AXIAL DISPERSION OF THE LIQUID PHASE IN VERTICAL TUBULAR CONTACTORS WITH STATIC MIXERS

Marie FIALOVÁ[a], Karl-Heinz REDLICH[b] and Kurt WINKLER[b]

[a] *Institute of Chemical Process Fundamentals, Czechoslovak Academy of Sciences, 165 02 Prague-Suchdol, Czechoslovakia and*
[b] *Central Institute of Physical Chemistry, Academy of Sciences of the G.D.R., 1199 Berlin, G.D.R.*

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Axial dispersion characteristics in the liquid phase have been determined for three selected types of static mixers using the impulse response technique in a vertical tubular contactor for single phase (water) and two phase (water–air, cocurrent flow arrangement) systems. The character of the measured dependences for individual types of static mixers has been found different and also corresponding values of axial dispersion have been found significant. From the stand point of axial dispersion the behaviour of the static mixer under the two phase flow has been found different from its behaviour in the single phase flow system.

Static mixers have been used in chemical processes to achieve rapid mixing of fluids with low energy requirements while the fluids may have either similar or different viscosity[1–6]. The properties of a good static mixer are good radial mixing on as short as possible flow path, low pressure drop, and as low as possible (zero) axial mixing.

The data on axial mixing for individual types of static mixers are usually missing in scientific as well as commercial literature. Only Sulzer (Gebrueder Sulzer Aktiengesellschaft CH-8401, Winterthur, Schweiz) gives an orientational value of the Peclet number for its SMX products (Pe > 110, d = 0·1 m, L/d = 22) which appears sufficiently high for this type of static mixer.

The aim of this paper has been to test the assumption of negligible axial dispersion in the liquid phase in general for three selected types of static mixers different in geometry and design. The values of axial dispersion in the liquid phase have been measured in a single phase (water) and a two phase (water–air) system.

EXPERIMENTAL

Experimental set-up and experimental conditions. Three types of static mixers were selected, two manufactured of metal sheet — designated as C1[7] (Fig. 1) and M3[8] (Fig. 2) — developed in the Central Institute of Physical Chemistry of the German Academy of Sciences, and a Pyrapak 480 type, manufactured of expanded metal sheet in axial direction (Packets 0·1 m high, each

