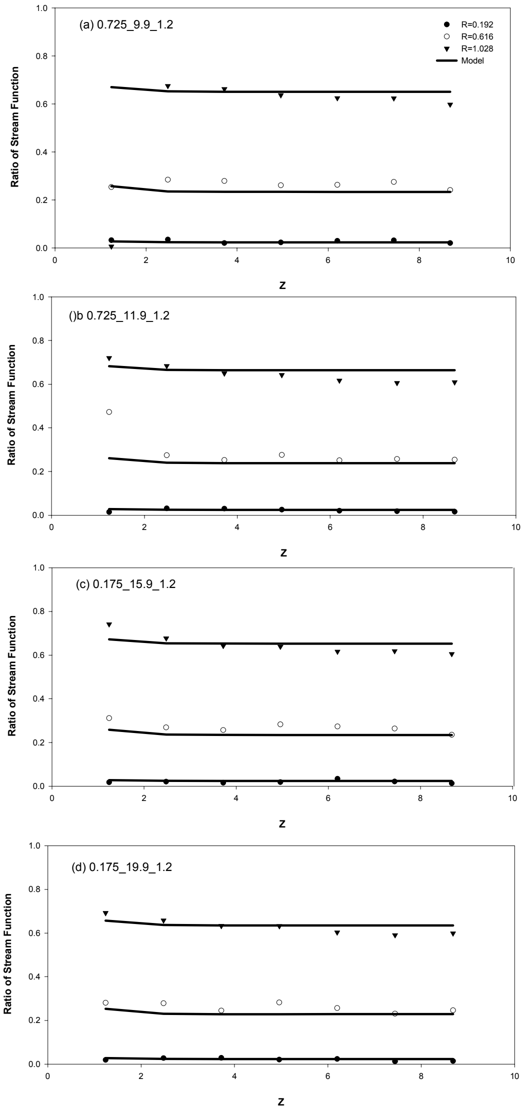

Figure 4. Liquid Distribution for Different Total Liquid Flow at $\gamma = 0.725$ and G = 1.2

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