ELSEVIER

Chemical Engineering Journal 68 (1997) 207–210

Chemical Engineering Journal

Short Communication

Experimental observation of pressure drop overshoot following an onset of gas flow in counter-current beds

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Received 13 November 1996; revised 6 August 1997; accepted 19 August 1997

Abstract

The paper presents results of an experimental study of the hydrodynamics of a counter-current packed bed column undergoing a step change in the inlet velocity of the gas phase. The experimental transient curves are presented for the total pressure drop across the column and the pressure profile along the column height. Characteristic overshoots have been observed on the transient curves of the pressure drop and pressure profiles within the bed when the irrigated bed is suddenly exposed to the flow of gas. These rather unexpected overshoots appear temporarily after the onset of gas flow and cannot be explained by existing two-phase flow models. © 1997 Elsevier Science S.A.

Keywords: Pressure overshoot; Counter-current; Liquid hold-up; Pressure drop; Transient flow

1. Introduction

There exists continuing interest in the study of fluid dynamics in irrigated packed beds due to its theoretical importance and potential for industrial practice [1–11]. In spite of this interest the ability of describing the phenomena taking place under the counter-current flow in a packed bed in terms of first principles is rather limited.

Our earlier papers [4,5] in this field concentrated on the development of the experimental set-up capable of providing reliable experimental data regarding the instantaneous state of the gas–liquid flow and the liquid hold-up and gas pressure drop in particular.

Other papers [6–11] presented the experimental results of liquid hold-up and gas pressure drop. Steady state results were interpreted on the basis of automodel properties, transient data interpreted in terms of a simple first order kinetic model and as maps in the gas and liquid flow rate domain.

This paper presents result of experimental observation of an overshoot on the pressure drop transient profiles.

2. Experimental

The experimental part of this study has been carried out on a set-up developed earlier for the measurement of the steady state and transient hydrodynamics of counter-current packed bed columns [4].

The principal part of the apparatus is a column suspended under operating conditions on a tensometric balance. Various columns may be employed up to a maximum of 0.3 m diameter and a maximum of 1.25 m total column height. In the current study the column was packed with 10 mm diameter glass spheres to 1 m depth. In the experiments the irrigating liquid was tap water and the gas was air.

The instantaneous value of liquid hold-up is computed from the instantaneous apparent weight of the column indicated by the tensometric gauge and from the total pressure drop of gas.

The set-up enables also measurement of the pressure profile along the column height using piezo-resistive pressure transducers. The pressure ports are located evenly at 0.2 m pitch along the wall of the packed section of the column starting from the grid supporting the packing. There is a total of six pressure transducers.

The port picking up the overall pressure drop is located in the gas-occupied space below the supporting grid. The last port is level with the top of the packing. The last transducer detects eventual presence of gas–liquid mixture on the top of the packed section indicating the onset of flooding.

The set-up enables step changes imposed on the flow rate of either gas or liquid. In both cases this is achieved by manual-control by-pass loops in the gas and liquid lines each equipped with a manual regulation valve and an on–off mag-

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PII S1385-8947(97)00096-X

netic valve. The magnetic valve triggers the step change in the flow rate whose magnitude is pre-set by the adjustment of the manual control valve in the by-pass loop.

The whole set up is monitored by a Hewlett-Packard data logger and computer. These instruments provide also for a programmed control of the imposed flow rate change and simultaneous data acquisition.

3. Results and discussion

3.1. Pressure overshoot observation

An experiment has been devised in which the bed was irrigated by water at a constant rate while the gas flow rate was suddenly increased. The above described experimental set up monitored the transients of the liquid hold up, overall pressure drop and pressures at all ports along the height of the packed section. The monitoring took place throughout the transient process until the system reached a new steady state.

The experiment thus represents the response of an irrigated column to the onset of gas flow. The instant when the flow change action is triggered is at time equal 8 s in the following figures.

Fig. 1a–e plot the time development of the overall gas pressure drop following a step change of gas flow rate from zero to 5 m^3/h while the liquid volume flow rate was kept constant and equal 1.4 m^3/h.

