# STATISTICAL PRESSURE CHARACTERISTICS IN MODELLING OF GAS-LIQUID REACTORS

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Received January 19th, 1978

The integral characteristics (average porosity and product $k_La$) and the fluctuating component of static pressure inside the gas-liquid system were measured in two types of column reactors with different gas distributors. It has been determined that at the same gas velocity in the reactor with a Venturi tube as the gas distributor the mean porosities are about 1·5 times greater than with the sieve plate reactor. To this corresponds, especially, at small gas flow rates even higher ratio of coefficients $k_La$. Standard deviation of pressure fluctuations becomes with the Venturi tube reactor for orders of magnitude greater then with the sieve plate reactor. The analysis of pressure fluctuations has demonstrated that in the reactor with the Venturi tube the decisive portion of fluctuation output corresponds to frequencies within the band 10—30 Hz, while in the reactor with the given type of the sieve plate to the band 0—10 Hz. In the reactor with the Venturi tube formation of surface waving has no considerable effect on flow of the gas phase, though the amplitudes in both types of reactors are comparable.

In our former study[1] we have pointed out by means of the frequency mapping technique of pressure fluctuations in vicinity of the distributing plate, that the gas flow pattern depends on two dynamic, mutually interfering phenomena. These are namely the formation of surface waves and the formation of bubbles at the orifices of distributing plate. The relations between them is determined through construction parameters-free area, orifice diameter and the geometrical distribution of orifices on the plate, through operating parameters and the height of dispersion. It then determines the uniformity of gas flow through the plate in time[2] as well as the spatial inhomogeneity inside the system, internal circulating streams and the over-all flow model of both phases. All these factors have to be considered when scaling-up the reactor. Usually only time-averaged values of pressure and porosity are considered in experimental studies of the gas-liquid reactor hydrodynamics. The experimental information about the time variable values of these quantities has been obtained and used rather scarcely till now. Recently in series of papers Agakawa and coworkers[3-6] have carried out an extensive experimental statistical study of the pressure, pressure drop and porosity fluctuations at the "slug-flow" regime inside the tube. Their results, which have confirmed the correspondence of pressure and porosity fluctuations have been also approximated by a theoretical stochastic model together with the verification by experiment.

For our experimental study we have chosen like the first one the column reactor with sieve plate distributor of preselected parameters like the second one the column reactor with the Venturi tube[7-9] distributor with recirculating liquid. In the first one there exists the interdependence of formation of surface waves and bubble formation mechanisms, whereas at the reactor with the Venturi tube which represents itself rather "hard" gas source, considerably less effect of surface waves can be expected, together with substantially less inhomogeneity over the horizontal cross-section. The purpose of our present experimental study consists in the verification of this assumption on one hand and in the possible interpretation of statistical characteristics obtained on the other hand.

For the instantaneous value of pressure in certain horizontal level of dispersion holds

$$p_H \approx \Delta p_{stat} + \Delta p_a + p_0 \,. \tag{1}$$

For the time averaged values holds

$$\bar{p}_H \approx \Delta \bar{p}_{stat} + p_0 = \varrho_L g \int_H^{L_0} (1 - \bar{e}) \, dy \,, \tag{2}$$

$$\Delta p_{stat} \approx \varrho_L g \int_H^{L_0} (1 - e(t)) \, dy \; ; \quad \Delta p_a = \varrho_L' \int_H^{L_0} (1 - e(t)) \frac{\partial v}{\partial t} \, dy \tag{3}$$

$H$, $L_0$ being the vertical distances of the measuring point and of some hypothetical boundary of the dispersion respectively from the reference level of the distributor, $p_0$ being the pressure above the system boundary which can be considered as constant.

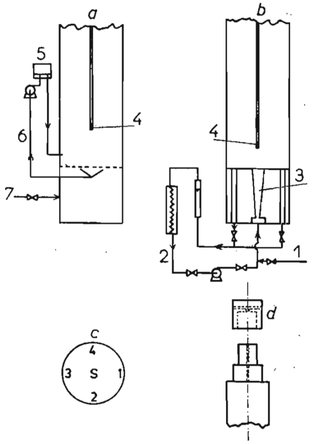

Fig. 1

Experimental Apparatus with Location of Measuring Points

*a* Column reactor with sieve tray; *b* column reactor with Venturi tube; *c* location of measuring points; *d* pressure sensor. *1* Air, *2* water, *3* Venturi tube, *4* pressure probe, *5* over-flow, *6* water, *7* air.