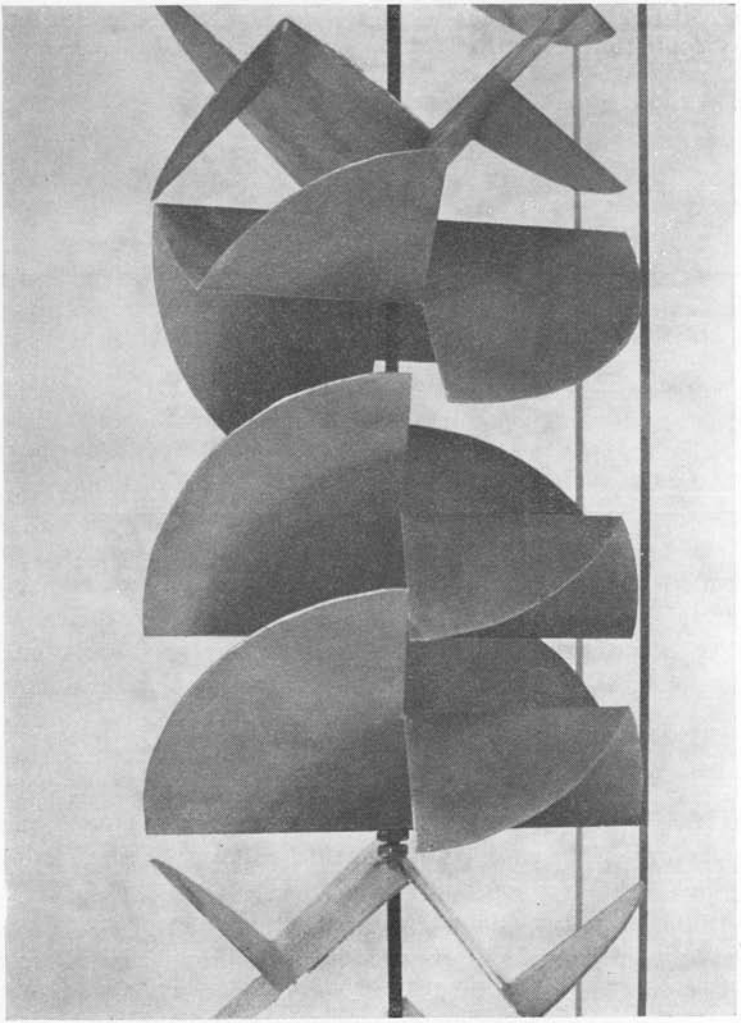

FIG. 1
Mixer type C1

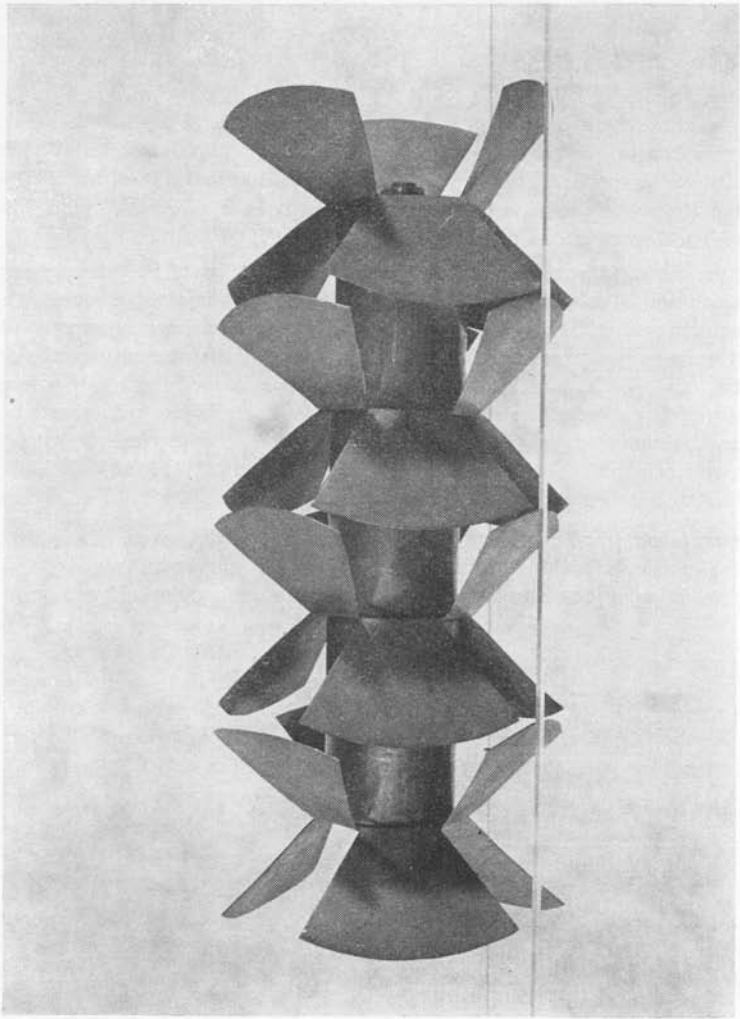

FIG. 2
Mixer type M3

containing 16 segments)[9]. Pyrapak is manufactured industrially by VEB Chemieanlagebaukombinat, Leipzig-Grimma. The experimental equipment is shown schematically in Fig. 3. The tests of the above specified packings were carried out in a column made of a plastic tube 0·1 m in internal diameter, the bottom section of which was transparent. The bottom part was equipped with a streamliner to ensure laminar flow in the entrance section and the top part was equipped with an overflow. Tap water, metered by a rotameter, was fed into the bottom part of the column and discharged *via* the overflow. Air for the two phase flow measurements was brought from the pressurized air network *via* a regulating valve and a rotameter into the column through a cap distributor below the packed section formed by static mixers. The air discharged freely into the atmosphere in the upper part of the column. The height of the packed section was in all cases 2 m in order to ensure sufficient accuracy of measurement. Volume flow rate of liquid across the packed section ranged between 100 and 1 000 l/hour. Corresponding values of the Reynolds number, related to the internal tube diameter, were 350 and 7 000, respectively. The flow rates of air were 0, 300, 900, and 1 500 l/hour.

The impulse signal was realized within 0·75 second by injection of 1·5 cubic centimeters of 40 g per 100 ml solution of natrium benzoate. This amount was injected through a hyppodermic needle using micropump (Micro-dose Pump Type 335, made in Poland) onto the upper surface of the distributing cap for gas and, in this manner, evenly distributed over the column cross section. The response characteristic — the changes of the concentration of natrium benzoate in the stream of liquid were measured by a differential UV analyzer with constant wavelength of 254 nm and simultaneously recorded on a chart recorder and, *via* a digital voltmeter and transducer, on a printer. These measurements were performed in two locations along the column, *i.e.* at the inlet and the outlet into the packed section.

