

AN EXPERIMENTAL STUDY OF GAS PHASE BACK MIXING UNDER THE COUNTER-CURRENT GAS-LIQUID FLOW ON A VERTICAL EXPANDED METAL SHEET PACKING BY STATIC TRACER TECHNIQUE

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Gas phase back mixing has been measured in a column packed with vertical expanded metal sheet under the counter-current flow of gas and liquid by the static method using a tracer. The observed experimental concentration profiles have not confirmed our earlier proposed model of back mixing, based on the concentration profiles in absorption runs. These profiles do not even conform with the axially dispersed plug flow model currently used to describe axial mixing in packed bed columns. The concentration profiles may be described by a combination of the axially dispersed plug flow model with back flow.

In the earlier paper¹ we have reported a significant effect of gas phase back mixing on mass transfer in those cases when the superficial velocity of liquid equalled in the order of magnitude to that of the gas. This phenomenon was studied by measuring gas phase concentration profiles during steady state absorption of carbon dioxide in water. The results revealed that the axially dispersed plug flow model (AD model) currently used to describe axial mixing in packed bed columns is not suitable. The concentration profiles could be well described by the back flow model without lateral mixing (BF model).

The BF model is a single parameter one. The coefficient of back mixing, q , was defined as a ratio of the sum of the inlet superficial velocity of gas and the back flow to the inlet superficial velocity of gas: $q = (v_g + v'_g)/v_g$. It may assume values from unity for plug flow up to infinity for an ideal mixer.

The AD model and the BF model strongly diverge in scale-up considerations when one applies the results from an experimental set-up to a column with a much larger number of transfer units (doubled or even higher). The BF model in scale-up calculations predicts considerably greater column height. In fact more difficult absorptions would be technically unfeasible according to this model, while the AD model puts the column height still into feasible limits. This fact together with the rather improbable physical interpretation of the BF model has compelled us to verify the suitability of the model by an independent method.

For the analysis of the problem it appeared as most suitable to apply the static

tracer technique in the gas phase. The method consists of establishing a tracer distributor distributing the tracer over the whole area of column cross section while its steady state concentration is measured in various distances upstream of the gas flow. The evaluation of parameters of back mixing from experimental data is simple for both models considered. Using a dimensionless coordinate for the AD model³ and $z > z_0$

$$R = \frac{\ln(y/y_0)}{z - z_0} \quad (1)$$

for $z \leq z_0$ we have $y/y_0 = 1$. For the BF model and $z > z_0$

$$q = 1/(1 - y/y_0) \quad (2)$$

and for $z \leq z_0$ we have also $y/y_0 = 1$. Both models may be conveniently interpreted graphically in z versus $\log(y/y_0)$ coordinates. The dependence $y/y_0 = f(z)$ for the AD model and $z > z_0$ is a straight line with a slope $-R/2.303$. For the BF model and $z > z_0$ the dependence $y/y_0 = f(z)$ is a straight line parallel to the z axis. For $z = z_0$ there is a step change in case of the BF model.

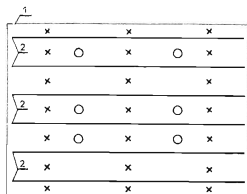
EXPERIMENTAL

The column with the vertical packing was of rectangular 102.5×72.5 mm cross section. The length of the jacket was 2035 mm. At both ends the column was equipped with cylindrical chambers 150 mm in internal diameter, 260 mm long. These chambers housed a liquid distributor and a collector. The packing consisted of a bunch of six parallel sheets of expanded metal. A more detailed description of the experimental set-up has been published earlier¹.

The principal problem of the static method using a tracer rests in the realization of the plane source of the tracer. The method employed in this work was as follows: The tracer was introduced into the column through discharge nozzles, three of these nozzles being always located between each pair of the expanded metal sheet (see the crosses in Fig. 1 marking location of the nozzles).