While the second term in Eq. (*2*) which corresponds to the pressure variation due to acceleration or deceleration caused by surface waves is significant under the conditions of oscillatory regime of sieve trays[10], it is possible to demonstrate that at amplitudes of waves at low gas velocities in bubble reactor this term can be neglected. In Eq. (*1*) the possible variations of the pressure caused by acoustic effects, surface tension or friction at the column wall have not been considered. The fluctuating component of pressure reflects itself therefore the dynamic changes in porosity, which as shown before[9] substantially influences the mass transfer coefficient value.

## EXPERIMENTAL

Both experimental equipments are schematically drawn in Fig. 1. For pressure measurements, the special pressure sensor with semiconductor membrane tensometer produced by the Institute of Thermomechanics of the Czechoslovak Academy of Sciences, constructed for the direct measurement inside the two phase dispersion, has been used[11,12]. It permits the measurement of pressure fluctuations of very low amplitude of the order Pa and of high frequencies (max 1 kHz). The electric signal was amplified into the range 0—5 V and processed by the statistical data analysis system described elsewhere[1] (Fig. 2). The signal was processed in two different ways *i.e.* without the filtration of high frequency components and after the passage through the analogue filter with the upper limiting frequency 30 Hz. In this way the more detailed statistical information has been obtained about the fluctuations occuring within the frequency range notified in the former works[1,3-6]. At the processing of filtered signals the sampling frequency used to be 1 kHz and the estimates of dispersion and autocorrelation function were obtained from the total of 16 × 1024 samples. At the processing of filtered signals sampling frequency used to be 100 Hz and the total of samples 2 × 1048. The estimates of power spectral densities from the

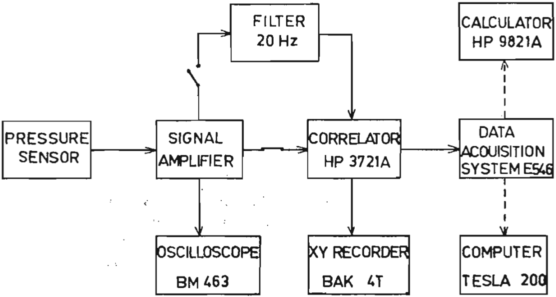

FIG. 2
Systems for Signal Processing

values of the estimates of autocorrelation function and at maximum time lag 100 samples were calculated at the corresponding resolutions 10 Hz for unfiltered and 1 Hz for filtered signal respectively.

## RESULTS

In Table I the most important integral characteristics for two reactors and regimes studied are given. The average porosity values were obtained through the integration of porosity profiles given in Fig. 3 obtained from the time averaged pressure differences over the height of reactor[10]. The considerable dispersion of the curves in Fig. 3 reflects the difficulty in obtaining the estimates of mean value of pressure in time with enough accuracy. Mass transfer coefficients $k_La$ were obtained by the method described by Kaštánek and coworkers[13]. At the same gas flow-rate values approximately 1·5 times higher values can be obtained on the average in reactor with the Venturi distributor as compared with the results obtained in the reactor with sieve distributor. This corresponds, especially, at low gas flow rates to significantly higher ratio of coefficients $k_La$ as can be seen from Table I.

The statistical changes of the estimates of basic statistical characteristics of pressure fluctuations- *i.e.* of the standard deviation of unfiltered and filtered signals are pre-

TABLE I

Comparison of Selected Integral Characteristics of Column Reactor with Sieve Tray and Venturi Tube (in brackets, relative values are given)