Experimental data processing. The obtained experimental data were processed on the basis of the axial dispersion model by the analysis of moments. From the difference of variances of the concentration curves of the tracer between the two locations along the column length

$$\Delta\sigma_t^2 = (\sigma_t^2)_2 - (\sigma_t^2)_1 , \tag{1}$$

(where the subscripts 1 and 2 relate to the first and the second measuring point) one can evaluate the Peclet number, $\mathrm{Pe} = vL/D$. For a packed bed the Peclet number may be computed from an expression published by Bischoff[10] (valid for open–closed or closed systems):

$$\Delta\sigma^2 = \Delta\sigma_t^2(\dot{V}/V)^2 = 2/\mathrm{Pe} + (\exp(-2\,\mathrm{Pe}) + \\ + 4\exp(-\mathrm{Pe}) + 4\,\mathrm{Pe}\exp(-\mathrm{Pe}) - 5)/\mathrm{Pe}^2 . \tag{2}$$

The applied input signal (time of injection 0·75 s, minimum volume of equipment with a correction on the void fraction amounted to 13·145 l), however, satisfied even at the minimum flow rate of water 100 l/hour the criterion recommended by White[11] for an ideal inlet impulse signal:

$$\Delta t\,\dot{V}/V < 0{\cdot}05 . \tag{3}$$

As in our case the value of this criterion was 0·003, it was in all cases possible to evaluate the Peclet number from the response in a single point, *i.e.* the column outlet, only.

In this case, for a packed bed system (a closed system), we may write[12]

$$\sigma^2 = 2(1 - (1 - \exp(-\mathrm{Pe}))/\mathrm{Pe})/\mathrm{Pe} \tag{4}$$

while for the empty tube without packing and the single and the two phase flow system (open–

-closed system) we have[13]:

$$\sigma^2 = 2/\mathrm{Pe} + 3/\mathrm{Pe}^2 . \qquad (5)$$

RESULTS AND DISCUSSION

The Single Phase Flow System

The values of the axial dispersion characteristics in Fig. 4 indicate that the investigated types of static mixers are considerably different as far as their mixing characteristics are concerned. In addition, the corresponding intensities of axial mixing are not negligible. Minimum values of axial dispersion, characterized in terms of the Peclet number reaches in the whole investigated range the M3 mixer. The C1 type mixer, in the laminar and part of the turbulent region, appears better, as far as axial dispersion is concerned, than Pyrapak 480. For comparison the figure shows also experimental data for the empty tube (without packing).

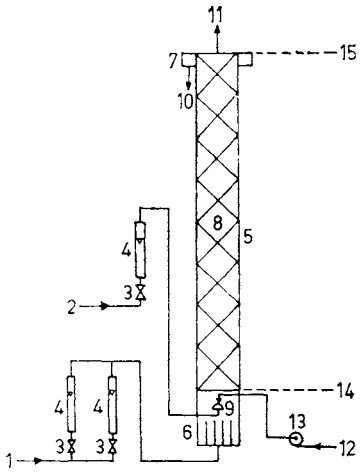

FIG. 3

Scheme of experimental set-up. **1** — water feed, **2** — air feed, **3** — regulating needle valve, **4** — rotameter, **5** — vertical tubular contactor, **6** — flow streamliner, **7** — liquid overflow, **8** — static mixer column packing, **9** — cap gas distributor, **10** — liquid discharge, **11** — air vent, **12** — tracer injection point, **13** — micro dose pump, **14** — inlet signal recording point, **15** — outlet signal recording point

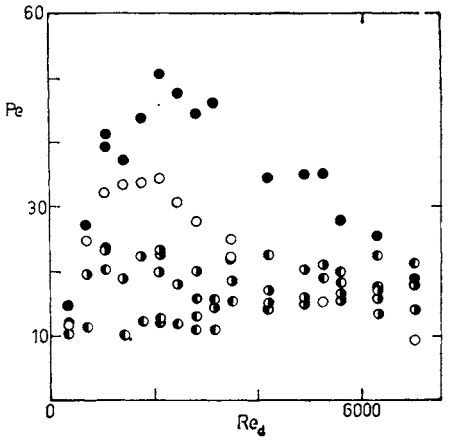

FIG. 4

Axial dispersion for selected types of mixers and water. ○ — type C1, ● — type M3, ◑ — Pyrapak 480, ◐ — empty tube

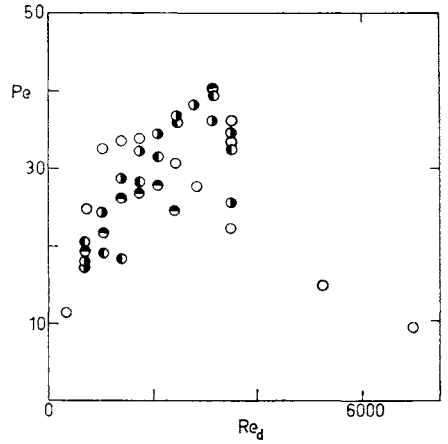

FIG. 5

Axial dispersion for C1 mixer, water–air system and various superficial gas velocities w_G, m/s: ○ — 0; ◑ — 0·105; ◓ — 0·314; ◐ — 0·523

