AXIAL DISPERSION IN THE LIQUID PHASE IN A HORIZONTAL TWO-PHASE TUBE REACTOR

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The characteristics of axial dispersion in the liquid phase were measured for two basic flow regimes in a horizontal two-phase tube reactor. The data obtained indicate that in some flow regions, axial dispersion can be quite significant.

Virtually no experimental data requisite for the description of axial dispersion in a two-phase flow in a horizontal tube reactor are available from the literature. Plug flow is usually assumed for the two phases when designing and modelling chemical reactors with annular flow of the liquid phase[1], and this concept is corroborated by some experimental data by Russel and Lamb[2]. For the bubble and plug flow regimes, however, no experimental data exist.

The aim of the present work therefore was to determine axial dispersion in the liquid phase for the basic flow regimes in a horizontal two-phase tube reactor using the water–air system.

EXPERIMENTAL

The experiments were performed in a horizontal tube reactor made of plexiglass, 5·08 m long and 0·05 m i.d., in the water–air system at atmospheric pressure and room temperature (20 ± 3°C). A detailed description of the apparatus has been presented elsewhere[3].

The axial dispersion characteristics were established for the basic flow regimes shown in Fig. 1. The experimental conditions (liquid and gas flow velocities) are plotted in the flow regime map[4] in Fig. 2.

The input pulse signal was realized by injecting 0·2 to 0·5 ml of saturated KCl solution into the fluid stream at the tube bottom, 0·57 m before the measuring section. The conductivity responses of the system to the pulse injection of the tracer were measured with two pairs of wire electrodes spaced 1·08 m and located 2·4 mm above the bottom wall of the tube. The response characteristics at the locations in the tube reactor were recorded in the two-channel mode by means of a QR 6000-PCS 1 microcomputer controller (Tesla Třinec), which enabled the signal to be sampled in 0·0005 s intervals. A total of 10—20 experiments were performed and evaluated for each set of experimental conditions.

The experimental data were evaluated by the moment analysis based on the dispersion model. Assuming a nonideal input pulse signal, the value of the Bodenstein number ($Bo = D/(vL)$) was determined from the difference of variances of curves of tracer concentrations between the two points downstream:

$$\Delta\sigma_t^2 = (\sigma_t^2)_2 - (\sigma_t^2)_1\,, \qquad (1)$$

where subscripts 1 and 2 refer to the two measuring points, respectively. In the case studied, given the tracer injection mode and the conductivity response measuring mode, the two-phase flow in the tube reactor can be regarded as an open system. The Bodenstein number value then can be determined based on the simple relation by Aris[5],

$$\Delta\sigma^2 = \Delta\sigma_t^2(\dot{V}/V)^2 = 2Bo\,. \qquad (2)$$

RESULTS AND DISCUSSION

A survey of the axial dispersion characteristics for selected experimental conditions is given in Table I, and plots of the axial dispersion in the various flow regimes are shown in Fig. 3. In terms of the axial dispersion scale by Levenspiel[6], in the stratified smooth flow region (SS) the axial dispersion is none or small (SD); as the gas velocity is increased to reach the stratified wavy flow region (SW), the dispersion can be

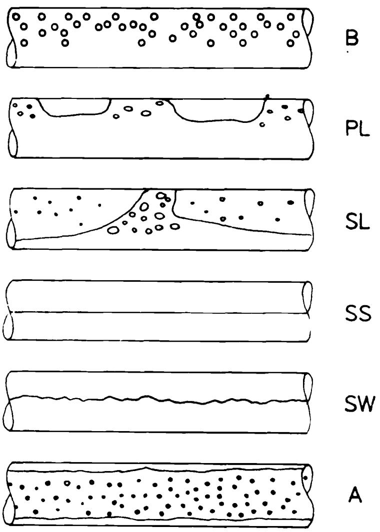

FIG. 1

Basic types of flow regime. B bubble flow, PL plug flow, SL slug flow, SS stratified smooth flow, SW stratified wavy flow, A annular flow

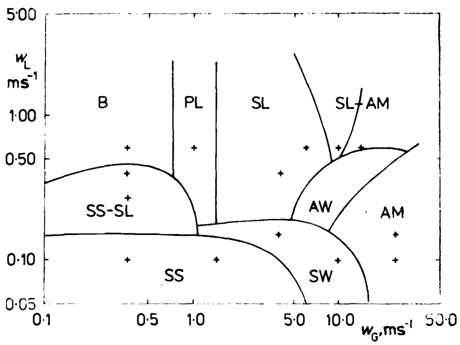

FIG. 2

Flow regime map[4] showing the experimental conditions. Labelling as in Fig. 1; AM annular flow, AW annular-wavy flow classed as small to intermediate (SD to ID). This qualitative assessment of the axial dispersion magnitude is consistent with the situation expected according to the basic characteristics of the flow regimes shown in Fig. 2. Annular flow is a flow of a thin layer along the walls of the tube, during which the liquid is better mixed due to the flow, and higher axial dispersion values emerge. Also, in the region of a high