| | Sieve, $\varphi = 6\%$, $d = 5$ mm | | Venturi, $L = 75\ \text{l min}^{-1}$ | | Venturi, $L = 90\ \text{l min}^{-1}$ | |
|---|---|---|---|---|---|---|
| G, $\text{l h}^{-1}$ | $\bar{e}$ | $k_La$ | $\bar{e}$ | $k_La$ | $\bar{e}$ | $k_La$ |
| 2 000 | 0·80 | 0·003 | 2·04 | 0·018 | 2·49 | 0·015 |
| | (1·00) | (1·00) | (1·00) | (1·00) | (1·00) | (1·00) |
| 4 000 | 3·77 | 0·017 | 5·45 | 0·036 | 4·84 | 0·034 |
| | (4·72) | (5·65) | (2·67) | (2·00) | (1·94) | (2·26) |
| 8 000 | 9·78 | 0·041 | 13·25 | 0·086 | 13·35 | 0·101 |
| | (12·21) | (13·70) | (6·52) | (4·78) | (5·35) | (6·72) |

| G, $\text{l h}^{-1}$ | $\bar{e}$ (Venturi)/$\bar{e}$ (Sieve) | $\overline{k_La}$ (Venturi)/$\overline{k_La}$ (Sieve) |
|---|---|---|
| 2 000 | 2·83 | 5·50 |
| 4 000 | 1·36 | 2·06 |
| 8 000 | 1·36 | 2·27 |

sented in Table II. The changes of the total average of the estimates from all measuring points $\sigma_{AV}$ at different regimes are given together with the standard deviation of the averages obtained by averaging the estimates from measuring points at the same horizontal ($\sigma_{vert.}$) and vertical ($\sigma_{hor.}$) coordinate from the total average $\sigma_{AV}$. From the Table the order of magnitude difference in values of $\sigma_{AV}$ in two different reactors can be seen, considering the values at corresponding gas flow rates. At the same time its increase when augmenting gas flow rate in both equipments results. Finally its increase when augmenting the flow of recirculating liquid through Venturi tube at the constant gas flow rate can be seen. At the same time, however, the vertical inhomogeneity considerably increases in the reactor with Venturi tube as compared with that of the sieve tray, especially at larger gas flow rates characterizing the variation coefficient $V_{vert.}$. When augmenting the gas flow rate the vertical inhomogeneity in the Venturi tube reactor increases, whereas the opposite is true with the sieve tray reactor. The inhomogeneity over the horizontal cross-section is, however, in the reactor with the Venturi tube remarkably less, as is demonstrated by the values of

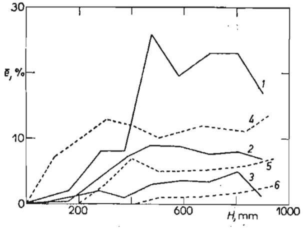

FIG. 3

Porosity Profiles along the Height of Gas–Liquid Mixture Obtained from Differences of Static Pressure

Reactor with Venturi tube 1 $G = 8000\ l\ h^{-1}$, $L = 90\ l\ min^{-1}$, 2 $G = 4000\ l\ h^{-1}$, $L = 90\ l\ min^{-1}$, 3 $G = 2000\ l\ h^{-1}$, $L = 90\ l\ min^{-1}$; reactor with sieve tray 4 $G = 8000\ l\ h^{-1}$, 5 $G = 4000\ l\ h^{-1}$, 6 $G = d = 2000\ l\ g^{-1}$.

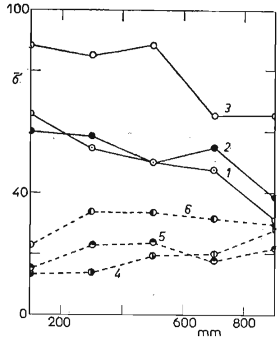

FIG. 4

Dependence of Standard Deviation of Original and Filtered Signal of Pressure Fluctuations on Distance from Distributing Tray

| $G$ $l\ h^{-1}$ | Original signal | Filtered signal |
|---|---|---|
| 2 000 | 1 | 4 |
| 4 000 | 2 | 5 |
| 8 000 | 3 | 6 |

variation coefficient $V_{\text{hor.}}$. The dependence of the values $\sigma$ obtained by averaging the estimates from measuring points over the same horizontal cross section at the vertical distance from distributor is plotted in Fig. 4.