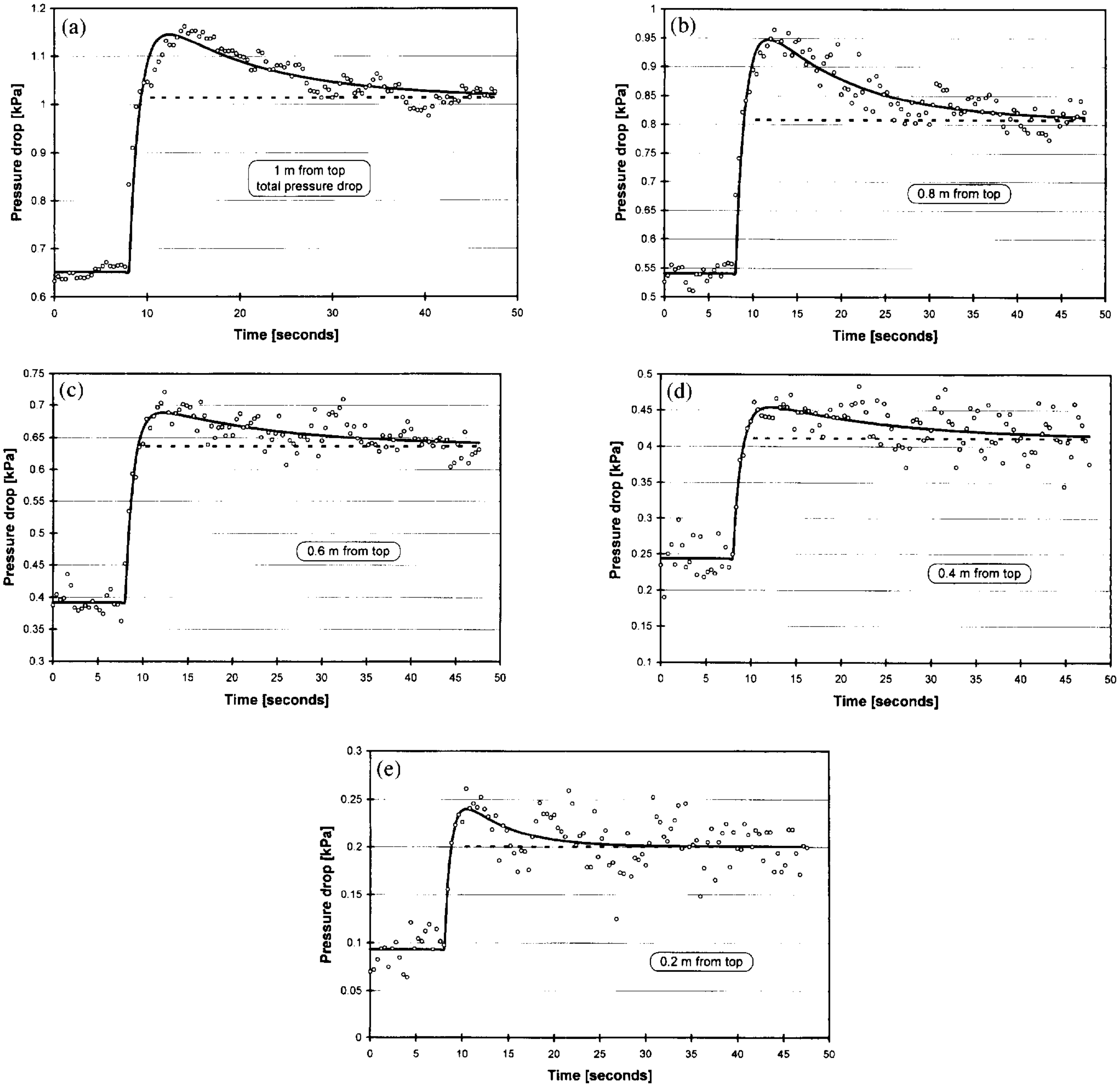

Fig. 1. (a–e) Transient pressure drop following a step increase in gas rate for different section of the packed bed. Solid lines: fitted curve; broken lines: final steady; empty circles: experiment.

Individual figures plot the transient development of the pressure over different sections of the packed height: Fig. 1a shows the pressure difference across the whole packed section of the column 1 m deep, i.e., the total pressure drop. Fig. 1b–e plot the pressure differences over 0.8 m, 0.6 m, 0.4 m and 0.2 m deep sections of the packed height respectively. The height of these sections was in all cases measured from the top of the packed bed.

Fig. 1a displays a rather unexpected pattern of behaviour: after the onset of gas flow the overall pressure drop sharply increases and significantly exceeds the final steady state value. The new steady state pressure drop is reached from above and it takes about 1 min.

For clarity and some quantitative evaluation the experimental data points were fitted by a curve consisting of two exponentials. This optimum curve is shown by a solid line. Broken line shown in the figure indicates the final steady state pressure drop. The final steady state value is an experimentally determined quantity.