TABLE I

Axial dispersion characteristics of the various flow regimes

Flow regime	w_L ms^{-1}	w_G ms^{-1}	$Bo \,.\, 10^4$
Stratified smooth flow	0·10	0·35	1—26
	0·10	1·50	1—41
Stratified wavy flow	0·10	10·0	14—67
	0·15	4·0	9—102
Annular flow	0·10	25·0	12—217
	0·15	25·0	64—375
Stratified smooth-slug flow	0·25	0·35	3—11
	0·40	0·35	4—108
Bubble flow	0·60	0·35	50—88
Plug flow	0·60	1·00	25—168
Slug flow	0·40	4·00	14—420
	0·60	6·00	2—11
Slug-annular flow	0·60	10·0	44—256
	0·60	15·00	65—180

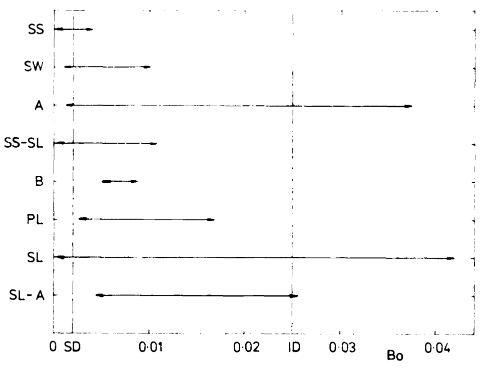

FIG. 3

Axial dispersion characteristics for selected basic flow regime types liquid flow velocity in the bubble flow regime (B), where the liquid is stirred by bubbles, the axial dispersion is higher than small (SD) and lower than intermediate (ID). With increasing gas velocity in the plug flow (PL) region the axial dispersion values remain within the same range, only they are higher. In the slug flow (SL) region, the axial dispersion values cover a wide range from zero to intermediate dispersion (ID). This high dispersion of measured data is fully consistent with the nature of the flow (Fig. 1), where the moment (or site) of injection into the liquid is of importance.

This qualitative evaluation of the axial dispersion in the liquid phase for the basic flow regimes in a horizontal tube reactor demonstrates that, contrary to the common belief[1], axial dispersion is not always negligible; actually, this assumption is only met in the region of the stratified smooth flow regime (SS). In the other flow regimes, the axial dispersion is low as compared to other types of gas–liquid reactors but it is not zero. The data measured lie within a region that can be classed as small dispersion (SD) to intermediate dispersion (ID). Such values should be taken into account when designing chemical reactors. This also applies to the study of flow hydrodynamics in horizontal tube reactors employing the method for the determination of absolute liquid and gas flow velocities based on response conductivity measurements with a pair of electrodes[3].

SYMBOLS

$Bo = D/(vL)$	Bodenstein number
D	axial dispersion coefficient, $m^2 s^{-1}$
L	distance between the two measurement points (length of the measuring section of the reactor), m
v	mean flow velocity in the horizontal direction, $m s^{-1}$
V	volume of the measuring section of the reactor, m
$\dot{V}$	flow rate, $m^3 h^{-1}$
w_G	superficial gas velocity, $m s^{-1}$
w_L	superficial liquid velocity, $m s^{-1}$
$\sigma^2 = \sigma_t^2(\dot{V}/V)^2$	dimensionless variance of the response curve
σ_t^2	variance in time units, s^2

REFERENCES

1. Kaštánek F., Zahradník J., Kratochvíl J., Čermák J.: *Reaktory pro systém plyn–kapalina.* Academia, Prague 1991.
2. Russel T. W. F., Lamb D. E.: Can. J. Chem. Eng. *43*, 237 (1965).
3. Ebner L., Drahoš J., Ebner G., Čermák J.: Chem. Eng. Process *22*, 39 (1987).
4. Ebner L., Drahoš J., Ebner G., Zahradník J.: Presented at *9th CHISA Congress, Prague, August 30—September 4, 1987*; lect. No. A 6. 162.
5. Aris R.: Chem. Eng. Sci. *9*, 266 (1959).
6. Levenspiel O.: *Chemical Reaction Engineering.* Wiley, New York 1962.

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