The ratio of values $\sigma_{\text{AV}}$ for filtered and unfiltered signal points to the considerable fraction of high frequency components in the spectrum of pressure fluctuations. At the reactor with the sieve tray the value of this ratio does not depend on gas flow rate, whereas at the Venturi tube reactor the fraction of higher frequency components considerably decreases when augmenting gas flow rate. At the same time the results obtained have shown, that the value of the ratio increases with the distance from sieve tray distributor, being the opposite true in Venturi tube reactor. Even if some former studies report the presence of high frequency components of the order $10^2$ Hz at the passage of very small bubbles in two phase gas–liquid flow, this explanation could not be accepted without caution. As the source of high frequencies the accoustic phenomena in gas–liquid dispersion, mechanical vibrations as well as the proper

TABLE II

Selected Statistical Characteristics of Pressure Fluctuations in Column Reactor with Sieve Tray and Venturi Tube

| $L$ <br> l min$^{-1}$ | $G$ <br> l h$^{-1}$ | $\sigma_{\text{AV}}$ <br> Pa | $\bar{\sigma}_{\text{vert}}$ <br> Pa | $\bar{\sigma}_{\text{hor}}$ <br> Pa | $V_{\text{vert}}$ | $V_{\text{hor}}$ | $\frac{\sigma_{\text{AV}}(\text{filtered})}{\sigma_{\text{AV}}(\text{original})}$ |
|---|---|---|---|---|---|---|---|
| | | | Sieve | | | | |
| — | 2 000 | 49·5 | ±12·98 | ±7·48 | 0·262 | 0·151 | —[a] |
| — | 4 000 | 62·2 | ± 8·52 | ±4·40 | 0·163 | 0·084 | —[a] |
| — | 8 000 | 78·1 | ±12·24 | ±8·93 | 0·157 | 0·114 | —[a] |
| — | 2 000 | 18·9 | ± 6·14 | ±5·03 | 0·325 | 0·266 | 0·382[b] |
| — | 4 000 | 20·2 | ± 3·97 | ±3·82 | 0·196 | 0·189 | 0·387[b] |
| — | 8 000 | 30·2 | ± 4·47 | ±3·78 | 0·148 | 0·125 | 0·387[b] |
| | | | Venturi | | | | |
| 75 | 2 000 | 418·3 | ±162·10 | ± 5·38 | 0·388 | 0·012 | —[a] |
| | 4 000 | 463·9 | ±221·07 | ±29·91 | 0·477 | 0·064 | —[a] |
| 90 | 2 000 | 1 099·2 | ±288·10 | ±41·72 | 0·262 | 0·038 | —[a] |
| | 4 000 | 736·7 | ±387·20 | ±48·80 | 0·526 | 0·066 | —[a] |
| 75 | 2 000 | 196·7 | ±116·55 | ± 1·91 | 0·593 | 0·010 | 0·470[b] |
| | 4 000 | 332·7 | ±207·35 | ± 2·14 | 0·623 | 0·006 | 0·717[b] |
| 90 | 2 000 | 345·9 | ±231·60 | ±15·34 | 0·670 | 0·044 | 0·315[b] |
| | 4 000 | 495·3 | ±316·2 | ±13·65 | 0·638 | 0·028 | 0·672[b] |

[a] Original, [b]filtered.

dynamics of sensor can be considred. This merits itself a separate study. The characteristic frequencies which occur in different frequency ranges of pressure fluctuations spectrum are given in Tables III and IV. We have found of special interest the distribution of the power of pressure fluctuations into different frequency ranges as expressed by the ratio $k_{f1-f2}$. From Tables V and VI the changes of this quantity for some selected frequency bands in the original and filtered signal which result with varying the measuring position and operating parameters of the reactors can be seen. The variation coefficients of the estimates $\bar{k}_{f1-f2}$ obtained by averaging the values of $k$ from measuring points with the same horizontal or vertical ordinate point out similarly as the values of standard deviation to the higher inhomogeneity over the horizontal cross section in sieve tray reactor. The dependences of $\bar{k}_{0-10}$ and $\bar{k}_{20-30}$ obtained by averaging the values from measuring points at the distance $H$ from the distributor are plotted in Figs 5 and 6. It is obvious that in the reactor with sieve tray the fluctuations in the band 0–10 Hz prevail over the whole volume of