FIG. 1

Scheme of Location of Tracer Feed Points
1 Column jacket, 2 sheet of packing;
x tracer feed point, O sampling point.



Uniform distribution of gas between individual nozzles was ensured by equalizing the resistance between the branching point and individual discharge openings. For this purpose we used hypodermic needles of equal length and inner diameter. The amount of the tracer discharging from the outlets between the outermost sheets and the wall was half of that from the others. The gas was sampled by withdrawing samples through a hypodermic needle. The composition of the gas was analyzed by chromatography. The method of sampling was described in more detail in the previous paper¹. The gas below the feed of the tracer was sampled at seven horizontal levels. At each level the gas was sampled from six positions shown by circles in Fig. 1. The results indicate the average value. The variational coefficient of these six values ranged between 10 and 35% against 4% found in the absorption runs. The upper level of this range was approached in horizontal levels closer to the feed of the tracer.

Propane was used as tracer. The error due to its absorption and subsequent desorption is negligible for it amounted to less than 1% of the least concentration used.

RESULTS

Part of the set of experimental results for a single velocity of liquid and various gas velocities is shown in Figs 2a–d. It is apparent that the experimental values do not exhibit a step change at the point of the tracer feed. The BF model is thus unsatisfactory. The AD model seems acceptable in case of very low gas velocities. At higher gas velocities, however, the concentration profiles in semi-log coordinates are strongly nonlinear. The AD model thus appears also unsatisfactory. Nevertheless, the mean values were evaluated of the q coefficient for the BF model and the mean values of the Peclet number R for the AD model. The area was evaluated under the curve passing through the experimental points. Next, values of q and R were adjusted so that the area under the curves $y/y_0 = (q-1)q$ and $\log(y/y_0) = -R(z-z_0)/2.3$ take the above values. These straight lines are shown in Fig. 2 for the AD model by the broken line and for the BF model by the dash-and-dot line. The computed values of the parameters q and R are summarized in Table I.

A comparison of the coefficient of back mixing q following from the tracer measurement and the absorption runs is furnished in Fig. 3. The solid line shows the correlation presented in the previous paper¹. The agreement of the coefficient q obtained by the two methods is good.

A similar comparison of the values of the Peclet number is furnished in Fig. 4. The Peclet numbers R from the absorption runs are approximately twice as large as those from the measurements with the tracer.

The course of the experimental concentration profiles depicted in Fig. 2 suggests that they could be fitted by a combination of the AD and the BF model. This combination originates from the idea that part of the gas from the column top is entrained to the bottom of the column to mix with the fresh inlet gas. There is no interaction taking place between the back flow and the streaming gas or liquid. The bulk flow of gas streaming upwards is being mixed in accordance with the concept of the AD model.

The combined model is a two parameter one. The coefficient of back mixing, q' , characterizes the back flow while the Peclet number, R' , characterizes axial mixing in the bulk stream of gas. The combined model reduces for $q' = 1$ to the AD model while for $R' \rightarrow \infty$ to the BF model.

The expression for the concentration profile of the tracer following from the combined model is again relatively simple