Inspection of Fig. 1b–e reveals qualitatively the same picture: The overshoot appears on all experimentally investigated sections of the bed. In all cases the new steady state after the onset of gas flow is approached from above.

Correlation of the newly reached steady state pressure drops against the depth of the depth of the section over which the pressure drop was measured yielded the following equation:

$$\Delta P_{\mathrm{newsteadystate}}[\mathrm{kPa}] = 0.0056 + 1.014\, z[m] \tag{1}$$

with a high correlation coefficient equal to 0.9983.

The value of the intercept in the above correlation is low compared to the mean value of pressure drop (zero pressure drop over zero depth of the section). This result indicates that the distribution of energy dissipation along the height of the packed section is fairly uniform without significant irregularities and flow nonuniformities.

The following is the result of the correlation of the peak values of the overshoots against the depth of the bed of the section over which the overshoot occurred. The values of the overshoots were evaluated on the basis of optimum fitted curves.

$$\Delta P_{\mathrm{overshoot}}[\mathrm{kPa}] = 0.0044 + 1.151\, z[m] \tag{2}$$

As in the previous case the correlation coefficient is high and equal to 0.9986. Also the value of the intercept is small.

A similar correlation as in Eq. (2) forcing, however, zero intercept exists with nearly the same correlation coefficient (0.9985) and slope (1.157 [kPa/m]).

Based on the validity of these correlations one could say that within the scatter of experimental data the peak overshoot increases proportionally with the depth of the packed section. This suggests that the pressure overshoot takes place in the whole volume of the bed. Also the dissipation of energy during the peak overshoot is essentially uniform in the whole volume of the bed.

The pressure drops plotted in Fig. 1a–e pertain to the increased depth of the section of the bed corresponding to the location of pressure ports. In order to further inspect the distribution of the overshoot within the bed pressure overshoots in sections 0.2 m deep with variable distance from the top of the bed were correlated with the distance from the top of the bed.

These data were not directly measured but were computed from the experimental data as a difference between neighbouring pressure ports. Correlation of these incremental pressure overshoots yielded the following result:

$$\Delta P_{\mathrm{0,2msectionovershoot}}[\mathrm{kPa}] = 0.241 - 0.02\, z[m] \tag{3}$$

with the correlation coefficient equal to 0.0729.

The negative slope of this correlation thus would suggest that the energy dissipation during pressure drop overshoot is higher closer to the top of the packed section and lower near the supporting grid. Nevertheless the low correlation coefficient does not support this hypothesis.

4. Conclusions

The experiments designed to study the transient phenomena in a gas–liquid counter-current column revealed appearance of an overshoot on the pressure drop transient curve when the liquid irrigated bed is suddenly exposed to gas flow. This overshoot was detected shortly after introducing the gas into the bed and intermediate instantaneous values of pressure exceeded those corresponding to the final steady state by about 15%. The system took about 1 min to reach the new steady state from above.

The simultaneous measurement of the liquid holdup showed that within the scatter of the data there is no surge in the liquid holdup that would help explain the phenomenon. The experiment also did not reveal formation of gas–liquid mixture on top of the packed section during the transient experiment. The presence of gas–liquid mixture on top of the packed section is routinely monitored and recorded by an auxiliary pressure transducer to provide information about eventual development of the flooding conditions.

The phenomenon cannot be attributed to the flow capacity transients. The gas pipe is of 25 mm diameter equipped with a fast magnetic valve of the same cross section.

No severe initial liquid channelling may be the cause as the liquid is brought on the top of the packing by a distributor with a number of small needles arranged in a 10 m square pitch.

The finding that the height of the overshoot peak relative to the corresponding value of the pressure drop remains essentially the same indicates that the overshoot is felt in all sections of the bed uniformly and simultaneously with approximately the same intensity. This seems to identify the overshoot with the flow of gas for which the transport delay is small in the context of the dynamics of the flow.

The phenomenon of pressure drop overshoot has not been so far described in the literature. This observed phenomenon is no doubt of significance both from the standpoint of theoretical study of gas–liquid flow as well as packed column and reactor operation practice.

5. Nomenclature

z	Distance from the top of packed bed [m]
ΔP	Pressure drop referred to by subscript [kPa]

Acknowledgements

The authors gratefully acknowledge financial support of the project by the Grant Agency of the Czech Republic under the grant number 104/94/1027.

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