TABLE III

Characteristic Frequencies in the Spectra of Original and Filtered Signals of Pressure Fluctuations in Reactor with Sieve Tray

| $G$<br>l h$^{-1}$ | $H$, m | | | | | Frequency band Hz |
|---|---|---|---|---|---|---|
| | 0·1 | 0·3 | 0·5 | 0·7 | 0·9 | |
| 2 000 | — | 20 | 20 | 20 | — | 0–20 |
| 4 000 | 20 | 20 | — | — | — | |
| 8 000 | — | — | — | — | — | |
| 2 000 | — | 80 | — | 40; 90 | 80 | 20–100 |
| 4 000 | 50; 70 | 30; 70 | 30; 70 | 30, 70 | 70 | |
| 8 000 | 40; 80 | 40; 90 | 40; 70 | 40; 70 | 50; 90 | |
| 2 000 | 120 | 120 | 120 | 120 | — | 100–200 |
| 4 000 | 170 | 120 | 120 | 150 | — | |
| 8 000 | 150 | 150 | 130 | 110 | — | |
| 2 000 | 260 | 260 | 260, 30 | 200 | 220, 270 | 200 |
| 4 000 | 230, 270 | 290, 370 | 370 | 210 | 230 | |
| 8 000 | 310 | — | — | — | — | |
| 2 000 | 1; 3 | 1 | 1; 2 | 1; 2 | 1; 3 | 0–10 |
| 4 000 | 1; 2 | 1; 2 | 1 | 1 | 1; 3 | |
| 8 000 | 1; 4 | 1; 4 | 1; 3 | 1; 3 | 1, 3 | |
| 2 000 | 18; 31 | 18; 29 | — | 29 | — | 10–30 |
| 4 000 | 18; 29 | 25 | — | — | 15 | |
| 8 000 | 18; 29 | 18; 29 | 18 | 18 | 19 | |

dispersion (from Table IV results, that there are frequencies 1, 3 – 4 Hz), the decisive fraction in the reactor with Venturi tube corresponds to the band 20 – 30 Hz. In Table VII there are given equivalent amplitudes-contributions of pressure fluctuations in the separate frequency bands to the total amplitude of filtered fluctuations in their absolute value and in their relative value after division by the corresponding average pressure value. The relative values approximately correspond to the fluctuations of porosity within the reactor section between levels $H$-$L_0$.

Comparison of the relative values at $H = 0{\cdot}9$ m for the two reactors points out, that the very low frequency porosity fluctuations (0 – 10 Hz) near the dispersion boundary, which are caused predominantly by surface waves, are comparable in magnitude in both types of reactors (with the amplitude 1 – 5 mm). The porosity fluctuations within the band 20 – 30 Hz caused by bubble passage are substantially higher in the reactor with the Venturi tube. This fact with no regards to the additional information, could be interpreted in different ways especially as for the equivalent

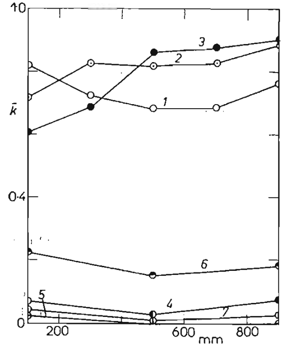

Fig. 5

Relative Power $\bar{k}$ in Frequency Band 0—10 Hz of Filtered Signal Reactor with Sieve Tray

1 $G = 8000\ \text{l h}^{-1}$, 2 $G = 4000\ \text{l h}^{-1}$, 3 $G = 2000\ \text{l h}^{-1}$; reactor with Venturi tube 4 $G = 2000\ \text{l h}^{-1}$, $L = 75\ \text{l min}^{-1}$ 5 $G = 2000\ \text{l h}^{-1}$, $L = 90\ \text{l min}^{-1}$, 6 $G = 4000\ \text{l h}^{-1}$, $L = 75\ \text{l min}^{-1}$ 7 $G = 4000\ \text{l h}^{-1}$, $L = 90\ \text{l min}^{-1}$.