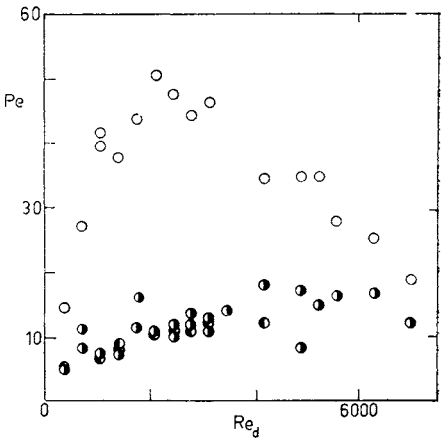

FIG. 6

Axial dispersion for M3 mixer, water–air system and various superficial gas velocities w_G, m/s: ○ — 0; ◑ — 0·105; ◐ — 0·523

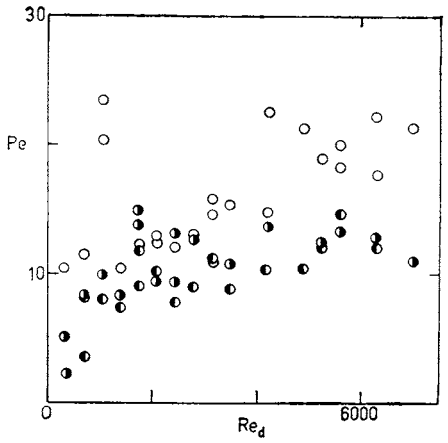

FIG. 7

Axial dispersion for Pyrapak 480 Mixer, water–air system various superficial gas velocities w_G, m/s: ○ — 0; ◑ — 0·105; ◐ — 0·523

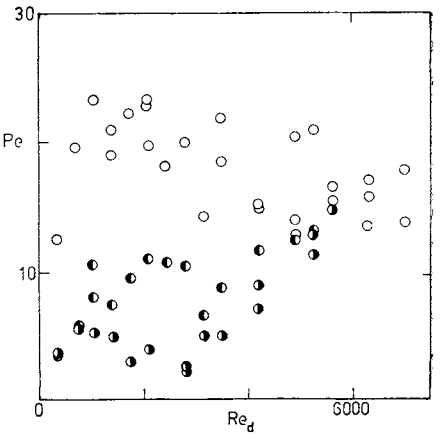

FIG. 8

Axial dispersion in an empty tube and bubble column (water–air system) for various superficial gas velocities w_G, m/s: ○ — 0; ◑ — 0·105; ◐ — 0·523

The Two Phase Flow System

The above static mixers used in a tubular reactor under the two phase flow (water–air) display again, as far as their axial dispersion properties are concerned, a different behaviour one from another and, in addition, different also from the behaviour in a single phase flow system (see Figs 5–8). Unlike the single phase flow case minimum axial mixing displays the C1 type (Fig. 5). The M3 type (Fig. 6) and Pyrapak 480 (Fig. 7) do not differ very much from corresponding values for the empty tube without mixer (Fig. 8). The large scatter of experimental results is ascribed to the character of the employed experimental method and relatively limited number of experiments which ruled out statistical processing.

CONCLUSIONS

From the above experimental results it follows that individual static mixers display different course of the dependence of axial dispersion on the flow rate of the phases both for the single and the two phase flow system. It cannot be *a priori* stated that a static mixer exhibiting good radial mixing properties[9] would in all cases display also low axial mixing. For instance, the C1 and M3 static mixers are so good in mixing efficiency that total extinction of the testing agent (length of the last extinction criterion) takes place already between the first and the second segment of the static mixer. The value of this criterion is better for the C1 type, while the value of the criterion of axial dispersion is more favourable for the M3 type. Equally, a good static mixer, suitable from the stand point of axial mixing for the single phase flow system (in our case the type M3), need not display low axial mixing in the two phase flow case.

The values of the axial dispersion depend on the type of the mixer and on the fact whether the mixer is used in the single or the two phase flow system. These properties can be ascertained by no other than experimental means.

LIST OF SYMBOLS

d	diameter of equipment m
D	coefficient of axial dispersion m^2/s
L	distance between two measuring points (reactor lenght) m
$Pe = vL/D$	Peclet number
$Re_d = 4V/(\pi dv)$	Reynolds number related to the internal tube diameter
Δt	time of duration of the input signal s
v	mean velocity in axial direction m/s
V	reactor volume m^3
$\dot{V}$	volume flow rate m^3/hour
w_G	superficial gas velocity m/s
ν	kinematic viscosity m^2/s
$\sigma^2 = \sigma_t^2(\dot{V}/V)^2$	dimensionless variance of the response curve
σ_t^2	variance in units of time s^2

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