$$y/y_0 = (q' - 1)/q' + (1/q') \exp[-q' R'(z - z_c)] \quad (3)$$

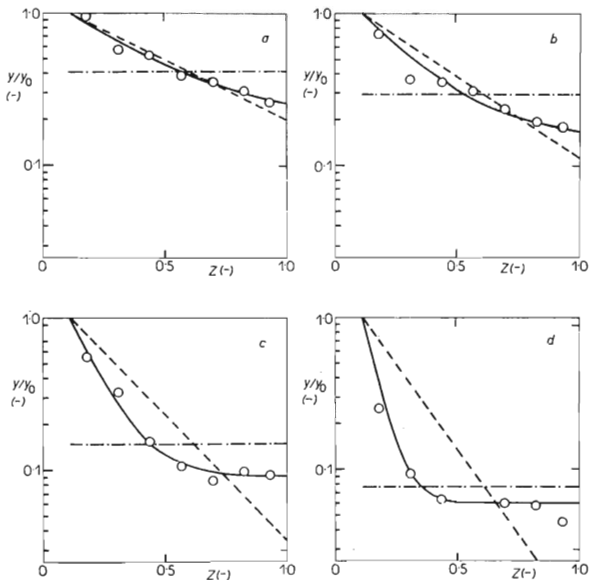


FIG. 2

Tracer Concentration Profiles for $v_L = 3.2 \cdot 10^{-2}$ m/s

○ Experimental data; - · - · - BF model; - - - AD model; — combined model.

a) $v_g = 2.43 \cdot 10^{-2}$ m/s; b) $v_g = 3.74 \cdot 10^{-2}$ m/s; c) $v_g = 6.01 \cdot 10^{-2}$ m/s; d) $v_g = 8.97 \cdot 10^{-2}$ m/s.

The values of the parameters q' and R' were determined from experimental data and have been summarized in Table I. The concentration profiles computed from Eq. (3) are shown in Fig. 2 by solid lines. The good agreement of the shape of these curves with the character of the experimental profiles is obvious.

Processing of experimental data according to the combined model has revealed that within the range of experimental gas velocities employed the superficial velocity of the back flow is independent of gas velocity. For the above experiments with the

TABLE I
Parameters of Models

$v_L \cdot 10^2, \text{ m/s}$	$v_g \cdot 10^2, \text{ m/s}$	AD model	BF model	Combined model	
		R	q	R'	q'
3.20	2.43	1.80	1.686	2.36	1.250
3.20	3.74	2.47	1.410	3.96	1.176
3.20	6.01	3.80	1.175	8.05	1.100
3.20	8.97	5.15	1.082	15.8	1.064
2.02	0.97	1.24	2.160	1.55	1.285
2.02	1.50	1.90	1.629	2.46	1.190

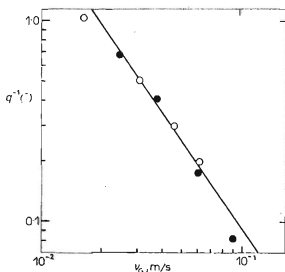


FIG. 3

A Comparison of the Coefficient of Back Mixing from the Absorption and Tracer Runs for $v_L = 3.2 \cdot 10^{-2} \text{ m/s}$

○ Absorption runs, ● tracer runs; the line corresponds to the correlation presented in the previous paper.

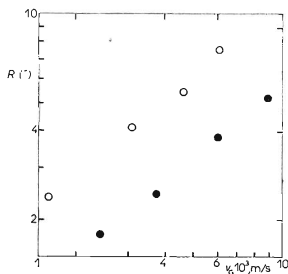


FIG. 4

A Comparison of the Peclet Number for the Absorption and the Tracer Runs

○ Absorption runs, ● tracer runs.

superficial velocity of liquid $v_L = 3.20 \cdot 10^{-2}$ m/s the superficial velocity of the back flow amounted approximately to $v'_g = 0.61 \cdot 10^{-2}$ m/s. For experiments with $v_L = 2.02 \cdot 10^{-2}$ m/s then to $v'_g = 0.28 \cdot 10^{-2}$ m/s.

The combined model was also applied to concentration profiles in the gas phase in the absorption runs measured in the previous work¹. The model for the case of back mixing in only the gas phase may be described by the following set of differential equations

$$\begin{aligned} dX/dz &= T(X^* - X) \\ \frac{dY}{dz} + \frac{1}{q'R'} \frac{d^2Y}{dz^2} &= \frac{Q}{q'} T(X^* - X) \end{aligned} \quad (4)$$

with the boundary conditions

$$\begin{aligned} X &= X_{in}, \quad Y = Y_{out}, \quad q'Y + \frac{1}{R'} \frac{dY}{dz} = q'Y_{out} \quad \text{for } z = 0, \\ X &= X_{out}, \quad Y_{in} + (q' - 1)Y_{out} = q'Y + \frac{1}{R'} \frac{dY}{dz} \quad \text{for } z = 1. \end{aligned}$$