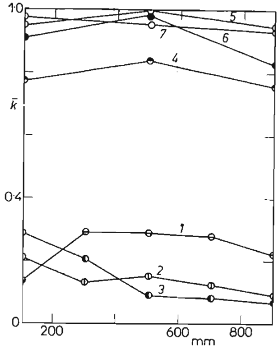

Fig. 6

Relative Power $\bar{k}$ in Frequency Band 20—30 Hz of Filtered Signal

Reactor with sieve tray 1 $G = 8000\ \text{l h}^{-1}$, 2 $G = 4000\ \text{l h}^{-1}$, 3 $G$ $2000\ \text{l h}^{-1}$. Reactor with Venturi tube 4 $G = 4000\ \text{l h}^{-1}$, $L = 75\ \text{l min}^{-1}$, 5 $G = 4000\ \text{l h}^{-1}$, $L = 90\ \text{l min}^{-1}$, 6 $G = 2000\ \text{l h}^{-1}$, $L = 75\ \text{l min}^{-1}$, 7 $G = 2000\ \text{l h}^{-1}$, $L = 90\ \text{l min}^{-1}$.

TABLE IV

Characteristic Frequencies in the Spectra of Original and Filtered Signals of Pressure Fluctuations in Reactor with Venturi Tube

| $G$<br>l h$^{-1}$ | $L$<br>l min$^{-1}$ | $H$, m |  |  | Frequency band Hz |
|---|---|---|---|---|---|
|  |  | 0·1 | 0·5 | 0·9 |  |
| 2 000 | 75 | 18 | 18 | 18 | 0—20 |
|  | 90 | 20 | 3; 20 | 20 |  |
| 4 000 | 75 | 12; 13 | 13; 14 | 12; 15 |  |
|  | 90 | 10; 20 | 10; 20 | 10; 20 |  |
| 2 000 | 75 | 24; 48 | 24; 48 | 48 | 20—100 |
|  | 90 | 24; 80 | 24; 48 | 80 |  |
| 4 000 | 75 | 36; 50 | 30; 80 | 40; 80 |  |
|  | 90 | 40; 80 | 30; 80 | 40; 80 |  |
| 2 000 | 75 | — | — | 140 | 100—200 |
|  | 90 | 110 | — | 160 |  |
| 4 000 | 75 | — | — | 108 |  |
|  | 90 | 130 | 130; 180 | 130; 170 |  |
| 2 000 | 75 | 1; 8—10 | 2; 8—10 | — | 0—10 |
|  | 90 | 1; 9—10 | 9—10 | — |  |
| 4 000 | 75 | 1; 8—10 | 9—10 | 8—10 |  |
|  | 90 | 2; 8 | — | — |  |
| 2 000 | 75 | 18; 24 | 18; 24 | 18; 24 | 10—30 |
|  | 90 | 10; 25 | 10; 25 | 25 |  |
| 4 000 | 75 | 12; 24; 36 | 12; 13; 25 | 12; 25 |  |
|  | 90 | 13 | 15; 24 | 15; 25 |  |

TABLE V

Dispersion of Mean Fraction $\bar{k}$ of Filtered Output Signal of Pressure Fluctuations in Different Frequency Bands in Reactor with Sieve Tray

| $G$<br>l h$^{-1}$ | $k_{AV}$ | $\sigma_{vert}(\bar{k})$ | $\sigma_{hor}(\bar{k})$ | $V_{vert}$ | $V_{hor}$ | Frequency band Hz |
|---|---|---|---|---|---|---|
| 2 000 | 0·7891 | 0·1461 | 0·0880 | 0·1851 | 0·1125 | 0—10 |
| 4 000 | 0·8137 | 0·0607 | 0·0176 | 0·0746 | 0·0209 |  |
| 8 000 | 0·7441 | 0·0576 | 0·0231 | 0·0774 | 0·0311 |  |
| 2 000 | 0·0883 | 0·0487 | 0·0308 | 0·5510 | 0·3493 | 10—20 |
| 4 000 | 0·0795 | 0·0146 | 0·0170 | 0·0183 | 0·2140 |  |
| 8 000 | 0·1808 | 0·0505 | 0·0220 | 0·2793 | 0·1216 |  |
| 2 000 | 0·0604 | 0·0458 | 0·5304 | 0·7592 | 0·5035 |  |
| 4 000 | 0·0641 | 0·0333 | 0·0699 | 0·5200 | 0·1541 | 20—30 |
| 8 000 | 0·0563 | 0·0200 | 0·355 | 0·0076 | 0·1590 |  |

diameter and number of bubbles which are passing through the control volume per unit of time. Jointly with the difference in values of the average porosities the natural explanation of the formation of greater number of bubbles of less diameter is at hand, which would involve the increased interfacial area and thus the higher values of $k_La$.

As the bubbles themselves are statistical in nature, the dispersion of any integral quantity resulting from the sum of statistical quantities increases proportionally to the number of these quantities. On the other hand the changes in the statistical parameters of individual quantities have to be taken in question, *i.e.* not only the change in equivalent diameter, but also the size distribution characterized in the simplest case by the dispersion of diameters of individual bubbles only. Together with statistical quantities which characterize the process of bubble formation in time-like the correlation among the moments of formation of the individual bubbles, their velocities *etc.* All these factors have to be included when attempting to formulate a statistical model which would fitt the presented experimental data. This is beyond the scope of the presented paper.

Finally, it could be concluded: The experimental results have confirmed some advantages of the bubble reactor with the Venturi tube distributor as it results in higher average porosities and higher values of $k_La$ parameter at the same gas flow rate. With it goes substantially higher homogeneity over the horizontal cross-section.

TABLE VI

Dispersion of Mean Fraction $\bar{k}$ of Filtered Output Signal of Pressure Fluctuations in Different Frequency Bands in Reactor with Venturi Tube

| $G$ l h$^{-1}$ | $L$ l min$^{-1}$ | $k_{AV}$ | $\sigma_{vert}(\bar{k})$ | $\sigma_{hor}(\bar{k})$ | $V_{vert}$ | $V_{hor}$ | Frequency band Hz |
|---|---|---|---|---|---|---|---|
| 2 000 | 75 | 0·0545 | 0·0068 | 0·0275 | 0·5048 | 0·1244 | 0—10 |
| 2 000 | 90 | — | — | — | — | — | — |
| 4 000 | 75 | 0·185 | 0·0351 | 0·0354 | 0·190 | 0·191 | |
| 4 000 | 90 | 0·0187 | 0·0137 | 0·0056 | 0·7334 | 0·3001 | |
| 2 000 | 75 | 0·551 | 0·1328 | 0·00283 | 0·2411 | 0·0051 | 10—20 |
| 2 000 | 90 | 0·086 | 0·0922 | 0·01371 | 1·072 | 0·1594 | |
| 4 000 | 75 | 0·724 | 0·0734 | 0·0410 | 0·1013 | 0·0566 | |
| 4 000 | 90 | 0·908 | 0·0593 | 0·0014 | 0·0654 | 0·0016 | |
| 2 000 | 75 | 0·364 | 0·0864 | 0·0170 | 0·2374 | 0·0466 | 20—30 |
| 2 000 | 90 | 0·867 | 0·0767 | 0·0057 | 0·0885 | 0·0065 | |
| 4 000 | 75 | 0·0679 | 0·0497 | 0·0062 | 0·7320 | 0·0915 | |
| 4 000 | 90 | 0·0610 | 0·0432 | 0·0028 | 0·7085 | 0·0464 | |

TABLE VII

Equivalent and Relative Amplitudes of Filtered Signal of Pressure Fluctuations (in Pa) in Frequency Bands 0—10 and 10—30 Hz in Reactor with Sieve Tray and Venturi Tube