The assumptions involved in the formulation of the set (4) are identical with those for the set of equations for the AD model, which had been verified in the previous work¹. In the processing we used values of the coefficient q' obtained from the measurements with the tracer. The Peclet number, R' , was computed from experimental values of the inlet and outlet concentrations, flow rates of both phases and the known number of transfer units. The concentration profiles computed with the aid of thus obtained values of parameters q' and R' , however, do not follow the experimental profiles (Fig. 5). Near the gas outlet there is the region of strong effect

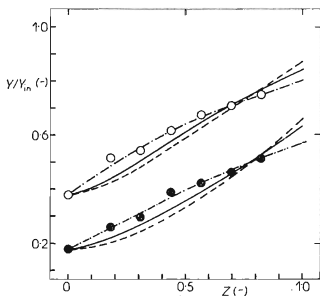


FIG. 5
Concentration Profiles for Absorption of CO_2 in Water at $v_L = 3.2 \cdot 10^{-2}$ m/s
- - - Profile computed from the BF model; - · - profile computed from the AD model; — profile computed from the combined model; ● $v_g = 1.62 \cdot 10^{-2}$ m/s; ○ $v_g = 3.08 \cdot 10^{-2}$ m/s.

of the boundary condition valid for the axially dispersed plug flow model

$$\left(\frac{dY}{dz}\right)_{z=0} = 0. \quad (5)$$

This condition though is not met by the experimental data for the region near the gas outlet.

The discrepancy between the course of the experimental concentration profiles from the absorption runs with the boundary condition (5) is marked. In fact, it seems to be the probable cause for the considerable difference of the Peclet numbers from the absorption and tracer measurements (Fig. 4). The experiments, however, were carried out in single column and one thus cannot rule out eventual effect of the inlet and outlet section of the equipment on the concentration profiles under the absorption runs. Similar concentration profiles available from the literature neither confirm nor refuse the results of this work. The experiments of Brittan and Woodburn⁴ were carried out under the flow rates of phases when the back mixing of the gas phase is insignificant. The experiments published later by Woodburn⁵ were carried out in a column equivalent to a large number of transfer units and hence the theoretical profiles in the gas outlet region for individual models do not practically differ.

Since the boundary conditions (5) for the axially dispersed plug flow model has been used to apply the results of tracer measurements to the calculation of the absorption runs it seems worthwhile to verify it properly or modify it.

CONCLUSION

Static measurement with the tracer in a column with the vertical plane packing can be described neither by the axially dispersed plug flow model with back mixing. The combined model, however, does not satisfy the absorption experiments. The application of the back flow model presented earlier^{1,2} including the correlation for the coefficient of back mixing, for design calculations of equipment exceeding in length 3 to 4 meters is improper. The resulting column heights would be considerably conservative. The correlation may be recommended for the estimation whether the back mixing in the gas phase may become significant under the given conditions.

LIST OF SYMBOLS

- Q ratio of volume flow rate of solvent to that of the inert gas
- q coefficient of back mixing for the back flow model
- q' coefficient of back mixing for the combined model
- R column Peclet number of the axially dispersed plug flow model
- R' column Peclet number for the combined model

T	number of transfer units
v_g	superficial velocity of gas, (m/s)
v'_g	superficial gas velocity of back flow, (m/s)
v_L	superficial velocity of liquid, (m/s)
X	concentration of absorbed component in liquid (kg/m ³ of solvent)
y	tracer concentration (vol %)
Y	concentration of absorbed component in gas phase (kg/m ³ of inert)
z	dimensionless axial coordinate, $z = 0$ at the top, $z = 1$ at the bottom
*	equilibrium
in	inlet end
out	outlet end
o	tracer feed

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