| $H$, m | $Y^a$ for $G$ | | | $X^b$ for $G$ | | |
|---|---|---|---|---|---|---|
| | 2 000 | 4 000 | 8 000 | 2 000 | 4 000 | 8 000 |
| Sieve tray, band 0—10 Hz | | | | | | |
| 0·1 | 10·3 | 12·5 | 20·8 | 0·12 | 0·14 | 0·26 |
| 0·3 | 11·4 | 21·5 | 29·0 | 0·17 | 0·32 | 0·47 |
| 0·5 | 18·1 | 21·5 | 28·0 | 0·37 | 0·46 | 0·63 |
| 0·7 | 14·8 | 15·8 | 26·0 | 0·63 | 0·56 | 0·98 |
| 0·9 | 27·0 | 20·1 | 26·2 | 2·80 | 2·16 | 3·00 |
| Sieve tray, band 10—30 Hz | | | | | | |
| 0·1 | 7·1 | 6·8 | 8·6 | 0·08 | 0·08 | 0·11 |
| 0·3 | 6·2 | 8·7 | 17·0 | 0·09 | 0·13 | 0·27 |
| 0·5 | 5·9 | 9·2 | 18·2 | 0·12 | 0·20 | 0·41 |
| 0·7 | 5·7 | 6·2 | 16·8 | 0·20 | 0·22 | 0·64 |
| 0·9 | 7·7 | 6·6 | 14·1 | 0·80 | 0·70 | 1·60 |
| Venturi tube, $L = 75$ l min$^{-1}$, band 0—10 Hz | | | | | | |
| 0·1 | 87·4 | 246·8 | — | 0·90 | 2·90 | — |
| 0·5 | 28·5 | 140·0 | — | 0·60 | 3·00 | — |
| 0·9 | 17·1 | 48·3 | — | 1·80 | 4·70 | — |
| Venturi tube, $L = 75$ l min$^{-1}$, band 10—30 Hz | | | | | | |
| 0·1 | 323·4 | 462·4 | — | 3·69 | 5·50 | — |
| 0·5 | 185·9 | 329·8 | — | 3·90 | 7·18 | — |
| 0·9 | 57·3 | 98·5 | — | 6·00 | 10·63 | — |
| Venturi tube, $L = 90$ l min$^{-1}$, band 0—10 Hz | | | | | | |
| 0·1 | 82·6 | 138·8 | — | 0·95 | 1·64 | — |
| 0·5 | — | 47·0 | — | — | 1·00 | — |
| 0·9 | — | 14·3 | — | — | 1·94 | — |
| Venturi tube, $L = 90$ l min$^{-1}$, band 10—30 Hz | | | | | | |
| 0·1 | 561·9 | 741·4 | — | 6·44 | 8·75 | — |
| 0·5 | 350·8 | 583·0 | — | 7·21 | 12·42 | — |
| 0·9 | 104·2 | 140·8 | — | 10·37 | 14·99 | — |

[a] $Y = (\sqrt{}k_{0-10} \cdot \bar{\sigma})_{\mathrm{hor}}$ or $(\sqrt{}k_{10-30} \cdot \bar{\sigma})_{\mathrm{hor}}$, [b] $X = Y/\varrho_L g \int_H^{L_0} (1 - \bar{e})\,\mathrm{d}y\ 10^2$.

The formation of surface waves is not of any importance to the bubble formation process. This is particularly favourable from the point of view of scaling up this type of reactor compared to the reactor with sieve distributor.

The increased vertical inhomogeneity in this type of reactor indicates that substantially closer approximation to plug-flow model of gas phase results, what could be advantageous in special cases.

There was found no adequate explanation of the presence of high frequency components in the spectrum of pressure fluctuations, which have not been reported often so far, possibly for the reason of sensors used (connecting tubes filled with liquid which have dumping effect on these frequencies).

Our observations regarding the dependence of standard deviation of pressure fluctuations on gas flow rate, the distance from boundary and liquid flow rate agree with the results published recently[3-6].

## LIST OF SYMBOLS

| | |
|---|---|
| $e$ | porosity (—) |
| $f$ | frequency (Hz) |
| $g$ | gravitational acceleration (m s$^{-2}$) |
| $G$ | gas flow rate (l h$^{-1}$) |
| $H$ | vertical distance from distributor (m) |
| $k$ | power fraction (—) |
| $k_La$ | mass transfer coefficient (s$^{-1}$) |
| $L$ | liquid flow rate (l min$^{-1}$) |
| $p$ | pressure (Pa) |
| $t$ | time (s) |
| $v$ | velocity (m s$^{-1}$) |
| $V$ | variation coefficient (ratio between standard deviation and the mean value or their estimates) |
| $R(\tau) = (1/T) \int_0^T p(t)\, p(t + \tau)\, \mathrm{d}t$ | estimate of autocorrelation function of pressure fluctuations (Pa$^2$) for time lag $\tau$(s) and the time record of the length $T$ (s) |
| $S = \int_0^{\tau_{\max}} k(\tau)\, R(\varrho) \cos(2\pi f\tau)\, \mathrm{d}\tau$ | estimate of power spectral density of pressure fluctuations for maximum time lag $\tau_{\max}$ and weight function $h(\tau)$ |
| $\varrho_L$ | liquid density (kg m$^{-3}$) |
| $\sigma^2$ | dispersion, estimates of dispersion |
| $\sigma$ | standard deviation |

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Translated by M. Rylek.